Energy Conversion and Management 265 (2022) 115795

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Planning positive energy districts in urban water fronts: Approach to La Marina de València, Spain

Isabel Aparisi-Cerdá, David Ribó-Pérez [*], Ivan Cuesta-Fernandez, Tomás Gómez-Navarro

Institute for Energy Engineering, Universitat Politècnica de València, Camí de Vera S/N, 46022 València, Spain

ARTICLE INFO

Keywords:
Positive energy districts
Urban water fronts
Renewable energy
Energy planning

ABSTRACT

Cities consume two-thirds of the energy supply, and 70% of carbon dioxide equivalent emissions come from urban environments. Positive Energy Districts are innovative tools to achieve energy and climate neutrality in cities. Positive Energy Districts are regions or neighbourhoods with a positive annual energy balance, obtained mainly through energy efficiency and energy generation from renewables. Urban Waterfronts are extended areas close to the sea, which makes them suitable for several types of production with renewables, therefore seeming to be a suitable location to develop Positive Energy Districts. This paper proposes a method that combines strategic planning for project management and the procedure for energy audits to design the optimal district configuration. The study presents and analyses the case of La Marina de València, a district in a Mediterranean city. Three strategic scenarios, both technically feasible and with a positive energy balance, are presented. All the alternatives include PV and switching to light-emitting diode in lighting. The different strategies presented together with a sensitivity analysis facilitate the decision-making process in energy planning and establish a common pathway to achieve Positive Energy Districts in Urban Water Fronts. The results suggest that urban waterfronts are uniquely suited to achieve a positive annual energy balance, thus emerging as a crucial springboard to provide traction to the positive energy districts policy agenda.

1. Introduction

Interest in new energy models is growing, motivated by EU and international emission reduction targets [1]. Cities consume two-thirds of the energy supply, and 70% of carbon dioxide (CO_2) emissions come from urban environments, making cities a key agent in the ongoing energy transition [2]. Cities involve large concentrations of population and different activity types. They include residential, commercial, industrial areas and areas that combine these three types. Different uses and urban layouts affect energy consumption available resources and imply different energy planning strategies to make cities carbon neutral.

Cities can become a driving force to catalyse the energy transition. Urban planners are reconsidering how to approach energy planning and take urban districts as their unit of analysis to turn them into Net-Zero Energy Districts (NZED) or Positive Energy Districts (PED) whenever possible to deal with this complexity. The NZEDs are a step beyond the individual approach of Net-Zero Energy Buildings (NZEBs) [3]. They involve larger areas with different uses, spaces, and consumptions. This implies considering more variables and constraints to reduce consumption while increasing distributed renewable generation. The concept of NZED [4] refers to municipalities with objectives of reducing energy demand and including energy supply from renewable energy sources on a local and decentralised basis. These models combine energy objectives [5] with other sustainability criteria related, for example, to waste reduction and urban planning [6]. If NZED evolves from NZEB, the Positive Energy Districts (PED) concept is a step further from NZED. Unlike NZED, PED is not limited to a zero balance of imported energy and emissions. It aims to achieve a positive balance that allows sharing the energy surplus with nearby neighbourhoods or districts with fewer possibilities or resources. Nevertheless, PED has ambitious objectives that face difficulties in built-up districts.

Today PEDs are still an innovative concept under development. A programme from the JPI Urban Europe, the PED and Neighbourhoods for Sustainable Urban Development, aims to support the planning, deployment, and replication of 100 Positive Energy Neighbourhoods by 2025 [7]. The programme provides a multi-stakeholder platform to develop implementation pathways, exchange information, experiences, and visions with other European cities, forming a European Positive

---

[*] Corresponding author.
E-mail address: david.ribo@iie.upv.es (D. Ribó-Pérez).

https://doi.org/10.1016/j.enconman.2022.115795

Energy Cities network and funding concrete initiation projects. For this purpose, they developed the Reference Framework for Positive Energy Districts and Neighbourhoods [8] and the Implementation Plan [9].

The measures to address PEDs are in three main energy efficiency areas: energy efficiency, renewable generation, and reliability. These aspects will be interdependent in some of the actions undertaken. Energy production in PEDs is based on maximising renewable energy supply based on a locally distributed Renewable Energy System (RES) within the district's geographical boundary and through local energy sources adjacent to the district. Energy efficiency measures will contribute to reducing energy consumption. These measures encompass balancing different sector needs, building insulation and orientation, energy, and transport and mobility. PED also involve flexibility for energy usage within the districts. Along these lines Kılkış et al. [10] went even further and proposed another concept Net-Zero Exergy Districts based upon the quality of energy. Furthermore, not only new urban development areas but also the existing building stock both need to be addressed [11].

Citizens' involvement strategies and political support are considered the main success factors for PED development [7]. Implication and collaboration with citizens and end-users from the beginning will avoid their reluctance to the change of paradigm that a PED implies in social, economic, and energy aspects. Political support is necessary to activate programmes and develop new funding opportunities since access to funding and business models has been shown to remain the main barrier.

In Europe, the JPI programme is facilitating the evolution of methodologies for developing PEDs in cities, but this point is still under development given its novelty. Along these lines, but referring to an entire city, [12] presents a methodology for integrated city energy modelling and assessment, from characterising the city's current energy performance to developing and assessing future scenarios. Bottom-up approaches are combined with top-down data for the energy characterisation, and scenarios are developed through a multi-criteria impact assessment model. Most authors have studied PEDs with case studies, i.e., Calise et al. in Naples [13]. Brozovsky et al. [14] conducted a state of the art review and observed that more than half of the reviewed papers applied their research to case studies. Other authors have studied a methodology, its objectives and phases and its replication, i.e. Alpagut et al. [15]; some have conducted a techno-economic analysis for high-suffiency districts, to find cost-optimal solutions, i.e. Laitinen et al. [16].

PEDs are challenging but there has been meaningful progress in developing renewable energy technologies and methods that can contribute to the energy transition and Clime Target Plan [17]. The review on renewable energy technology status for sustainable development by Østergaard et al. [18] showed recent progress. Repowering wind farms with the latest technologies is profitable. Moreover, there are still unexploited wind, wave, and solar power resources, among others. Photovoltaic (PV) systems are improving their performance and feasibility. Furthermore, despite its lesser maturity, wave energy's suitability for sustainable energy supply has been proven. Integrated and hybrid energy systems have demonstrated their relevance because they can integrate fluctuating renewables and exploit synergies through sector integration [19]. Therefore, spaces that can combine several of these renewable energy production systems have a significant potential to contribute to the energy transition. Ports and Urban waterfronts meet these characteristics.

1.1. Ports

The initiatives in the energy transition in the European Union ports of Valencia [20,21], Hamburg [22], Amsterdam [23], and Rotterdam [23,24] are summarised in Table 1 as a representative sample of the main sustainability initiatives for ports. In all of them, the reduction of CO_2 emissions is sought to be in line with the Climate Target Plan's European objectives. They all resort to energy production, as ports in terms of space and resources are often rich environments. The leading technologies are PV panels and wind turbines. Efficiency is also present but without the same importance in all cases; interest in electric mobility and alternative fuels seems more substantial.

1.2. Urban waterfronts

Urban waterfronts (UWF) are among the most favourable environments for PEDs in coastal cities since they usually present different space and resources options; however, their potential is still unstudied. A UWF is the port district or the coastal area of a town. They are usually defined as old ports reconverted into industrial, residential or commercial areas due to the growth of a larger commercial port. Redefining these spaces' use has a crucial role in cities, promoting one or another sort of development for the city. UWFs are particularly interesting in energy terms since they have great renewable generation possibilities near urban centres, allowing for an energy surplus that could be shared with nearby city areas.

The main actions taken in 5 waterfronts, Victoria and Alfred (V&A) Waterfront in Cape Town, Torre Annunziata in Naples, Shoonship in Netherlands, Zero Village Bergen in Norway and Gruž in Dubrovnik, Croatia, are ssummarised in Table 2. Those waterfronts were selected due to the available information about sustainability and energy measures, either undertaken or planned. V&A Waterfront [26] and Torre Annunziata [27] were declining areas reconverted into commercial areas (like LMDV), although Torre Annunziata also has a residential area. Although transforming this UWF into a PED is not an explicit aim, there is nonetheless a commitment to improving efficiency in lighting and renewable energies generation (specifically PV) in both cases. Neither of them includes improvements to existing buildings, and even though water and waste management is outside the scope of this energy study, they play an essential role in both cases. It would be appropriate to consider the improvement possibilities in other UWFs. Shoopschip [28,29] is a PED pilot in a residential waterfront with new buildings. The main characteristics are the high energy standards of the buildings, the onsite production with PV and thermal panes and the storage system. Zero Village Bergen [30] and Gruž [31] have adopted zero emission neighbourhood and zero energy perspectives, but their agenda has not yet been implemented.

Whilst detailed data exists on renewable energy generation and emission reductions strategies in ports (Table 1), in the case of waterfronts details are limited, since some of them still are in their planning stage. Although some measures have been implemented or planned, the literature review found no specific methods for planning and exploitation of the full potential of the UWF.

1.3. Contributions

There are great possibilities of generation in the outskirts, like ports,

Table 1
Ports measures.

	Renewable energy generation	Efficiency measures	Emissions plan	Electric mobility	Alternative fuels	References
Valencia Port	PV project	LED	Reduction	Progressive replacement	LNG, CNG	[20,21]
Hamburg Port	Wind power, PV, Solar thermal	–	Reduction	AGVs	–	[22]
Amsterdam Port	Wind power, PV, biomass	Shared Energy Platform	Reduction	–	LNG, H_2	[23]
Rotterdam Port	Wind power, PV, biomass	Residual heat recovery	Reduction and capture	E-trucks	LNG	[24,25]

Table 2
Urban waterfronts measures.

	Renewable energy generation	Efficiency measures	Emissions plan	Electric mobility	Alternative fuels	References
V&A Waterfront	PV (2 MW) Seawater cooling system (6 MW)	Cooling systems replacement. BMS ((Building Management Systems)) air conditioning control. 95% common areas Light-emitting diode (LED), sensors Net Zero GBCSA rating	No plan. 35% reduction achieved in 2018	–	–	[26]
Torre Annunziata	PV (3,067,585 kWh/year)	LED (859.93 MWh/yr savings)	Absorption with trees (658,395 kg CO_2/Year expected)	Cold ironing	–	[27]
Schoonship	516 PV panels with storage batteries, 60 thermal panels	30 heat pums, houses well isolated, showers with heat recovery system, green roofs, sustainable materials	–	Electric cars,cargo bikes and e-bikes	–	[28,29]
Zero Village Bergen	PV panels, district heating	Replacement of building materials (lower emissions materials)	Zero emissions	Electric vehicles	Hydrogen	[30]
Gruž	PV panels, solar thermal, wind turbines	Bioclimatic design, post-isulation, galgae or greenhouse facades, heat pumps	Zero emissions	More use of public electric transportation	–	[31]

industrial parks, or isolated areas without great consumption; however, in cities there is usually high consumption but little generation capacity. This combination makes urban waterfronts a different typology from the energy point of view. Some UWFs implement actions to reduce their environmental impact, including renewable energy systems, more efficient air-conditioning systems with BMS technology [26], natural-based solutions, or cold ironing [27], among others. This paper addresses the characteristics of UWFs that set them apart from other spaces and their potential to become PEDs, aiming to understand if these urban spaces have the potential and how to become PEDs. Therefore, the aim is to prove that UWFs are urban districts that are particularly appropriate to become PEDs.

To prove the feasibility and how UWFs are appropriate to become PEDs, the study is applied to La Marina de València, the UWF of València, Spain. The proposal combines strategic planning for project management and the procedure for energy audits to design the optimal district configuration that aligns with the definition and objectives of a PED, depending on the specific characteristics of the studied UWF. A study of different scenarios is conducted in parallel to facilitate the decision-makers final selection for the UWF. Studying different strategies and a sensitivity analysis allows establishing a common pathway to achieve PEDs in UWF. The rest of the paper is structured as follows: Section 2 presents the method followed; section 3 explains the case study of La Marina de València (LMDV) in Spain; section 4 summarises the results of the case study; section 5 presents the discussion and finally, section 6 concludes.

2. Materials and methods

In this section, a method for PEDs in UWFs that combines strategic project planning and energy audits is suggested to design the most optimal configuration that aligns with the definition and objectives of a PED, depending on the specific characteristics of the studied UWF. UWFs are extended areas close to the sea, making them suitable for several types of production with renewables, similar to ports. Furthermore, UWFs are contiguous to densely populated areas. Considering their location and potential for renewable energy production, UWFs appear as suitable locations for developing PEDs. For those reasons, a study for energy planning on urban waterfronts is conducted based mainly on strategic planning for project management [32] and the procedure for energy audits and aiming to develop PEDs in UWFs.

Based on strategic project planning, some of the methodology's main phases define the project and its objectives, the SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis, and the risk assessment [32]. Although these phases are shared with the strategic planning of projects, they have been defined more specifically for urban waterfronts' energy planning. The first step is the project definition, which involves the study of three main points:

- The UWF background, to better know the contexts, previous studies in energy and sustainability, and waterfront activities.
- The resources and capabilities of the area, in terms of energy resources, space availability, and possible barriers and possibilities to avoid them if any.
- The past performance analysis, regarding energy consumption and production.

An interview with the person responsible or involved entities and a literature review complete the first point. The two following points require a more elaborate procedure. The resources and capabilities study requires a review of the possible barriers and a more detailed process to identify and quantify renewable resources. The main aspects in which barriers might be found and should be assessed are space aspects as well as regulatory, financial, technological, social, or heritage aspects. Painuly et al. [33] identified barriers and policy implications of renewable energy technologies. Good et al. [34] studied the barriers and specific challenges for Energy Positive Neighbourhoods and elaborated recommendations. The resources available for energy planning will be all kinds of resources in the environment that can contribute to energy planning. These can be either operational or management resources or natural resources. Resources at the operational or management level will be detected in the context review phase, previous studies, and first interviews with the agents involved. Natural resources are the resources available for the generation of renewable energy. The availability of resources will be assessed first. A waterfront can be rich in various resources, such as solar radiation, wind, marine, geothermal or biomass; for each case, the availability must be assessed. Once the availability of resources is known, their potential for energy production at the location and their suitability related to energy demand must be assessed, considering their technical and economic feasibility. Section 3.1 defines this process and details the process of quantifying the resource and energy production potential for the available resources in the case study.

The next step for the project's definition is the past performance study, which gathers information about energy demand, consumption, and production (if any) and analyses it following the existing energy audits norm. Available information is collected, and installations are visited. If some information is not available and can be measured, the appropriate measurements are made. Data is continuously reviewed and completed in the analysis process as much as possible. If there is already energy production on-site, it will be determined from which sources, schedules, or conditions, and its power will be quantified. In the consumption characterisation, a distinction will be made between thermal and electrical demand. Moreover, information about consumption characteristics and hourly data for one year to carry out simulations will be collected.

Once this is completed, a SWOT analysis is carried out, taking the information from the background and the resources and capabilities. It provides an overview that allows the proposal of actions previous to the construction of strategic scenarios. The objectives of the project must be defined before proposing actions. The objectives of UWF correspond to the entities that comprise it; however, there may be an overall objective of increasing the waterfront's sustainability but no clear energy objectives in some cases, as has been found for two cases in the state of the art and the case study in this paper. In that case, considering the SWOT analysis previously carried out, several objectives can be proposed, and a strategic scenario can be generated for each one. Once the objectives have been defined, actions and measures are proposed to achieve them. From this point on, the different scenarios are defined and run in parallel; at the end, they are compared to select the most convenient option. To this end, a series of representative indicators should be selected to compare scenarios with each other and determine their suitability for the defined objectives. Indicators shall address emissions, economic and social criteria aligned with Sustainable Energy and Climate Action Plan (SECAP) and the PED definition.

The scenario(s) definition involves a series of measures under its main objective. Having defined the strategic scenario(s), it is time to simulate. The software HOMER [35] is used for the simulations since it provides economic and technical results that will later be used to compare the scenarios. Once the first simulation is completed, the risks and the uncertainty variables must be identified.

After a literature review [34] and the SWOT, the risk analysis [36] must be conducted, and the uncertainty variables must be identified. For the risk analysis, first, the aspects with a risk of variation are identified: Consumption, Best Available Technology (BAT), prices, financial and economic, administrative and legal and cultural and social. Then, concerning these aspects, a series of risks and their consequences are detected for the case study. A qualitative risk analysis evaluates the priority of the identified risks using the probability of occurrence and the corresponding impact on the project. Then, contingency plans for risk management are proposed to reduce risk. A sensitivity analysis is then carried out by introducing variations in the variables corresponding to these aspects. The consequences of the variations introduced will be analysed to identify how they affect the optimal configurations for the strategic scenarios and the final selection for the project. The final strategy will follow different pathways depending on the evolution of uncertainty parameters; the sensitivity analysis will guide this decision-making. Some of the phases described above require a specific procedure to be developed. The following sections of this chapter explain these procedures.

2.1. Production analysis

This step consists of quantifying the renewable energy produced in the UWF, if any, and studying the production potential. The renewable energy resources to be considered are determined by analysing the available resources, available space for the installation of equipment and the production potential, and the maturity of the technology and its costs. First of all, the potential of different resources is assessed to dismiss low resource options. Also, some technologies might be rejected considering the type of demand to cover (thermal, electrical, or both). The suitable options for renewable energy production are finally selected, ensuring that the options are feasible. The feasibility is determinate by assessing the maturity and cost of the needed technologies and considering the capabilities and barriers identified.

UWFs can aggregate multiple renewable resources. Their proximity to the sea and their spatial characteristics contribute to significant renewable production potential. Resources can be provided to cover thermal demand through RES, such as geothermal, solar thermal, or biomass, or to cover electricity demand, such as PV, wind, or marine energy. This paper focuses on those used to cover the electricity demand of the case study, whereby Fig. 1the process of Fig. 2, marine is discarded due to its high cost and lack of maturity in its applications with potential on the Mediterranean coasts [37].

2.1.1. Solar

It is necessary to identify the available spaces and obtain the power that could be installed regarding photovoltaic production. The district is examined for possible locations for installation, then the institutions involved are consulted to check the availability of such spaces for the installation of panels. Once available locations are checked, the installation's available areas are measured or obtained from cadastral information. Two cases of PV panel installations have been differentiated on existing rooftops and new structures in parking areas.

- Rooftops area

It has been decided to use the photovoltaic viewer supported by the Cátedra de Transición Energética Urbana [38] to assess rooftops. This tool obtains the roof area from cadastral information, which is reduced by defect by a factor of 70% to consider obstacles, railings, or others. The reduction factor of the photovoltaic viewer is calculated from a sample of buildings from Valencia city, similar to the one obtained by Arcos-Vargas et al. [39] for Seville (68%). The area/power ratio used by the photovoltaic viewer is 10 m^2/kWp. Thus, the peak power is obtained applying equation (1). Where A_{roof} is the rooftop area (m^2), $f_{reduc} = 0.7$, $r_{area-power} = 0.1kWp/m^2$ and P is the peak power for that area(kWp).

$$P = A_{roof} f_{reduc} r_{area-power} \tag{2}$$

The solar radiation on the panels is estimated from an hourly Typical Meteorological Years (TMY) climate data file for Valencia provided by EnergyPlus [40], and a radiation isotropic model. The model considers shadows cast by all the buildings or obstacles adjacent within a radius of 200 m from a representative point on the roof. The shadows are calculated from Light Detection and Ranging (LIDAR) data and cadastral data.

- New structures area

In the zones without buildings where the installation of panels is proposed, the maximum number of panels and the power are obtained as follows. First, the available area is measured. Then, knowing the space's width and length, the structures' slope angle to install the PV panels and the panels' power is obtained in order to discover the total power for each area. The equations used for each area are:

$$N_P = N_L N_W \tag{3}$$

$$N_L \approx \frac{L}{L_p} \tag{4}$$

$$N_W \approx \frac{\frac{W}{\cos(\alpha)}}{W_p} \tag{5}$$

$$P = N_P P_p \tag{6}$$

Where N_L and N_W are the maximum number of panels to install, L is the length and W the width of the available area respectively, L_p and is W_p for the panel dimensions, β the angle of inclination of the structure, P_p the panel peak power and P de peak power for that area.

The radiation data is obtained from the Photovoltaic Geographical Information System (PVGIS) website [41]. Weighted average values are used for the azimuth and the slope of the panels (equations (7)(8)) to obtain the PVGIS radiation and carry on the simulations since it will be considered as a single installation for the scenario simulations. Where ϕ is the weighted average angle, ϕ_i is the angle and rp_i is the ratio of the

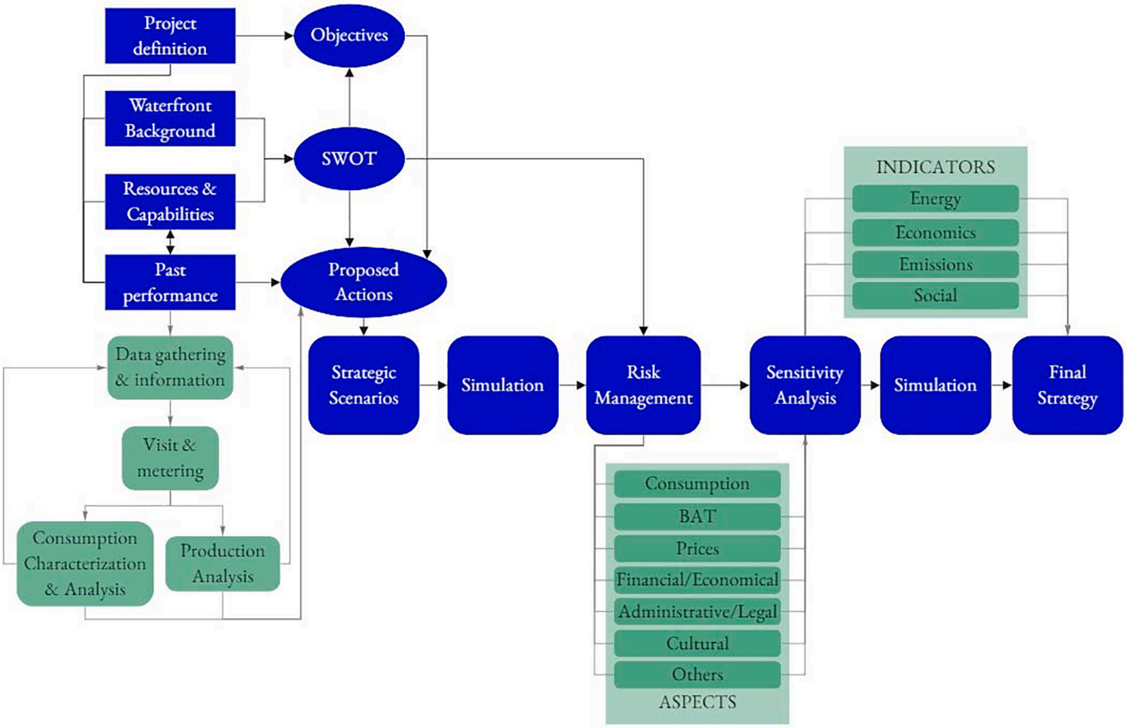

Fig. 1. Methodology to plan PEDs in UWFs.

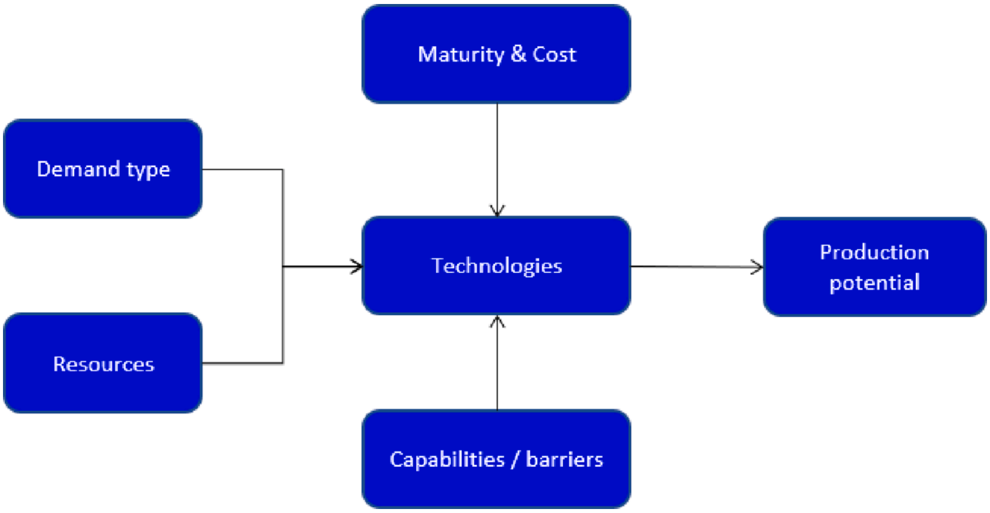

Fig. 2. Renewable energy resources assessment.

power of the installations with the angle ϕ_i to the total power.

$$\phi = \sum (\phi_i rp_i) \tag{7}$$

$$rp_i = \frac{P_{\phi_i}}{P_{tot}} \tag{8}$$

- Shadows

The shadow pattern will be projected onto the Sun-path diagram. The shadow pattern is obtained for a central point of the roof. The distance and height of the obstacles' vertices are obtained with respect to this point. The solar elevation angle (β) and azimuth (α) are obtained for each vertex of the obstacle employing trigonometric relations. The shadow pattern is then defined and can be projected onto the diagram. With the pattern of shadows overlaid on the diagram, it can be seen in which months and hours the obstacle prevents radiation reaching the point on the roof being analysed. Then, the realistic hourly radiation data generated for the entire year before is modified, setting the hours at which shadows occur to zero. This procedure is done for as many roofs or points as required by the geometry of the buildings.

Finally, weighted average radiation is obtained. A different coefficient is obtained for each zone with shadows and another one for the area without shadows. The weighting is made with respect to the installed power, with the coefficient for each zone being the power installed in that zone divided by the total installed power.

- Connection to consumption points

Although a single photovoltaic installation linked to the total demand will be considered, it should be noticed that this is a simplification. An additional study is needed to link the PV production facilities with different consumption points, adapt schedules, power, and consider the current legislative framework. In Spain, self-consumption installations are currently defined by RD 244/2019 [42], which specifies that the distance between production and consumption point must not exceed 500 m.

Mapping is conducted connecting the proposed PV generation points. According to the current regulation, the map shows the minimum radius circumference between generation and supply for each generation point. The consumption points within this area are established as options. Then, the installations' peak power is compared with the different consumptions and schedules, so the most suitable combinations are established. The annual consumption of each point is also compared with the estimated annual production of the photovoltaic viewer.

2.1.2. Wind

The wind data have been obtained by interpolating Energy Plus and the Institute for Diversification and Saving of Energy (IDAE) data. Energy Plus provides average hourly wind speeds for each month for the location. The IDAE's data is from 2018 when its wind atlas [43] was still available. The information provided is for a more specific location, with annual, seasonal, and wind direction values.

With the hourly data of average speeds for each month obtained interpolating, it is possible to establish if the resource will be enough to produce energy with a wind turbine. For the simulations, hourly data will be used. The wind turbine's best orientation is determined by obtaining the wind roses for frequency, speed, power, and energy. The power and energy for each orientation are calculated with the expressions:

$$P_j = \frac{1}{2}\rho\frac{\pi D^2}{4}v_j^3 \tag{9}$$

$$E_j = f_j P_j h_{yr} \tag{10}$$

Where j is the wind direction, ρ is the air density, which is variable depending on the height above the sea, D is the wind turbine's rotor diameter, and v is the average speed for each direction. E is the energy, P the power, f the frequency percentage and $h_{yr} = 8,760$ hours in a year. After evaluating the wind resource, the location suitable for installation is selected. Once the location is known, the maximum number of wind turbines is determined by taking measurements in the available location and following the inequation below, where d is the distance between wind turbines and D the rotor diameter.

$$d \geqslant 3D \tag{11}$$

2.2. Indicators

Four indicators have been selected to assess the results of each scenario, these consider economic, environmental, and energy variables. Social indicators have been left out in the simplification applied to the case study, but they are another aspect to be considered in PEDs. The selected indicators are four outputs of HOMER:

- Net present value (NPV) or present worth: the difference between the present value of cash inflows and the present value of cash outflows over a period of time (€). The NPV of each scenario is calculated with the following equations:

$$NPV = NPC_{scenario} - NPC_{ini} \tag{12}$$

$$NPC = \frac{C}{(1+i)^n} - \frac{R}{(1+i)^n} \tag{13}$$

Where C is the costs of installing and operating the component over the project lifetime, R revenues that it earns over the project lifetime, i the real interest rate and n the lifetime. $NPC_{scenario}$ is the NPC of the whole system for each scenario, and NPC_{ini} for the current system.

- Levelized cost of energy (LCOE): average cost per kWh of useful electrical energy produced by the system (€/kWh).

$$LCOE = \frac{C_{ann,tot}}{E_{served}} \tag{14}$$

Where:$C_{ann,tot}$ is the total annualised cost of the system (€/yr). The total net present cost times the capital recovery factor. E_{served} is the total electrical load served (kWh/yr), the total amount of energy that went towards serving the primary and deferrable loads during the year, plus the amount of energy sold to the grid.

- Renewable energy production: the total amount of electrical energy produced annually by the renewable components of the power system (kWh/yr).
- CO_2 grid emissions:

$$Annual\ CO_2\ savings = \sum_{t=1}^{t=8760} E_{purch,c\_t} f_{co2\_t} - \left(E_{purch,sc\_t} - E_{sold,sc\_t}\right) f_{co2\_t} \tag{15}$$

Where E_{purch_t} is the grid purchases at hour t from the current systems (E_{purch,c_t}) or the strategic scenario (E_{purch,sc_t}), E_{sold_t} the grid sales at hour t and $f_{co2_t}$the emission factor (g/kWh) at the correspondent hour.f_{co2_t} is obtained for the year 2019 (the same year as consumption data) from Red Eléctrica de España (REE) website for the entire year.

3. Case study: La Marina de València

València is a city located on the east coast of Spain. It is situated on the banks of the Turia, fronting the Gulf of València on the Mediterranean Sea. It has a population of 789,744 inhabitants and a surface area of 134.65 km^2. València has a hot-summer Mediterranean climate with mild winters and hot, dry summers. The average annual temperature is 18.4 °C. August is the warmest month, with average maximum temperatures of 30–31 °C and minimum temperatures of 21–23 °C. The daily temperature range is low due to the maritime influence: around 9 °C on average. Also, the average annual humidity is relatively high (about 65 %) and with slight variation throughout the year due to the sea's influence.

La Marina de València (LMDV) is in a UWF in the city of Valencia (see Fig. 3). It was initially part of the city's port, but the preparations to host the 32nd America's Cup led to the separation of La Marina de València from the rest of the commercial port in the early 2000 s. Between 2007 and 2012, La Marina de València hosted two editions of the America's Cup and the Formula 1 Grand Prix, which led to the fast development of its infrastructure and debt accumulation. After that, many of these infrastructures built to host the two events were left without a defined use. Nowadays, space is increasingly being retrieved for the citizens. It is managed by Consortium 2007, and its current priorities are innovation and sustainability. These new priorities but with the lack of specific objectives are the reason why this UWF was selected as the case study.

After analysing its energy consumption, it was found that this is mainly due to electricity demand and that thermal energy consumption is negligible compared to this demand applying the Pareto principle. The consumption of some small boilers for Domestic Hot Water (DHW) compared to the consumption of 850 dock pedestals from 16A to 630A, 479 kW for pumps working intermittently and not all simultaneously, and total power of 229 kW for public lighting makes the boilers negligible. It will be considered a measure of efficiency to change the sodium or mercury vapour discharge systems to LED technology.

For the consumption characterisation and analysis, monthly

Fig. 3. LMDV map.

consumption electricity data has been collected from 25 electricity supply points dependent on Consorci València 2007, of which 17 have been analysed in more detail with the hourly load curves for the whole year. The consumption of LMDV for 2019 was 7,001 MWh/year. The main consumption points are concentrated in mooring areas and the lighting. There are consumption points with higher consumption than others, some with more diurnal consumption, which will be more suitable for the PV installations, and others with more nocturnal consumption, depending on the type of demands linked to them. However, the overall curve is relatively flat, with higher consumption at night (Fig. 4). Average consumption on Saturdays and Sundays is higher than the rest of the week. Consumption does not vary much throughout the year, being slightly higher from June to November.

For the analysis conducted, an estimation of the electricity demand produced by Electric Vehicles (EV) charging points has been included in the total electricity demand considering the forecast of 16% of the vehicle park for 2030 [44] and information about the parking places and schedules in LMDV. With the estimated curve for EVs, the annual consumption will increase by 1,849 MWh, 26.5% more than 2019 consumption (Fig. 5).

For the production analysis no renewable production has yet been introduced in LMDV. For the potential of production, due to the demand's main electric character, technologies to produce electricity from renewable sources are considered. The proximity to the Mediterranean Sea and the low level of sea roughness and availability of space away from towns make electricity production by wind turbines feasible. The climatic conditions and the wide availability of space make the production using PV panels viable. Besides, both technologies are mature and economically competitive. Those are the technologies considered for energy production in situ. Moreover, using a storage system with Li-ion batteries will be considered. The prices of the equipment under consideration are shown in Annex 1. Since these devices have a greater economy of scale, equations as a function of power have been obtained to approximate the price in € per kW for inverters and per kWh for batteries from several devices of different power and capacity. The Operation and Maintenance (O&M) cost for the inverters is 16 €/kW and 3 €/kWh for the batteries.

For the LMDV case study, three strategic scenarios are proposed to achieve a different target since no specific target was previously specified. The strategic scenarios are:

- **Maximum energy production (P)** from renewable sources in LMDV: Become a driving force in renewable energy in the area by exploiting its full potential.
- **Maximum renewable autarchy (A)**: Self-sufficiency, own renewable energy supply for LMDV independent of the electricity grid and any other external supply.
- **Minimum cost (C)**: efficient energy management leading to minimisation of energy costs.

The project's lifetime is considered to be ten years, within which time it is intended to meet the objective of making LMDV a sustainable area. For LMDV, the sensitivity analysis has been carried out using 25% upward and downward variations in the consumption and the electricity price. The presentation of results nomenclature contains a letter corresponding to the strategic scenario followed by a number: 0 for scenarios

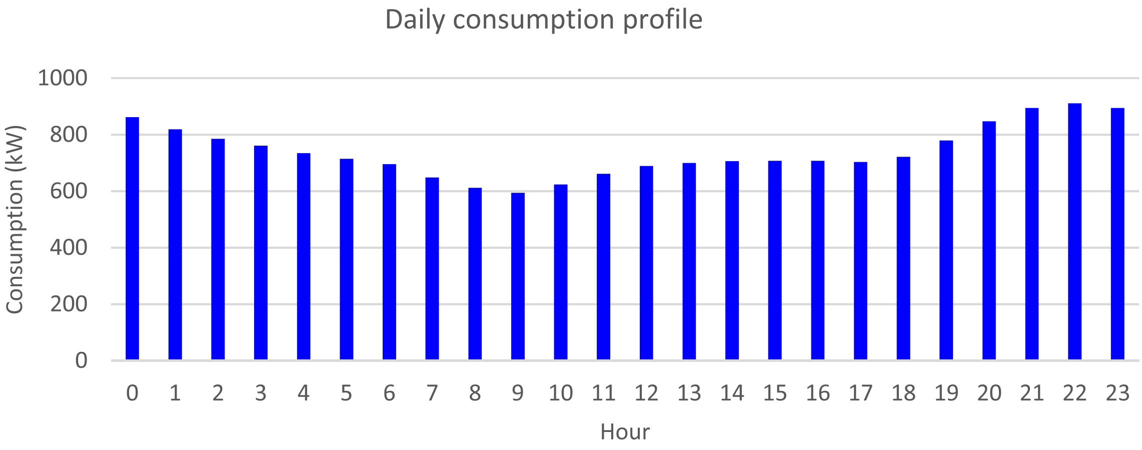

Fig. 4. Daily consumption profile.

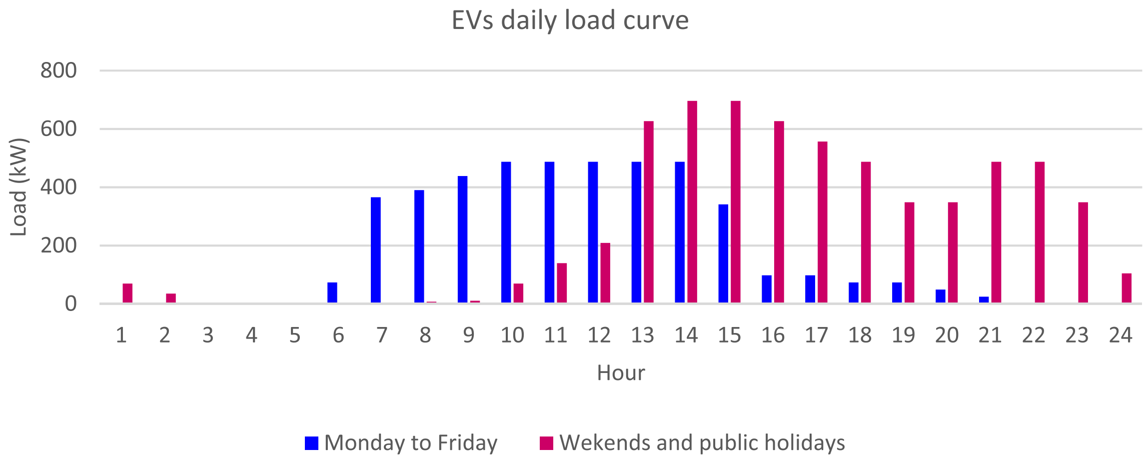

Fig. 5. EVs daily load curve.

without changes, 1 or 2 for increase or decrease in consumption respectively, and 3 or 4 for increase or decrease in electricity prices and 5 and 6 for increase or decrease in equipment price. Finally, the worst and best combinations for the different scenarios are simulated. The worst combination, labelled 7, assumes an increase in consumption and equipment and electricity prices simultaneously. The best combination is the opposite: consumption drop and equipment and electricity price drop (number 8).

4. Result and discussion

Once the scenarios have been defined, the first set of simulations is carried out to establish the proposals that will make up the scenarios. A sensitivity analysis is then carried out to review the scenarios and decide whether to apply modifications to them. Finally, the three scenarios are compared to establish the most convenient for forming a PED in LMDV. Each scenario includes integrating PV panels and wind turbines to a different extent depending on the results obtained in the simulations and each scenario's main objective. Besides, all include improving lighting efficiency by switching to LED technology. The lighting change represents a total cost of 114,762 € and saves 7.9% of energy and 62.94 tCO$_2$ emissions per year. The payback of this efficiency measure is 2.4 years as shown in Table 3.

After the first simulations, the configurations and the investment cost obtained for each scenario are shown in Table 4, while Fig. 6 shows the simulations' main results. In the maximum production scenario (P0), the maximum available PV and wind power will be installed. For the maximum autarchy scenario (A0), the option with the minimum number of batteries has been selected, as batteries exponentially increase the project costs. In the minimum cost scenario (C0), the configuration selected is the one that achieves the lowest LCOE at 6.1 cents €/kWh.

The three strategic scenarios are technically feasible and have net-zero emissions and a positive energy balance annually, but each has advantages and disadvantages. For P0 and C0 scenarios, the most feasible configurations do not include batteries. It is not a feasible option from the economic point of view but implies independence from the grid. C0 has a significantly lower cost than P0 and a higher NPV, while A0 has a negative NPV. In contrast, P0 means higher renewable energy production to sell to the grid. Both P0 and C0 reduce CO$_2$ emissions from the electricity grid, due to the discharge of clean energy into the grid. Savings in grid emissions are significantly higher in P0 (Fig. 7).

Table 3
Results of the switch to LED technology.

	Current	LED	Savings
Investment (€)	–	11,762	–
Payback (yrs)	–	2.4	–
Power (kW)	229.25	122.09	107.16
Consumption (MWh/yr)	1,170.78	626.51	547.27
Cost (€/yr)	100,817	53,692	47,126
Emissions (tCO$_2$)1	134.64	71.70	62.94

Table 4
Strategic scenarios configuration and investment cost.

SCENARIO	Installed power (MW)			Inverter (MW)	Batteries capacity (kWh)	Investment cost (€)
	PV	Wind	TOTAL			
P0	2.76	4	6.76	2.48	0	7,153,813
A0	2.76	4	6.76	2.48	5,240	8,072,946
C0	2.76	2	4.76	2.48	0	4,539,813

In the sensitivity analysis of the scenarios, the parameters with higher uncertainty, consumption, electricity price and equipment price, are selected to study the effect of its variation for the three strategic scenarios. The variations for those parameters hereby presented are ±25%.

4.1. *Maximum energy production.*

P scenarios configuration is always the same, since the maximum production target leads to installing the maximum power capacity available (see Table 5). The rise and drop of consumption (P1 and P2) affect the emissions savings. An increase in consumption results in lower grid emissions savings and vice versa. LCOE and NPV are affected by both changes in consumption and electricity prices. Reducing consumption (P2) increases the LCOE and significantly increases the NPV. The opposite effect occurs when consumption rises (P1). The increase in the price of electricity (P3) or the equipment price (P5) decreases the NPV, and the rise in the price increases it, with an effect weaker than those produced by consumption variations or electricity prices, but higher for equipment prices. The opposite effect occurs when prices drop (P4 and P6). For P7 (worst combination: consumption and price rise) and P8 (best combination: consumption and prices drop), emissions are the same as P1 and P2, as they have the same energy consumption and production. In P7, as in P5, the increase of electricity prices affects the LCOE negatively. The opposite occurs with P5 and P8. P7 and P8 have the worst and the best NPV result, respectively, with P7 being the only case with negative NPV and therefore economically unviable. This occurs because it is the worst and best combination of variations in the parameters. The results for the sensitivity analysis of the maximum energy production scenario also show that in all cases LMDV will be a PED (net-zero emissions and a positive energy balance on an annual basis) (Table 6).

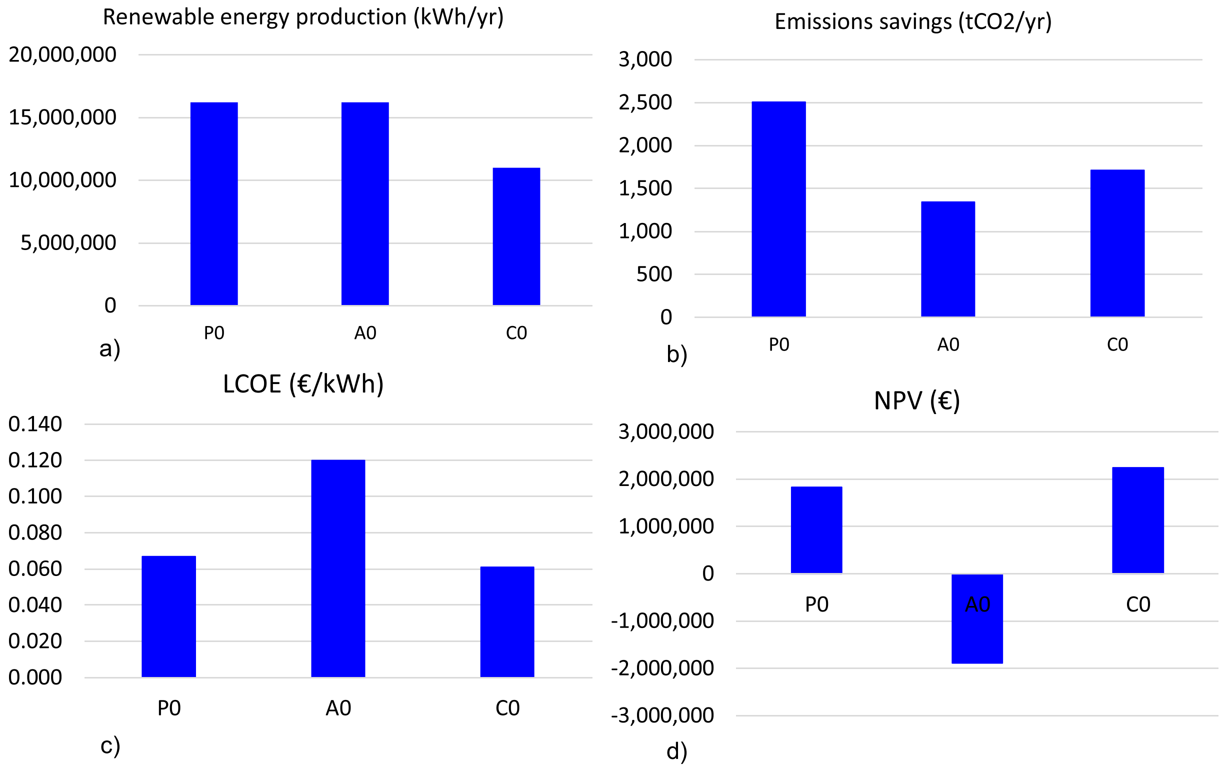

Fig. 6. Strategic scenarios results. *a) Renewable energy production of the strategic scenarios. b) CO2 emissions savings of the strategic scenarios. c) LCOE of the strategic scenarios. d) NPV of the strategic scenarios.*

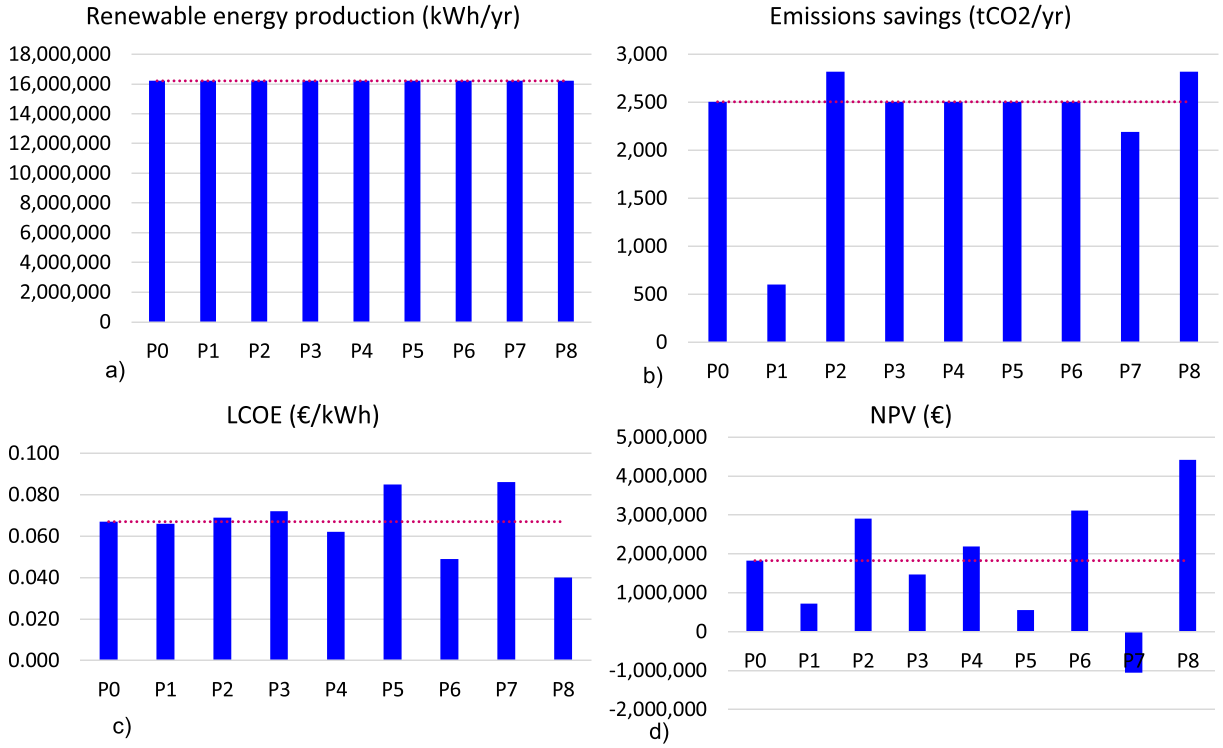

Fig. 7. Maximum production variations. *a) Renewable energy production of* max. *production variations. b)* CO_2 *emissions savings of* max. *production variations. c) LCOE of* max. *production variations. d) NPV of* max. *production variations.*

4.2. Maximum renewable autarchy

The maximum power would be installed for the maximum autarchy scenarios, excluding the consumption drop case (A2). Thus, production would be the maximum as in P scenarios. A2 is the only case that reduces the PV installed power, increases the storage system slightly, and lowers

Table 5
Renewable energy production of max. production sensitivity analysis configurations.

SCENARIO	Installed power (MW)			Inverter (MW)	Batteries capacity (kWh)	Investment cost (€)
	PV	Wind	TOTAL			
P0, P1, P2, P3, P4	2.76	4	6.76	2.48	0	7,174,809
P5, P7	2.76	4	6.76	2.48	0	8,939,820
P6, P8	2.76	4	6.76	2.48	0	5,409,797
P0, P1, P2, P3, P4	2.76	4	6.76	2.48	0	7,174,809

Table 6
Maximum autarchy sensitivity analysis configurations.

SCENARIO	Installed power (MW)			Inverter (MW)	Batteries capacity (kWh)	Investment cost (€)
	PV	Wind	TOTAL			
A0, A3, A4	2.76	4	6.76	2.48	5,240	8,072,946
A1	2.76	4	6.76	2.48	13,100	8,600,426
A2	2.5	4	6.5	2.48	5,502	5,054,522
A5	2.76	4	6.76	2.48	5,240	10,088,709
A6	2.76	4	6.76	2.48	5,240	6,099,129
A7	2.76	4	6.76	2.48	13,100	10,721,805
A8	2.50	2	4.50	2.48	4,912	3,790,619

the investment cost. Nevertheless, in A2, it must be ensured that the reduction in power consumption is applied uniformly. Suppose e.g., the reduction in consumption occurs during the dark hours but not during the daylight hours. In that case, the configuration described above may no longer be optimal, and the initial configuration (A0) may be preferred. However, increasing consumption (A1) would require a more significant storage capacity to guarantee the supply. The LCOE remains high compared to P scenarios, although it decreases in A8, A2, A6, and A1, with A2 and A8 the only cases with a positive NPV. Given the independence of the grid, the variations in the electricity price (A3 and A4) do not affect either the configuration or the results compared to A0. Without the grid and the economic compensation and having to install batteries, which are expensive, the best scenario is if consumption is reduced (A2) due to the reduction of the power installed and, therefore, investment reduction. A7 and A8 give the worst and the best result for NPV, but not for energy production and LCOE. A7 increases the price of equipment and consumption. As can be seen in Fig. 8c), in the case of increased consumption (A1), the LCOE is favoured compared to the base case (A0), due to increased use of on-site renewable energy, due to an increase in the storage system. In the case of increased equipment prices (A5), the LCOE is negatively affected. Therefore, A7 is, in this aspect, an intermediate case between A1 and A5. A PED will be achieved for all the scenarios resulting from the sensitivity analysis of this strategic scenario.

4.3. Minimum cost

The optimal configuration of the minimum cost case changes with respect to C0 when consumption or electricity price drops (C2, C4 and C5), resulting in the removal of wind energy generation. In the case of an equipment price drop (C6), the optimal configuration is installing the maximum available. The minimum LCOE is obtained in C8 followed by C6 and C4, since C8 is a combination of all cases where the LCOE falls below C0 (C2, C4 and C6). The lowest energy production is in C2, C4 and C5 since the power installed is lower. Thus, the emissions savings are lower too. In C2, the consumption is also reduced; thus, there are more emission savings. If the equipment price is reduced (C6), the best results are obtained in production and CO_2 savings because the maximum power is installed. In C8, the installed power is reduced to improve the LCOE and the NPV to the best values. C7, the combination of an increase in consumption and prices, is the only case with a negative NPV (Table 7).

Unlike the other strategic scenarios, the variations of the sensitivity analysis for the minimum cost scenario show that a PED will not always be achieved. For scenarios C2, C4, and C5, with less installed power (no wind turbines), therefore less production, the net-zero emissions, and

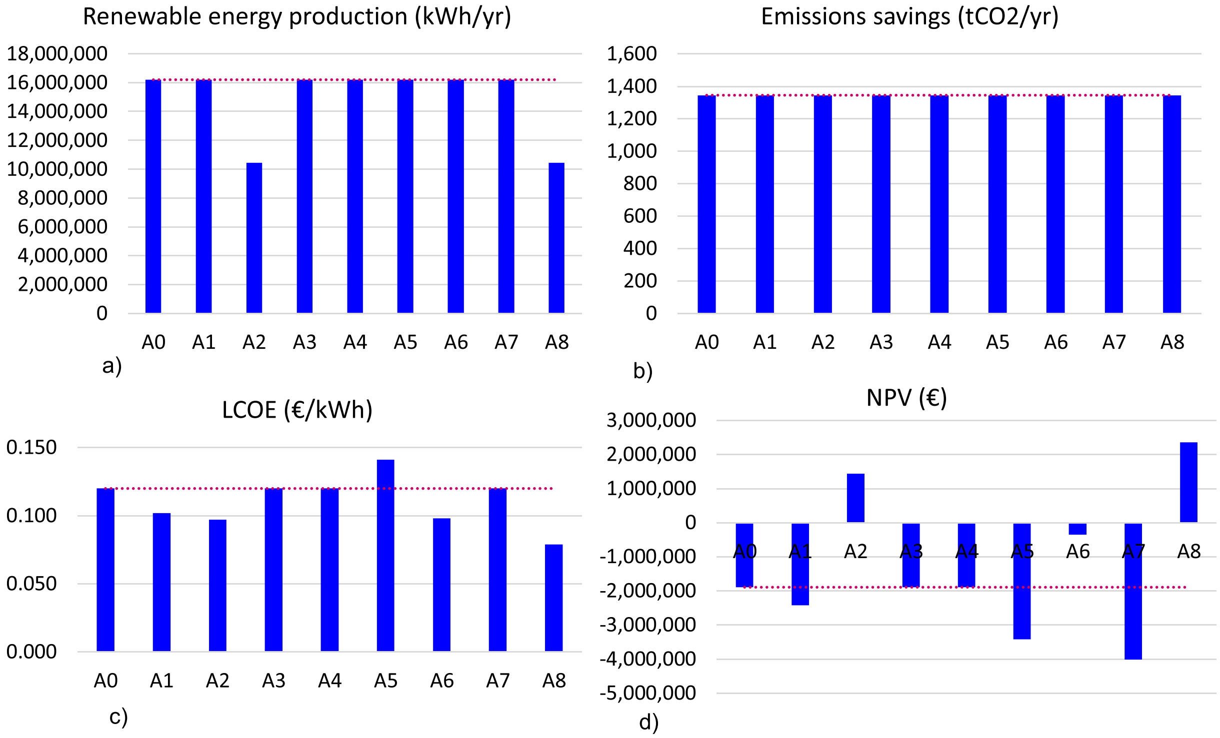

Fig. 8. Maximum autarchy variations. *a) Renewable energy production of* max. *autarchy variations. b)* CO_2 *emissions savings of* max. *autarchy variations. c) LCOE of* max. *autarchy variations. d) NPV of* max. *autarchy variations.*

Table 7
Minimum cost sensitivity analysis configurations.

SCENARIO	Installed power (MW)			Inverter (MW)	Batteries capacity (kWh)	Investment cost (€)
	PV	Wind	TOTAL			
C0, C1, C3	2.76	2	4.76	2.48	0	4,560,809
C2, C4	2.76	0	2.76	2.48	0	1,946,809
C5	2.76	0	2.76	2.48	0	2,404,821
C6	2.76	4	6.76	2.48	0	5,409,797
C7	2.76	2	4.76	2.48	0	5,672,321
C8	2.76	2	4.76	2.48	0	3,449,297

the positive energy balance are not achieved (Fig. 9).

4.4. Possible pathways

Fig. 10 represents nine alternatives from the sensitivity analysis for the three strategic scenarios. PV power is in magenta colour, wind power in blue, and the rest left to reach the maximum available power in grey. All the alternatives include PV; indeed, only two do not suggest to install the maximum PV power (2.76) and suggest 2.5 MW instead; both are from the maximum autarchy strategic scenario. Only three alternatives do not include wind power; all three are from the minimum cost strategic scenario. Those three alternatives correspond to a consumption or electricity price drop or an equipment price rise. Most of the alternatives (18) will include 4 MW of wind, but six will include only 2 MW.

The reduction in consumption is favourable in all three strategic scenarios, emphasising the importance of implementing efficiency measures (LED). The decrease in the price of electricity and equipment also has a positive effect, as expected. However, an increase in consumption due to increased activity in LMDV would worsen the alternatives. Therefore, further investigation of energy efficiency improvement options is recommended for future studies.

These results show that the final strategy will follow different pathways depending on the evolution of the uncertainty parameters analysed. The strategy of maximum autarchy is discarded since it is economically viable only on the assumption of consumption reduction (A2) or consumption reduction and equipment prices drop (A8) (Fig. 8). Furthermore, given the changing nature of consumption in LMDV due to occasional events, independence from the grid is a complex option that could compromise the continuity of supply. The decision is between the strategy of maximum production and minimum cost.

All the alternatives from the sensitivity analysis have two common points, the switch to LED and at least 2.5 MWp of photovoltaic, 2.76 MWp if discarding the strategy of maximum autarchy. This ensures the suitability and relevance of these two proposals for LMDV despite the strategy and changes that may occur in the future. Both switching to LED and photovoltaics can be implemented progressively, avoiding a significant investment all at once. Priority should be given first to the switch to LED as an efficiency-enhancing measure and then to the installation of photovoltaics. Once those have been progressively completed, the installation of wind turbines should be considered. From this point onwards, depending on the investment capacity, it would be decided whether to follow a strategy of maximum production (higher investments) or minimum cost (lower investments). Once the strategy has been decided, the evolution of prices and consumption should be assessed in order to determine the wind power capacity to be installed. If the investment capacity is sufficient and maximum production is chosen, 4 MW of wind power will be installed. If cost reduction is chosen and the minimum cost strategy is followed, it will depend on the evolution of electricity consumption, electricity prices, and equipment prices.

The differences between the maximum and minimum cost strategic scenarios are blurred when gradually approaching the energy strategy change. For the same price and consumption evolution, the minimum cost strategy always implies less power to install and less investment, except if the price of the equipment falls. In that case, the maximum production scenario and the minimum cost scenario match. In any case, the lower power configurations of the strategic minimum cost scenario always allow the evolution to the maximum production scenario by increasing the installed power up to the maximum possible. Either by

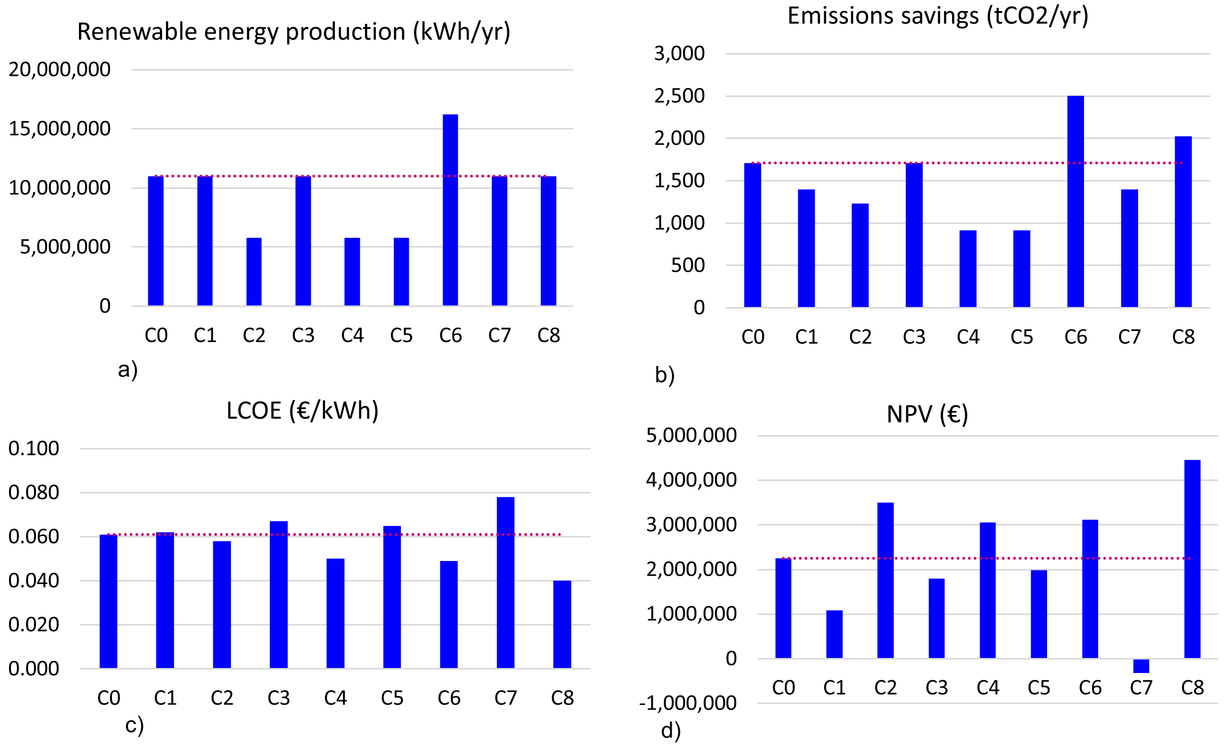

Fig. 9. Minimum cost variations. *a) Renewable energy production of* min, *cost variations. b) CO_2 emissions savings of* min. *cost variations. c) LCOE of* min, *cost variations. d) NPV of* min, *cost variations.*

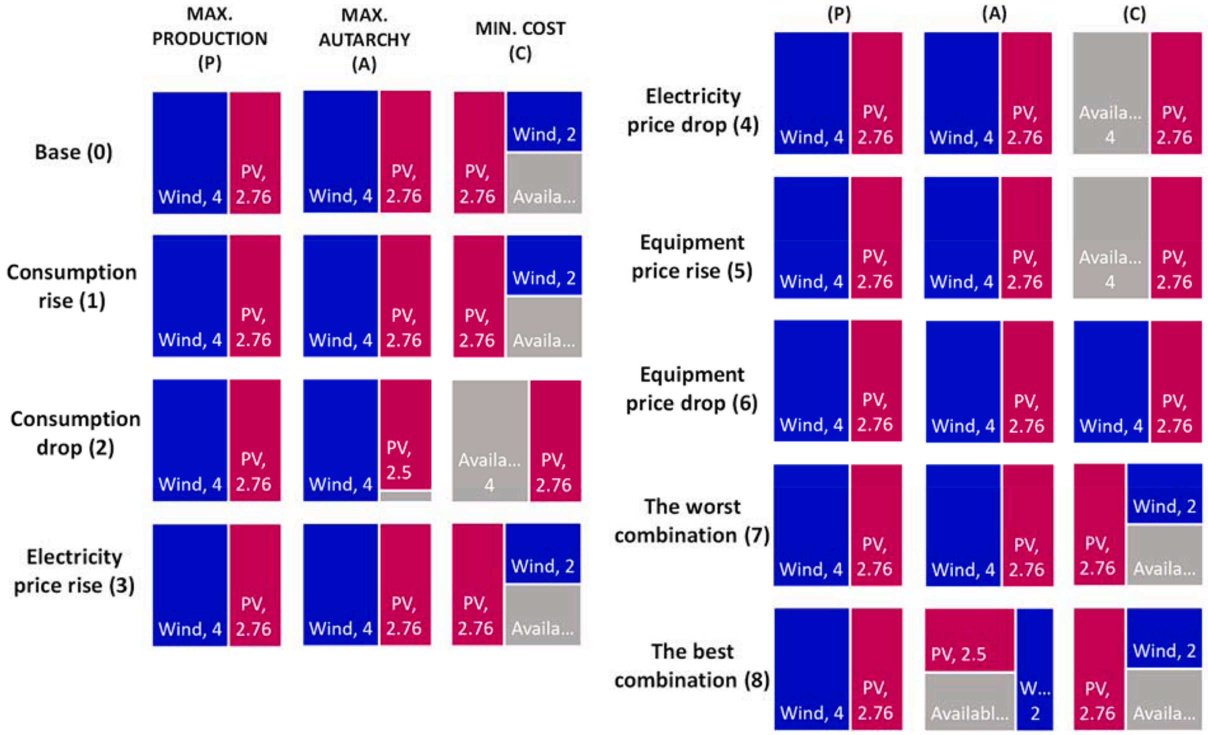

Fig. 10. PV and Wind power (MW) for each sensitivity analysis alternative.

installing one 2 MW wind turbine or two, depending on the case.

4.5. Discussion

Although the three strategic scenarios are feasible, the sensitivity analysis points out some differences between them. The sensitivity analysis determines that the minimum cost and the maximum autarchy scenarios are the most influenced by variations in the sensitive parameters. However, independently of the strategy ultimately defined, all the scenarios share the lighting change and a minimum of 2.5 MW of PV installations, 2.76 MW if discarding the maximum autarchy scenario. The difference between the configurations of one strategy or another is related to installing wind turbines or batteries but rarely affects PV's installation power. Furthermore, an advantage of the PV installations is the possibility of doing it progressively, avoiding big investments in short periods. At this point, depending on the evolution of uncertainty parameters, infrastructure planners could decide how much wind power to install, bearing in mind that not installing wind turbines means not achieving a PED. It would be necessary to install at least one wind turbine to achieve the PED target.

Working with several strategic scenarios in parallel facilitates the decision-makers' final selection. The sensitivity analysis shows how uncertainty affects scenarios and which are more affected. Moreover, the study of different strategic scenarios allows the establishing of a solid base of measures for the UWF common to all of them. The inclusion of further measures is dependent on the selected strategy. Still, the shared measures are the starting point for any energy strategy in the UWF, which are potential and unique candidates to become PED in urban areas. The energy planning for UWFs can be compared with the energy planning of islands conducted by Mimica et al. [45]. The main difference between islands and UWFs lies in costs, since the most cost-effective solution on the mainland could be significantly more expensive on the islands. Furthermore, the PED approach is better suited for UWFs due to the proximity to contiguous urban areas with which the UWF can exchange the surplus of energy.

Due to the availability of space and resources UWFs present a great opportunity for large generation in cities, enabling a positive energy balance to be achieved. Thus, the potential of UWF lies on the focus on renewable energy potential and use. Whereas in other areas of the city, such as residential districts, the focus lies on a higher penetration of energy and CO_2 saving measures. Future research could analyse the impact of UWFs on the whole city. To that end, the SDEWS Index [46], with which Valencia has been benchmarked with other 120 cities, could be a starting point. The SDEWES Index measures with different indicators 7 dimensions of the sustainable development. The potential and contribution of the UWF would be measured in the 7 dimensions comparing with the values for the whole city.

5. Conclusions

This paper presents different scenarios to achieve PED in a UWF. A method is applied based on data gathering, demand analysis, a study of the feasible renewable energy capacity, and techno-economic simulation of the different scenarios. The approach is validated in the UWF of the city of València with three scenarios, maximum renewable generation, autarchy, and minimum cost. UWFs are particularly interesting districts of cities, as in contrast to most urban districts, they have large spaces for renewable generation. The results show that a PED is achievable in LMDV, with only three exceptions among all the scenarios resulting from the sensitivity analysis of the minimum cost scenario. Moreover, all scenarios show a common path for the district. A combination of demand efficiency measures (LED lighting) and Solar PV installation is common in any scenario that aims to achieve a PED or improve the energy performance of the UWF.

The proposed method considers the context, the possibilities, and the expected evolution of the UWF. Based on the current state and the SWOT analysis, a prediction of future demand is made, barriers are also considered, and risk and sensitivity analyses of the proposals, consumption and prices are carried out. In addition to all this, a parallel study of several strategic scenarios is proposed to analyse the possible pathways and then establish the most appropriate one based on the indicators' results. Considering several scenarios parallel and carrying out a sensitivity analysis makes it easier to decide which scenario is the most suitable and which is the order of priorities within each scenario. Furthermore, the feasible measures in all scenarios are consolidated as a starting point in the energy strategy.

UWFs are districts with particularities such as greater availability of space and resources than other city districts. This makes them areas of interest for developing PEDs, a key strategy in the decarbonisation of cities. Although some UWFs have implemented energy efficiency and production measures, the PED approach in UWFs is still in its infancy. In addition to the novelty of the PED approach in UWFs, there is, in general, a difficulty for policymakers and competent authorities in PED planning. The decision of which measures to implement, whether efficiency or generation measures, must be based on energy demand and resource availability. But future barriers and predictions of consumption, prices, and technology evolution will also affect the suitability of the scenario and solutions to achieve a PED.

In sum, if cities are going to be a central effort in decarbonising societies, UWFs present a critical and ideal location to become a renewable generation oasis inside cities. While efforts in cities will concentrate on smaller self-generation facilities, energy efficiency measures, and the electrification of transport, the opportunity of larger scale generation must be considered. Future studies should analyse the global impact and potential of UWFs not only as single districts but as contributors to cities, and the particularities and impacts of real scale projects.

CRediT authorship contribution statement

Isabel Aparisi-Cerdá: Data curation, Methodology, Software, Writing – original draft. **David Ribó-Pérez:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Ivan Cuesta-Fernandez:** Supervision, Writing – review & editing. **Tomás Gómez-Navarro:** Methodology, Supervision, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This is an extended and updated version of a paper originally presented at the 16th Conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES 2021) held in Dubrovnik, Croatia over the period 10th to 15th October 2021 (denoted then as paper SDEWES2021.0666 - Planning Positive Energy Districts in Mediterranean cities, methodology and approach to València, Spain). We would like to thank el Consorci Valencia 2007 and the maintenance staff at the LMDV for their helpful insights and data provision. This work was supported in part by the Spanish public administration under grant FPU2016/00962, and by the Cátedra de Transición Energética Urbana (Las Naves-Fundació València Clima i Energía-UPV).

References

[1] Urbact, European Regional Development Fund. Urbact APN: Zero Carbon Cities. Using Science-based Targets to align cities' Sustainable Energy and Climate Action Plans to the Paris Commitment.

[2] IEA, Energy Technology Perspectives 2016. Towards Sustainable Urban Energy Systems., 2016.

[3] Cajot S, Peter M, Bahu J-M, Guignet F, Koch A, Maréchal F. Obstacles in energy planning at the urban scale. Sustain Cities Soc 2017;30:223–36.

[4] Amaral AR, Rodrigues E, Rodrigues Gaspar A, Gomes Á. Review on performance aspects of nearly zero-energy districts. Sustain Cities Soc 2018;43:406–20.

[5] Cortés P, Auladell-León P, Muñuzuri J, Onieva L. Near-optimal operation of the distributed energy resources in a smart microgrid district. J Cleaner Prod 2020; 252:119772.

[6] Becchio C, Bottero MC, Corgnati SP, Dell'Anna F. Decision making for sustainable urban energy planning: an integrated evaluation framework of alternative solutions for a NZED (Net Zero-Energy District) in Turin. Land Use Policy 2018;78: 803–17.

[7] Bossi S, Gollner C, Theierling S. Towards 100 positive energy districts in europe: preliminary data analysis of 61 European cases. *Energies* 2020;13(22):6083.

[8] Hinterberger R, Gollner C, Noll M, Meyer S, Schwarz HG. White Paper – Reference Framework for Positive Energy Districts and Neighbourhoods, JPI Urban Europe and SET-Plan 3.2 Programme on Positive Energy Districts, Viene, 2020.

[9] JPI Urban Europe, SET Plan Action 3.2 Implementation Plan, 2018.

[10] Kılkış Ş. A nearly net-zero exergy district as a model for smarter energy systems in the context of urban metabolism. J Sustain Dev Energy Water Environ Syst 2017;5: 101–26.

[11] Gouveia J, Seixas J, Palma P, Duarte H, Luz H, Cavadini G. Positive energy district: a model for historic districts to address energy poverty. *Front Sustain Cities* 2021.

[12] Muñoz I, Hernández P, Perez-iribarren E, Pedrero J, Arrizabalaga E, Hermoso N. Methodology for integrated modelling and impact assessment of city energy. *Energy Strategy Rev* 2020; 32.

[13] Calise F, Cappiello FL, Dentice d'Accadia M, Vicidomini M. Smart grid energy district based on the integration of electric vehicles and combined heat and power generation. Energy Convers Manage 2021;234:113932.

[14] Brozovsky J, Gustavsen A, Gaitani N. Zero emission neighbourhoods and positive energy districts – A state-of-the-art review. Sustain Cities Soc 2021;72:103013.

[15] Alpagut B, Akyürek Ö, Mitre EM. Positive energy districts methodology and its replication potential. *Proceedings* 2019.

[16] Laitinen A, Lindholm O, Hasan A, Reda F, Hedman Å. A techno-economic analysis of an optimal self-sufficient district. Energy Convers Manage 2021;236:114041.

[17] European Commission, Stepping up Europe's 2030 climate ambition. Investing in a climate-neutral future for the benefit of o ur people., 17 09 2020. [En línea]. Available: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0562. [Último acceso: 16 05 2022].

[18] Østergaard PA, Duic N, Noorollahi Y, Mikulcic H, Kalogirou S. Sustainable development using renewable energy technology. Renewable Energy 2020;146: 2430–7.

[19] Østergaard PA, Dui N, Noorollahi Y, Kalogirou S. Latest progress in Sustainable Development using renewable energy technology. Renewable Energy 2020;162: 1554–62.

[20] Autoridad Portuaria de Valencia, Boletín Ambiental 2020. Ecoport 59, APV, Valencia, 2020.

[21] Autoridad Portuaria de Valencia, Memoria Ambiental 2018, APV, Valencia, 2018.

[22] Acciaro M, Ghiara H, Cusano MI. Energy management in seaports: a new role for port authorities. Energy Policy 2014;71:4–12.

[23] Port of Amsterdam, The Sustainable Port. The Port of Amsterdam's sustainability objectives and initiatives, 2017. [En línea]. Available: https://globalmaritimehub.com/wp-content/uploads/attach_872.pdf. [Último acceso: marzo 2020].

[24] Port of Amsterdam, Incentive Scheme For Climate-Friendly Shipping, Amsterdam, 2019.

[25] Hentschel M, Ketter W, Collins J. Renewable energy cooperatives: Facilitating the energy transition at the Port. Energy Policy 2018;121:61–9.

[26] V&A waterfront Cape Town, V&A waterfront Cape Town, 2019. [En línea]. Available: https://www.waterfront.co.za/the-va/sustainability/our-journey-to-sustainability/. [Último acceso: abril 2020].

[27] Angrisano M, Bosone M, Ravezzi S, Ascione V. The implementation of circular economy model for the Torre Annunziata waterfront regeneration., *BDC. Approaches and Toold for implementing the circular ity model* 2018; 18(1): 33-46.

[28] Derkenbaeva E, Halleck Vega S, Hofstede GJ, van Leeuwen E. Positive energy districts: Mainstreaming energy transition in urban areas. Renew Sustain Energy Rev 2022;153:111782.

[29] Schoonschip, 28 April 2022. [En línea]. Available: https://schoonschipamsterdam.org/en/.

[30] Lausselet C, Borgnes V, Brattebø H. LCA modelling for Zero Emission Neighbourhoods in early stage planning. Build Environ 2019;149:379–89.

[31] van den Dobbelsteen A, Martin C, Keeffe G, Pulselli R, Vandevyvere H. From problems to potentials—The urban energy transition of Gruž, Dubrovnik. *Energies* 2018;11(4):922.

[32] Kerzner H. 3. Principles of Strategic Planning. In: de *Strategic Planning for Project Management Using a Project Management Maturity Model.* New York: John Wiley & Sons Inc; 2001. p. 15–40.

[33] Good N, Martínez Ceseña E, Macarella P, Monti A, Pesch D, Ellis K. Chapter Eight - Barriers, Challenges, and Recommendations Related to Development of Energy Positive Neighborhoods and Smart Energy Districts, de *Energy Positive Neighborhoods and Smart Energy Districts.*, Academic Press, 2017, pp. 251-274.

[34] Academic Press J, Wohlgemuth N. Chapter 18 - Renewable energy technologies: barriers and policy implications., de *Renewable Energy Driven Future. Technologies, Modelling, Applications, Sustainability and Policies.*, Academic Press, 2021, pp. 539-562.

[35] HOMER Energy, HOMER 2.68 beta, [En línea]. Available: https://www.homerenergy.com/index.html.

[36] Project Management Institute, Inc., Capítulo 11. Gestión de los Riesgos del Proyecto, de *Guía de los Fundamentos de la Dirección de Proyectos Guía del PMBOK).*, Project Management Institute, Inc, 2004, pp. 237-268.

[37] The Boston Consulting Group (BCG), Evolución Tecnológica Y Prospectiva De Costes De Las Energías Renovables. Estudio Técnico. PER 2011-2020, IDAE, Madrid, 2011.

[38] E. Fuster Palop, Desarrollo de un modelo en código R para la estimación en cubiertas del potencial solar fotovoltaico para la cobertura dela demanda eléctrica de edificios residenciales y terciarios en la ciudad de Valencia, Escuela Técnica Superior Ingenieros Industriales, Valencia, 2019.

[39] Arcos-Vargas A, Gomez-Exposito A, Gutierrez-Garcia F. Self-sufficient renewable energy supply in urban areas: application to the city of Seville. Sustain Cities Soc 2019;46:101450.
[40] EnergyPlus, [En línea]. Available: https://energyplus.net/weather-location/europe_wmo_region_6/ESP//ESP_Valencia.082840_IWEC. [Último acceso: 2019].
[41] PVGIS, [En línea]. Available: The daily average global horizontal irradiation . [Último acceso: 2019].
[42] BOE, Real Decreto 244/2019, de 5 de abril, por el que se regulan las condiciones, Boletín Oficial del Estado, Madrid, 2019.
[43] IDAE, "Atlas Eólico de España," Instituto para la Diversificación y Ahorro de la Energía, [Online]. Available: http://atlaseolico.idae.es/. [Accessed 2018].
[44] Ministerio para la Transición Ecológica y el Reto Demográfico., Plan Nacional Integrado de Energía y Clima (PENIEC), 2020.
[45] Mimica M, Krajačić G. The Smart Islands method for defining energy planning scenarios on islands. Energy 2021;237:121653.
[46] SDEWES International Centre, SDEWES Index, [En línea]. Available: https://www.sdewes.org/sdewes_index.php. [Último acceso: 03 05 2022].