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An Investigation on the Feasibility of Near-Zero and Positive Energy Communities in the Greek Context

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Abstract: Near Zero Energy and Positive Energy communities are expected to play a significant part in EU's strategy to cut greenhouse gas emissions by 2050. Within this context, the work presented in this paper aims to investigate the feasibility of: (a) a new-built positive energy neighborhood; and (b) the retrofit of an existing neighborhood to near zero energy performance in the city of Alexandroupolis, Greece. Proposed measures involve the rollout at the community scale of renewable energy technologies (PV, geothermal heat pump), energy efficiency (fabric insulation, district heating and cooling networks) and storage systems (batteries). A parametric analysis is conducted to identify the optimum combination of technologies through suitable technical and financial criteria. Results indicate that zero and near zero emissions targets are met with various combinations that impose insulation levels, according to building regulations or slightly higher, and consider renewable energy production with an autonomy of half or, more commonly, one day. In addition, the advantages of performing nearly zero energy retrofit at the district, rather than the building level, are highlighted, in an attempt to stimulate interest in community energy schemes.

Keywords: NZE communities; positive energy communities; renewable energy; energy storage; district heating and cooling

1. Introduction

The EU has set the ambitious target of achieving net-zero greenhouse gas emissions by 2050. Its long-term climate strategy also includes intermediate targets as set in the 2030 climate and energy framework. The key targets for 2030 are: achieving at least 40% reduction in greenhouse gas emissions compared to the 1990 levels, a minimum 32% share of renewable energy in the final energy consumption, and a minimum 32.5% increase in energy efficiency [1]. The building sector is one of the main energy consumers responsible for about 36% of greenhouse gas emissions (GHG), and therefore it has been the focus of regulatory reform, as part of the strategy towards reducing emissions over the past years [2]. The main use of energy by households in the EU in 2017 was for heating their homes (64.1% of final energy consumption in the residential sector) with Renewable Energy Sources (RES), accounting for almost a quarter of EU households space heating consumption. Heating and domestic hot water alone accounted for 78.9% of total final energy use of EU households in 2017 [3]. Provisions in increasing the energy efficiency of buildings are included in Directive 2010/31/EU on the Energy Performance of Buildings (recast) (EPBD). In this context, the EPBD (recast) requires that all new buildings should be nearly-zero energy buildings from 31st December 2020 onwards, while all new public buildings should be nearly-zero energy as from the 31st December 2018 [4]. Furthermore, Directive 2012/27/EU on Energy Efficiency requires a 3% renovation of the total floor area of public buildings on an annual basis [5].

Whilst there is continuing focus on improving the energy efficiency of the construction sector at the building level, there is also emerging interest in improving the energy performance at community scale. The EU's urban population is ever growing; cities accounted for approximately 75% of the EU population in 2015, while this percentage is expected to reach 80% by 2050 [6]. It is estimated that urban areas account for 70% of GHG emissions and two thirds of energy consumption in the EU [7]. Therefore, Net Zero Energy (NZE) settlements where the zero energy principles are considered at the district scale are expected to play a significant part in achieving the emissions reduction targets. Apart from their decarbonisation potential, these are seen as places that will stimulate environmental awareness, innovation, economic growth and social progress; however, it is acknowledged that achieving net zero performance at the community level has its own challenges and opportunities [8].

Many studies up to now have been conducted regarding the evaluation of Near Zero Energy Districts (NZED). Robinson et al. (2011) [9] focused on simulation approaches for sustainability in the urban environment with emphasis to building energy modelling. Pol and Robinson (2011) focused on the impact of the urban morphology on the energy performance of buildings [10]. Whilst there is a wide range of established tools for the analysis of building energy demand with high levels of accuracy, energy modeling at the district scale is more challenging and computationally intense; district scale modeling considers and integrates at the minimum a group of buildings, a source of energy and an energy distribution network. This often leads to the use of simplified models with somewhat reduced accuracy [11]. Jebaraj and Inivan (2006) reviewed 252 works focusing on the use of integrated energy models [12], while Vreenegoor et al. (2003) evaluated various simulation tools and certifications (i.e., LEED etc.) applicable at the district level analysis; the focus of that study was the residential building stock in Germany [13]. Alegrini et al. (2015) reviewed models and tools for the energy modeling of district systems, renewable energy production and the effect of urban microclimate to the district energy demands [14]. District heating networks are a core component in many energy communities. Haghighat et al. (2019) provides a review of case studies with district heating networks and the relevant source of thermal energy in [11]; CHP, geothermal, solar energy, waste to energy technologies and industrial excess heat were considered as well as the simulation tools used in the analysis.

In the work of Synnefa et al. (2017) [8] the evaluation of four NZE settlements across the EU (Cyprus, France, Italy and the UK) in terms of energy, environmental and cost performance was presented. The analysis conducted at both the building and the settlement level and it was found that that the targets of (i) annual net-regulated energy use less than or equal to 20 kWh/m^2 and (ii) annual renewable energy production greater than or equal to 50 kWh/m^2 were met in the four settlements investigated. The projects were also considered cost-effective as reduction of at least 16%, compared with current NZEB costs, was also reported. Hachem (2016) investigated the effect of design parameters on the performance of solar community incorporating roof-mounted PV in terms of GHG emissions reduction and the balance between electricity consumption and generation; design parameters included the building insulation levels, neighborhood density and type, as well as the design of streets and distance to commercial center. It was found that the energy upgrade of the community resulted up to 75% reduction in GHG emissions from the buildings, while transport was found to still have a significant environmental impact [15]. Hachem-Vermette et al. (2019) investigated the performance of a neighborhood in Canada towards achieving net-zero energy performance by means of solar thermal, coupled with borehole energy storage and PV [16]. Energy production up to 20% higher than the energy consumption of the neighborhood was achieved.

Several studies also focused on the cost aspects of NZE settlements. Isaac et al. (2020) studied the cost of Net Zero Energy communities, considering various scales and densities. A model was developed for identifying the optimum configuration of RES technologies for an NZE settlement in a cost-effective manner [17]. It was found that increasing the scale of the community up to a certain point reduced the associated energy cost, while urban density was found to have a more complex impact on costs.

Paduos and Corrado (2017) investigated the effectiveness of retrofit packages of measures for buildings to achieve nearly zero energy performance [18]. The analysis considered thirty reference buildings and several different packages of retrofit measures. Following a cost-optimal evaluation approach, the measure packages that met the nearly zero-energy target and were cost-effective were defined. It was shown that in most cases NZEB retrofit was technically feasible, with a high reduction of the non-renewable primary energy consumption. Nevertheless, it was found that the costs of retrofitting to such degree were still too high to be considered as attractive investments.

Planning district level energy systems often requires an iterative calculation process and the use of optimization techniques. Evins (2013) highlighted the need for tools that are able to conduct parametric analysis at the district scale and integrate them to optimization processes [19]. Allegrini et al. (2015) considered the provision of simple tools that can support decision makers at the early stages of project design of significant importance to district energy modeling [14]. Ala-Juusela et al. (2016) used a decision support tool, called AtLas, designed to inform the long term planning of neighborhood energy solutions, in order to evaluate the energy positivity level of a Finnish residential neighborhood, and part of a French university campus [20]. Positive energy neighborhoods were defined as those with annual energy consumption lower than the annual locally produced renewable energy. The energy positivity level of an area was estimated with calculating energy matching indicators: on-site energy ratio, annual mismatch ratio and other mismatch indicators. Rehman et al. (2015) investigated the development of positive energy community for the Nordic climate, considering the use of a district heating system combined with wind turbines and PV for electricity production, as well as electrical storage and electric vehicles [21]. Multi-objective optimization was performed to minimize the lifecycle cost and the imported electricity.

Despite the increased challenges of the districts, considering the near zero performance at the wider scale offers the flexibility of utilizing different levels of energy performance and energy production capacity and aggregating resources, costs and requirements [22]. In the 2050 Vision of the European Technology and Innovation Platform on Renewable Heating and Cooling, energy communities are considered to have the potential to shift to a new Renewable Heating and Cooling business model where citizens, rather than the operators, own the assets [23].

Cities and communities, therefore, will have an important role in EU's transition towards a carbon-neutral economy as they are 'a locus for innovation, they provide great opportunities for learning and networks, and they offer the possibility of achieving whole system change at local scales' [24] (pp. 81–82). The European Strategic Energy Technology Plan highlighted the importance of smart cities, and supported the roll-out of positive energy blocks and districts within cities that take advantage of the synergies and energy flows between buildings to deliver energy efficient heating, cooling and lighting [25].

Within this context, the European project 'Integrated and Replicable Solutions for Co-Creation in Sustainable Cities' (IRIS), funded under the Horizon 2020 Program, aims to support the development, demonstration and replication of near zero and positive energy districts and neighborhoods. This is done as part of the transition of three Lighthouse (LH) and four Follower cities (FC) towards becoming smart cities [26]. Lighthouse are the cities with the technical capacity to implement district-wide projects integrating and demonstrating novel technologies; LHs act as exemplars for the FCs. Follower Cities do not have the full competency to implement such wide scale projects; they aim at replicating the most appropriate solutions demonstrated by the LHs adapted to the local conditions. The IRIS Lighthouse Cities are Gothenburg (Sweden), Nice Cote d'Azur (France) and Utrecht (Netherlands); the Follower Cities include Alexandroupolis (Greece), Focsani (Romania), Santa Cruz de Tenerife (Spain) and Vaasa (Finland). The IRIS smart city transition takes place through increasing the share of renewable energy and energy management, e-mobility services and citizen engagement, while beneficiating from available multi-type available storage systems and is organized around the following five Transition Tracks (TT):

- TT#1—Smart renewables and closed-loop energy positive districts;
- TT#2—Smart Energy Management and Storage for Grid Flexibility;
- TT#3—Smart e-mobility sector;
- TT#4—City Innovation Platform;
- TT#5—Citizen engagement and co-creation.

Each Transition Track comprises several Integrated Solutions (IS). Planning and development of near-zero energy and positive energy blocks and districts is the main focus of TT #1; more specifically, IS1.1-Positive Energy Buildings and IS1.2-Near Zero Energy Districts of TT#1 examine the use of various energy efficient and renewable technologies in buildings, as well as the integration of smart-grids and thermal networks.

The work presented in this paper focuses on the replication activities to develop near and net zero communities in the Follower City of Alexandroupolis, Greece. The aim of the work is to evaluate the feasibility of such energy communities in Greece by selecting and replicating technologies and activities that are currently being demonstrated in the Lighthouse Cities, making them fit within the local context of Alexandroupolis. The most suitable technologies and combinations of these technologies that meet the technical requirements for nearly-zero or positive energy performance in a financially viable manner are identified. Various integrations of these technologies are evaluated with the use of suitable technical and financial Key Performance Indicators (KPIs), thus ensuring that proposed integrated solutions are also financially viable investments. KPIs are indicators designed to measure the degree that specific objectives of a project have been achieved and their selection is critical for measuring and communicating the level of the project's success [27].

It is envisaged that the study may act as a roadmap for the uptake and development of positive energy and near-zero energy communities in Greek Cities, similar to Alexandroupolis. In addition, it can be used as a decision support tool for policy makers when assessing alternative options towards the path to the decarbonization of the EU economy by 2050. This is in line with the recommendation made in [14].

2. Methodology

The technologies considered, as well as the various integration configurations, are assessed against selected technical and financial criteria, to ensure that proposed measures are both technically feasible and financially viable investments. First, the technical analysis is conducted using appropriate software to determine the energy flows at the building and district level. Suitable KPIs are then identified to evaluate the results obtained. In the following paragraphs, the selection process of the suitable assessment criteria used and the appropriate software are presented.

2.1. Assessment Criteria

Performance of the various technology integrations considered in this work is evaluated against suitable Key Performance Indicators. Several studies have dealt with the development and classification of KPIs in the context of smart city solutions [27–30]. A holistic framework for determining KPIs for smart city solutions has been developed as part of the IRIS project [27]. Indicators have been identified and classified in this study, based on domain (technical, environmental, economic, social, information and communications technologies (ICT) and legal), relevant stakeholders and level of evaluation (building, system, neighborhood etc.). Suitable indicators for this work were extracted from [27], considering the specific requirements of this study, namely: (i) the smart city domains addressed (energy and environmental); (ii) the level of evaluation (neighborhood); (iii) the nature of the study (simulation based); (iv) relevance of the KPIs to the project objectives; (v) data availability and ability to provide quantified results; and (vi) ability to be easily understood by the various stakeholders.

Based on these requirements the following KPIs were identified for this analysis:

1. Degree of Energetic Self-supply by RES. This is defined as the 'ratio of locally produced energy from RES and the energy consumption over a period of time (e.g., month, year). DE is separately determined for thermal (heating or cooling) energy and electricity' [31] (p. 60)

$$DE_T = \frac{LPE_T}{TE_C} \tag{1a}$$

$$DE_E = \frac{LPE_E}{EE_C} \tag{1b}$$

where,

DE_T, DE_E = degree of thermal and electrical energy self-supply based on RES respectively
LPE_T, LPE_E = locally produced thermal and electrical energy (kWh/month or kWh/year)
TE_C, EE_C = thermal and electrical energy consumption respectively (kWh/month or kWh/year)

2. Emissions reduction. This is defined as the amount of CO_2 emitted after the measures are considered less the CO_2 emitted in the base case.
3. Payback period. This is the time required for an investment to offset the capital cost required. In this case, two types of payback period are considered; static and dynamic. The static payback period is defined as:

$$EPP = \frac{ERI}{m} \tag{2}$$

The dynamic payback period accounts for change in energy prices in years following the investment, as well as the future value of money (via the use of a discount rate). It is defined as [31] (p. 79):

$$EPP = \frac{\ln(m\cdot(1+i)) - \ln(ERI\cdot(1+p) - ERI\cdot(1+i) + (1+p)\cdot m)}{\ln(1+i) - \ln(1+p)} - 1 \tag{3}$$

where,
ERI = energy related investment (€)
$m = TAC_{after} - TAC_{before}$ (€/year)
TAC_{after} = total annual costs (or revenues) after the energy related investment (€/year).
TAC_{before} = total annual costs before the energy related investment (€/year).
i = discount rate (%)
p = energy price increase rate (%)

Furthermore, the Net Present Value (NPV) and the Internal Rate of Return (IRR) have been used for the financial evaluation of the proposed measures. These are well established and commonly used financial indicators for the economic evaluation of potential investments; they have also been used extensively for the feasibility assessment of investment proposals under the Greek Development Law. For this reason, they were found suitable for use in the Greek context. The NPV is the present value of future cash flows (cash inflows–outflows) considering an appropriate discount rate (Equation (4)). The IRR is that discount rate that results in zero NPV. A positive NPV and an IRR value higher than a set value, commonly 5%, suggests the viability of an investment.

$$NPV = \left(\sum_{t=1}^{n} \frac{\text{Net Cash Flow}_t}{(1+i)^t}\right) - \text{Initial Investment} \tag{4}$$

where,
i = the discount rate (%)
t = time period (years)

2.2. Software Selection

In order to conduct the performance analysis of the measures considered, it is also necessary to identify suitable software to perform the energy modeling. The analysis follows a bottom up approach [32], where firstly, the energy consumption is determined at the building level, and then results are aggregated to the level of the community, in order to determine the energy balance at the district level. Due to the nature of this work, as the replication study is relying solely on simulations, the analysis is performed with law driven white box models [33]. The same approach is followed for both the new-built and the retrofit cases examined. The selection of appropriate software for both levels of the analysis (building and district scale) is based on the following criteria:

- Technical capacity to model the multi-type technologies considered. A range of technologies are examined and, therefore, it is required that the software selected should be able to model their performance;
- Levels of cost-effectiveness and user friendliness. This work is conducted on a feasibility analysis level and it is considered that several stakeholders (e.g., Municipalities Energy Offices, Investors) may be involved at this stage on a real-life scenario. Some of these stakeholders may not have required technical knowledge and therefore software user friendliness is considered of high importance;
- Ability to provide quick results in order to facilitate the iterative nature of the analysis when evaluating several replication measures;
- Ability to conduct the analysis at the scale required, i.e., building and district;
- Ability of the software to provide results using simplified and easy to obtain input data, since detailed information is not usually available at the preliminary stage of such projects;
- Ability to provide results in a suitable format that allows the evaluation of the different scenarios based on the selected indicators.

In order to determine software that can fit the above-mentioned criteria, a range of alternative software available in the market was examined. A review of the main model capabilities of the various alternatives was conducted, focusing on available attributes offered by each of them, such as: (a) range and type of technologies able to be considered (including power production, storage); (b) scale of the analysis (building envelope, building systems or both and district scale) that can be performed; (c) availability of multiple energy vectors (e.g., electricity, heating and cooling) and their integration potential; and (d) complexity of simulations and associated cost. Results of the review are presented in Table 1. Based on the above criteria, RETScreen Expert and EnergyPLAN were found suitable for conducting the replication analysis, for the case of Alexandroupolis.

RETScreen Expert is a Clean Energy Management software used for the feasibility analysis of renewable energy and energy efficiency projects [34]. The software may be used for conducting energy modeling, estimating greenhouse gas emissions, as well as performing financial analysis and risk assessment of potential investments. RETScreen includes databases for a range of renewable energy and energy efficient technologies, as well as databases from weather stations worldwide. The cost of the software is relatively low, or even free on viewer mode, which makes it a cost-effective solution for projects where many stakeholders are involved. RETScreen is used in this study for evaluating the energy consumption and the renewable energy production at the building level. Results are then aggregated and used as input in EnergyPLAN for the macro-scale analysis.

Table 1. Review of available software.

	Building Analysis	System Analysis	District/Grid Analysis	Heat	Electricity	Transport	Storage	Simulation Level	Access
TRNSYS	X	X	X	X	X	X	X	Detailed generic simulations of transient systems	Commercial
HOMER Pro	-	X	X	X	X	-	X	Advanced simulation for assessing power plant and grid performance	Commercial
PV syst	-	X	-	-	X	-	X	Advanced simulation for assessing PV system performance	Commercial
T*sol	-	X	-	X	-	-	X	Advanced simulation for assessing solar thermal system performance	Commercial
PV*sol	-	X	-	-	X	X	X	Advanced simulation for assessing PV system performance and electric vehicles	Commercial
Geo T*sol	-	X	-	X	X	-	X	Advanced simulation for assessing heat pump and solar thermal system integration	Commercial
IDA ICE	X	X	-	X	X	-	X	Detailed building performance simulation software	Commercial
ESP-r	X	X	-	X	X	-	-	Detailed building performance simulation software.	Free
EDSL Tas	X	X	-	X	X	-	-	Detailed building performance simulation software	Commercial
Design Builder	X	X	-	X	X	-	-	Detailed building performance simulation software	Commercial
Energy Plus	X	X	-	X	X	-	X	Detailed generic building performance simulation engine	Free
RETScreen	X	X	X	X	X	-	X	Preliminary analysis software of various renewable energy and energy efficiency measures	Commercial
EnergyPLAN	-	-	X	X	X	X	X	Advanced simulation of complex energy systems at regional and national level	Free
Energy Pro	-	X	X	X	X	-	X	Advanced simulation of complex energy systems at system/regional level	Commercial

EnergyPLAN [35] was developed for the energy modelling of national or regional energy systems, including all the main sectors of an energy system (heating, cooling, electricity, industry and transport). The software calculates the system's energy balance on an hourly basis, taking into account all the main renewable energy and storage technologies. It is deterministic in nature, and is structured as a simple input and output model, where the user enters the energy demands, as well as the capacities and fuels of power stations and renewable energy plants. The model then calculates the energy production, the energy balance, electricity imports and exports and the resulting emissions from an energy system.

The general simulation procedure for calculating the energy balances at the district scale is as follows. At first, the energy requirements at the building level are determined using RETScreen. Information regarding building geometry, thermal properties of building elements, occupancy patterns and internal conditions are used as inputs; the output of the simulation are the heating, cooling and electricity demands for each building. The energy demands of all buildings are then summed to determine the respective energy requirements at the district scale. The aggregated heating, cooling and electricity demands are then used as inputs in EnergyPLAN, in order to determine the energy balance of the whole district. The analysis considered post-processing of the hourly energy balance obtained as output from the software. Despite the fact that EnergyPLAN was developed to simulate much larger and complicated systems, it is found useful for conducting the technical analysis at a smaller scale, where the district is treated as an independent energy system and the resulting energy flows (electricity imports, exports) are determined. To achieve that, necessary restructuring of the underlying simulation settings has been made, highlighting those of: (a) considering that renewable energy has a high grid-stabilization share; and (b) the power flow from the national grid to feed the district is as minimum as possible. It is thereby ensured that renewable energy and stored electricity are given priority over electricity imports in covering the energy requirements of the district. Such assumptions would not stand true when simulating a national energy system, however, they were found acceptable on the much smaller scale of a district that was part of national grid.

3. Near Zero and Positive Energy Settlements in Alexandroupolis

The city of Alexandroupolis has a population of 72,959 people (2011 census) [36], and is the administrative center of the Regional Unit of Evros, Region of Eastern Macedonia and Thrace. It is situated near the border between Greece and Turkey. The strategic location of Alexandroupolis highlights its potential to become a hub for energy security and diversity of Europe. The city is also a member of the Covenant of Mayors, having a validated Sustainability Energy Action Plan (SEAP), and a being founding member of the Greek Green Cities Network. For this reason, it is considered as an ideal candidate for investigating the feasibility of Near-Zero and Positive Energy Settlements. Alexandroupolis has on average 1815 heating degree-days annually [37], and its baseline (2011) final energy consumption and CO_2 emissions have been estimated at approximately 930 GWh and 440 kt, respectively [38]. As part of the continuous efforts of reducing its carbon footprint, the feasibility of two energy community projects is investigated; i.e., the planning of a new-built positive energy neighborhood and the retrofit of an existing housing estate to a near zero energy level. A description of the two settlements and the proposed measures is presented in the following paragraphs.

3.1. New-Built Positive Energy Settlement

The selected site for the new-built positive energy neighborhood is located within a larger 4500-hectare site in the area of 'Kallithea-N. Chilli' of Alexandroupolis. It comprises three separate plots with a total area of approximately 42,000 square meters, as shown in Figure 1.

According to the town planning for the area of N.Chilli, the maximum coverage area is 40% of total plot area and the maximum building height is 8 m, which can be extended by 1.5 m in the case of buildings with inclined roofs. Effectively, this leads to buildings with maximum of two floors. Based on these restrictions, the proposed development comprises 100 two-floor detached houses, and is based on the fundamental principles of environmental design. Each house has a footprint of 60 m^2

(6 m · 10 m) and comprises 120 m^2 total heated floor area. All houses have south orientation (i.e., the main axis lies on the East–West axis) and large south facing glazing for maximizing solar gains. In addition, adequate distance between rows of houses is considered, to minimize shadowing from neighboring properties.

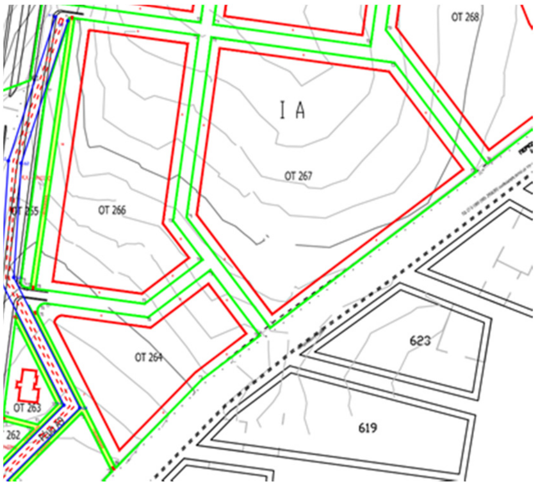

Figure 1. Close up view of the three available plots for the new-built positive energy district.

The following measures are considered for achieving positive energy performance:

- Increased fabric energy efficiency. Different levels of insulation are examined, in order to evaluate the suitability of current building regulations, as well as to assess the performance of increased insulation when considering positive-energy targets. Three cases are examined: (i) Case A considers the insulation levels required by current building regulations for the city of Alexandroupolis (Climatic Zone C) [39]; (ii) Case B considers the use of slightly increased insulation on the walls, roof and the floor; while (iii) Case C considers the use of further increased insulation on the walls, roof and floor, as well as the use of even more efficient windows (triple glazed windows instead of double glazed ones considered in Cases A and B). The thermal transmittance of building elements and the resulting neighborhood energy consumption for the three cases examined are presented in Table 2. As mentioned previously, the analysis is conducted at the building level with the use of RETScreen. Results from the building level analysis are then aggregated at the district level, and used as input in EnergyPLAN for the district level analysis.
- Low Temperature district heating and district cooling (DHC) network for the supply of thermal energy.
- Geothermal Heat Pumps for providing heating and cooling in the DHC network.
- PV panels for on-site electricity generation along with battery storage. After conducting a preliminary analysis, it is deduced that the minimum PV capacity required for meeting the electricity demand of the neighborhood is around 500 kW$_p$. A parametric analysis is then conducted during which various PV and battery capacities are examined, i.e., three different PV capacities are considered: 500, 525 and 550 kW$_p$. With an available clear roof space of approximately 37 m^2 for each building and an average size of 1.65 m^2 for a 250 W$_p$ crystalline panel (average value from a range of panels from the RETScreen database), it is considered that 5.5 kW$_p$ for each house is approaching the maximum capacity. Therefore, 550 kW$_p$ is potentially the upper limit for the neighborhood. Furthermore, four different electricity storage capacities are evaluated, according to the desired degree of autonomy, i.e., 750 kWh ensuring approximately half-day autonomy for the neighborhood, 1500 kWh—corresponding to a day's autonomy, 2250 kWh for a day and a half and 3000 kWh for 2 days autonomy.

Table 2. Thermal transmittance of building elements and energy consumption for the three cases examined.

	U-Value (W/m²K)		
	Case A	**Case B**	**Case C**
Walls	0.40	0.35	0.30
Roof	0.35	0.30	0.25
Floor	0.65	0.60	0.55
Windows	1.20	1.20	0.80
	Resulting Loads (kWh)		
	Case A	**Case B**	**Case C**
Heating	987,500	943,100	859,500
Cooling	673,900	669,600	661,000
Electricity	271,500	271,500	271,500

In summary, the following scenarios are examined with varying: (a) levels of insulation levels, (b) PV capacity and (c) battery storage capacity (Table 3). The performance of each configuration is assessed against that of a Business-as-Usual (BaU) scenario, i.e., buildings constructed according to current building regulations (i.e., insulation levels equal to Case A). No electricity generation and storage is considered for the BaU scenario. Heating and cooling are provided by heating oil boilers and air-conditioning (A/C) units, respectively.

Table 3. Summary of scenarios examined and the BaU scenario for the positive energy neighborhood.

	Case A			**Case B**			**Case C**		
	PV (kW)	**Batteries (kWh)**	**Heating/ Cooling**	**PV (kW)**	**Batteries (kWh)**	**Heating/ Cooling**	**PV (kW)**	**Batteries (kWh)**	**Heating/ Cooling**
BaU	0	0	Boiler+A/C	0	0	Boiler+A/C	0	0	Boiler+A/C
Conf. 1	500	750	DHC	500	750	DHC	500	750	DHC
Conf. 2	500	1500	DHC	500	1500	DHC	500	1500	DHC
Conf. 3	500	2250	DHC	500	2250	DHC	500	2250	DHC
Conf. 4	500	3000	DHC	500	3000	DHC	500	3000	DHC
Conf. 5	525	750	DHC	525	750	DHC	525	750	DHC
Conf. 6	525	1500	DHC	525	1500	DHC	525	1500	DHC
Conf. 7	525	2250	DHC	525	2250	DHC	525	2250	DHC
Conf. 8	525	3000	DHC	525	3000	DHC	525	3000	DHC
Conf. 9	550	750	DHC	550	750	DHC	550	750	DHC
Conf. 10	550	1500	DHC	550	1500	DHC	550	1500	DHC
Conf. 11	550	2250	DHC	550	2250	DHC	550	2250	DHC
Conf. 12	550	3000	DHC	550	3000	DHC	550	3000	DHC

3.2. *Near-Zero Energy Neighbourhood*

The proposed near-zero energy district is located in the western side of the city of Alexandroupolis. The district comprises 95 terrace and mid-terrace houses grouped together in several blocks within a total area of approximately 22,500 m². The houses are 2-floor buildings (each with a ground floor and a first floor) with a total heated floor area of about 73 m². The settlement was built in the 1970s as social housing and houses are now privately owned by the residents.

As the first regulation for the insulation of buildings came into effect in 1979, there was no provision for insulating the properties at the design stage. The construction of these dwellings is typical for that period, characterized by solid uninsulated walls with an uninsulated concrete frame, uninsulated concrete slab floors, a concrete slab roof and single glazed windows with metal frame. It is estimated that a number of houses have since been refurbished to a smaller or larger extent, while others have remained in their original condition. Therefore, it is considered that the houses of the district fall within one of the following categories according to their level of insulation: (a) uninsulated dwellings; (b) dwellings, in which minor interventions had taken place (i.e., buildings with single glazed windows that were replaced by double glazed windows with aluminum frame without thermal break); and (c) dwellings in which major retrofit interventions had been carried out (i.e., insulating the external walls and the roof to the current building regulations standard and replacing the single glazed windows with new efficient double glazed ones). The layout of the buildings and the different insulation categories are presented in Figure 2 while a summary of the U-values for the building elements based on the three levels of insulation considered is shown in Table 4.

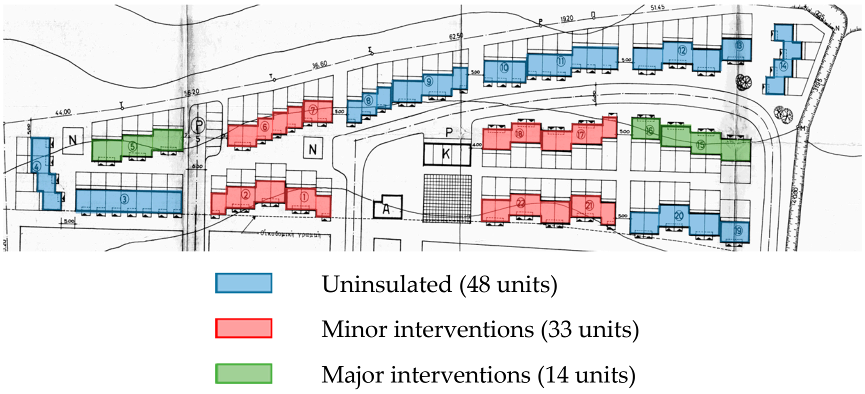

Figure 2. Arrangement of houses according to the insulation levels.

Table 4. Thermal transmittance of the main building elements for the three levels of insulation considered.

	Uninsulated (No Interventions)	Minor Interventions	Major Interventions
	U-Value (W/m^{2}K)		
External walls	2.38	2.38	0.40
Windows	4.6	3.3	1.40
Doors	3.5	3.5	1.40
Roof	4.7	4.7	0.35
Floor (contact with air)	2.75	2.75	0.35
Floor (contact with ground)	3.10	3.10	3.10

Planning of the near-zero energy district follows the same approach as the positive energy district. The energy requirements for each block (Figure 2) are determined in RETScreen and the sum of all the blocks is used as input in EnergyPLAN for the district level analysis. Increased insulation levels, grid-connected roof-mounted PV with storage for a certain degree of autonomy and ground-source heat pump supplying thermal energy through a district heating and cooling network are the measures considered. In order to establish a minimum level of insulation, the definition of near zero energy building is considered. There is currently no quantitative metric or definition; according to Article 2(2) of the EPBD, a NZEB 'means a building that has a very high energy performance ... The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby' [40] (p. 3). In Greece, it is considered that buildings with energy rating of A+ are very close to the NZEB target [41]. For this reason, a model for a representative building of the district has been developed using the energy rating software provided by the Technical Chamber of Greece for conducting Energy Performance Certificate assessments. Subsequently, a study is conducted to identify those insulation levels, and the necessary size of PV system required that can lead to an A+ rating. It is determined that a PV system of at least 2.2 kW$_p$ installed on the roof is required for achieving an A+ energy rating. The required insulation levels are shown in Table 5.

Table 5. Insulation levels for achieving A+ rating.

Building Element	U-Value (W/m^{2}K)
Walls	0.35
Roof	0.30
Floor	0.65
Windows	1.20

A parametric analysis is conducted in order to identify optimum combinations of technologies to achieve NZEB neighborhood in a cost-effective manner, during which, the capacity of the PV system and the size of the battery are the free variables. In summary, the combinations of technologies examined are presented in Table 6. In this case, as there is no restriction for achieving the target of 100% electricity self-supply, a configuration with no battery is also examined. A Business-as-Usual (BaU) retrofit scenario is also considered, in order to determine potential benefits arising from the implementation of additional measures towards achieving near-zero performance.

Table 6. Summary of scenarios examined and the Business-as-Usual (BaU) scenario for the NZEB district.

	PV (kW)	Batteries (kWh)	Heating/Cooling
BaU configuration	0	0	Boiler + A/C
Configuration 1	350	0	DHC + GSHP
Configuration 2	350	550	DHC + GSHP
Configuration 3	350	1100	DHC + GSHP
Configuration 4	350	1650	DHC + GSHP
Configuration 5	350	2200	DHC + GSHP
Configuration 6	300	0	DHC + GSHP
Configuration 7	300	550	DHC + GSHP
Configuration 8	300	1100	DHC + GSHP
Configuration 9	300	1650	DHC + GSHP
Configuration 10	300	2200	DHC + GSHP
Configuration 11	250	0	DHC + GSHP
Configuration 12	250	550	DHC + GSHP
Configuration 13	250	1100	DHC + GSHP
Configuration 14	250	1650	DHC + GSHP
Configuration 15	250	2200	DHC + GSHP

4. Analysis

The basic steps of the analysis from the simulation process and the results processing for the KPI calculation for the technical and financial assessment are presented in this section.

4.1. Simulation

The simulation steps were described in the Methodology section. The main assumptions for determining the energy flows at the building and district level are presented below:

- Thermostat settings. Indoor temperature was set to 20 °C and 26 °C for the heating and cooling period, respectively, following the recommendations of the relevant technical directive (20701-1/2010) for Energy Performance Certificate assessments [42];

- Occupancy schedule. It was considered that the average household comprises three people. A total of 18 hours of occupancy were considered as per the guidelines of the Technical Directive 20701-1/2010 [42];
- Thermal transmittance of the building elements. For Case A of the parametric analysis, these were based on the requirements of the Building Regulation on the energy efficiency in buildings for the city of Alexandroupolis (climate zone C) [39]. For Cases B and C, the U-values of the building elements were adjusted accordingly;
- Lighting gains. These were set to 4.5 W/m^2 based on the recommendations of Technical Directive 20701-1/2010 [42];
- Hot water requirements. These were calculated based on the recommendations of Technical Directive 20701-1/2010 to 50 l/person/day considering 45 °C target water temperature [42];
- Electricity consumption from electrical appliances. Reasonable assumptions were made on the use of electrical equipment based on values from the RETScreen database, and from market products considering the use of energy efficient equipment. The daily use of a television, kettle, laptop, refrigerator, vacuum cleaner etc. was considered for determining the electrical appliances gains;
- Mechanical ventilation. It was considered that mechanical ventilation was providing fresh air to each house to meet the minimum requirements on air quality, 0.75 l/m^3/h [42];
- The Coefficient of Performance (COP) and the Seasonal Energy Efficiency Ratio of the GSHP providing the thermal energy to the district network was considered to be 4.5 and 5, respectively. This was based on the results from a monitoring study of a thermal network in the city of Xanthi, which is in close to Alexandroupolis [43];
- The DHC network losses were considered to be 2%, taking into account the size of the positive energy and nearly-zero energy districts that are being investigated, and based on the results of the maturity study for the development of a thermal network in the wider area of Alexandroupolis [44].

The use of hourly distribution profiles is also required by EnergyPLAN for the energy demands and supply sources. With regard to the heating and cooling demand the distribution profile was developed with the use of a Typical Meteorological Year (TMY) file [45] developed from 15 years of readings (2003–2017) from the weather station of the Alexandroupolis International Airport. The hourly heating and cooling demand profiles were derived considering a base temperature of 18 °C for heating, which is commonly used as the base temperature for heating, and 24 °C for cooling, which is considered suitable for the Greek context [46]. The hourly distribution profile for the PV production was developed considering the global solar radiation data from TMY file and the panel temperature considering the RETScreen methodology [47] and data from the relevant Greek Technical Directive on the climatic conditions [37].

4.2. Technical Assessment

The KPIs used in the technical analysis are the electrical self-supply, the thermal self-supply and the emissions reduction. The technical evaluation is made upon the overall energy balance, including electrical and thermal energy vectors. The calculation of the degree of electrical self-supply is as follows: electricity produced from the PV system is either used by the consumers or stored in the battery for later use, or even exported to the grid (prosumers). The former two components are collectively referred to as 'electricity own-use'. In cases when demand in electrical energy surpasses the amount of electricity produced by the PV system and the battery, if 100% discharged (State of Charge, SoC = 0%), electricity is imported from the grid. The degree of electricity self-supply is then determined with the use of Equations (1a) and (1b) considering the above energy balance (self-production, exports and imports) in terms of primary energy; primary energy from the electricity self-production and exports are determined with a conversion factor of 1, while a factor of 2.9 is used for the electricity imports, based on the country's energy mix [42]. Nevertheless, it should be mentioned that in real-life microgrids operations, the SoC of the battery is around to 80% (or 20%, when discussing discharge) and not 100%, as the current study has assumed. For reasons of grid stability, and to overcome this limitation of the current model, one can oversize the battery used by 20% in terms of capacity (kWh).

With regards to thermal energy consumption, heating and cooling of the houses is provided by the GSHP district heating and cooling network in all cases examined. Therefore, the degree of thermal energy self-supply is 100% in all cases. Finally, the calculation of the emissions reduction is done considering the primary energy of each configuration and the BaU scenario and the respective CO_2 emissions factors for each energy source (0.861 $kgCO_2$/kWh for electricity imports [38] and 0.264 $kgCO_2$/kWh for the heating oil [42] used in the BaU scenario)

4.3. Financial Assessment

Financial evaluation of the proposed scenarios is conducted considering typical costs for the various technologies and fuels for Greece. These are presented in Table 7. The commonly used thresholds for assessing financial viability are used in this case as well, i.e., a positive Net Present Value and Internal Rate of Return greater than 5%. As this is a preliminary feasibility study, the viability of the investment at this stage is examined based on simplified assumptions. For the calculation of NPV and IRR, a 2% annual increase in energy prices is considered. Furthermore, an annual reduction in performance of the PV panels of 0.5% is also taken into account [48].

Table 7. Capital cost of equipment and energy prices.

Capital Costs	Operational Costs
- Geothermal Heat Pump: €1500/kW - DHC Network: €1,000,000 - PV system (panels, inverters, etc): €1000/kW - Battery storage: €400/kWh - Heating oil boilers: €1500/house - A/C units: €1500/house - Additional insulation costs: €3/m^2 per 0.05 W/m^2K reduction in the U-value - Cost of triple over double glazing: €100/m^2	- Selling Price of electricity: €0.065/kWh - Cost of electricity purchase: €0.10/kWh - Heating oil costs: €1.10/L

4.4. Limitations

The analysis of the integrated measures presented in the previous paragraphs was subject to limitations, mainly due to the nature of the study, i.e., a simulation study being conducted at the feasibility stage of an investment. The main limitations identified are discussed here. Firstly, the choice of software was based on the criteria discussed in the 'Methodology' section, and the tools selected are considered appropriate for conducting the analysis at this preliminary stage. RETScreen uses simplified methods for estimating energy consumption and renewable energy production. The limitation of EnergyPLAN in considering the battery SoC in the energy balance was also discussed previously. It is acknowledged that the use of dynamic building simulation software, as well as specialized software for each technology investigated, would increase the accuracy and confidence of the results. Furthermore, dynamic building simulation software would also allow the analysis to consider the indoor conditions and the thermal comfort of the residents, which is not possible to do with RETScreen. However, RETScreen and EnergyPLAN were found very useful in conducting the analysis fast, satisfying the need for tools that are able to conduct parametric analysis on the district scale, as highlighted in [19]. The use of specialized software would require significant resources, and would limit the ability to conduct the parametric analysis, due to the added complexity of integrating the inputs of the different software.

Secondly, the fact that the study is based solely on simulations contributed to increased uncertainty in the results. Despite that fact that every care is taken for the simulation inputs to be based on reliable sources (mainly complying to the relevant technical directives and building regulations), there were some cases where reasonable assumptions have been made (such as in the case of electrical appliance usage). Including the monitoring of electricity and fuel consumption in some or even all of the existing buildings in the methodology would make it possible to identify energy consumption profiles and increase the reliability of the results. It would also be useful for calibrating and fine-tuning the models. Findings from such analysis of monitoring data could be applicable to the new-built neighborhood simulation as well, and increase robustness of the analysis.

5. Results and Discussion

Results of the analysis for the two energy communities investigated are presented in the following paragraphs.

5.1. New-Built Positive Energy Neighbourhood

Each configuration presented in Table 3 is assessed against the set technical and financial criteria. It is noted that in order for a scenario to be considered as positive-energy, the degree of electrical and thermal self-supply should be at least 100%. Results of the analysis are presented in Table 8 below.

It can be seen that achieving at least 100% of thermal and electrical energy self-supply can be met by various combinations of the technologies considered; however, most configurations do not meet the financial criteria. Financially viable positive energy performance can be achieved in only three scenarios (Configuration 10 of Case A and Configurations 6 and 10 of Case B). Moreover, electrical storage providing one day of autonomy is identified as the optimum solution; smaller capacities are not adequate for achieving 100% self-supply, and sizing the battery for increased autonomy is not considered to be cost-effective, since the relevant scenarios did not meet the financial criteria (NPV > 0, IRR > 5%). The three configurations calculate a simple payback between 15.6 and 16.3 years and a dynamic payback period (i.e., considering an annual increase in energy prices and discount rate 5%) ranging from 12.5 to 12.9 years. The achievable emissions reduction is between 1325 and 1370 tonnes of CO_2 per year.

Table 8. Summary of results for the positive energy neighborhood scenarios examined. Results where all criteria are met are presented in bold.

		Electricity Own-Use (kWh)	Electricity Imports (kWh)	Electricity Exports (kWh)	Self-Supply-Thermal	Self-Supply-Electrical	NPV (€)	IRR (%)
Case A	Con.1	440,315	192,598	348,816	100%	79.0%	271,788	6.15%
	Con.2	515,012	117,898	274,104	100%	92.1%	26,681	5.10%
	Con.3	520,062	112,844	269,050	100%	93.1%	−256,285	4.09%
	Con.4	522,146	110,761	266,964	100%	93.6%	−540,869	3.22%
	Con.5	445,633	187,273	382,933	100%	83.8%	290,705	6.22%
	Con.6	522,521	110,380	306,030	100%	98.3%	46,792	5.18%
	Con.7	528,624	104,272	299,923	100%	99.7%	−235,600	4.18%
	Con.8	531,021	101,876	297,527	100%	100.3%	−520,011	3.31%
	Con.9	450,312	182,595	417,717	100%	88.6%	309,290	6.28%
	Con.10	**529,121**	**103,779**	**338,895**	**100%**	**104.6%**	**66,427**	**5.25%**
	Con.11	535,844	97,060	332,175	100%	106.2%	−215,635	4.25%
	Con.12	537,692	95,213	330,325	100%	106.7%	−500,348	3.39%

Table 8. *Cont.*

		Electricity Own-Use (kWh)	Electricity Imports (kWh)	Electricity Exports (kWh)	Self-Supply-Thermal	Self-Supply-Electrical	NPV (€)	IRR (%)
Case B	Con.1	437,916	184,199	351,242	100%	81.2%	230,144	5.95%
	Con.2	511,354	110,757	277,835	100%	94.8%	−15,599	4.94%
	Con.3	516,408	105,707	272,788	100%	95.9%	−298,565	3.96%
	Con.4	518,658	103,459	270,537	100%	96.4%	−583,060	3.12%
	Con.5	443,042	179,015	385,515	100%	86.1%	248,999	6.02%
	Con.6	**518,568**	**103,467**	**310,016**	**100%**	**101.2%**	**4415**	**5.02%**
	Con.7	524,591	97,445	303,992	100%	102.7%	−278,026	4.04%
	Con.8	527,009	95,030	301,581	100%	103.2%	−562,424	3.20%
	Con.9	447,557	174,512	420,489	100%	91.0%	267,504	6.08%
	Con.10	**524,862**	**97,225**	**343,225**	**100%**	**107.6%**	**23,839**	**5.09%**
	Con.11	531,410	90,678	336,678	100%	109.3%	−258,315	4.12%
	Con.12	532,961	89,130	335,131	100%	109.7%	−543,187	3.28%
Case C	Con.1	433,183	168,154	355,970	100%	85.7%	−214,599	4.18%
	Con.2	503,933	97,387	285,212	100%	100.4%	−463,738	3.37%
	Con.3	508,893	92,426	280,256	100%	101.6%	−746,884	2.55%
	Con.4	511,035	90,285	278,115	100%	102.1%	−1031,492	1.83%
	Con.5	437,936	163,344	390,634	100%	90.9%	−198,043	4.25%
	Con.6	510,438	90,833	318,128	100%	107.1%	−446,284	3.44%
	Con.7	516,248	85,026	312,323	100%	108.6%	−728,996	2.63%
	Con.8	518,036	83,240	310,534	100%	109.1%	−1013,791	1.91%
	Con.9	442,127	159,129	425,909	100%	96.1%	−181,779	4.32%
	Con.10	515,860	85,408	352,177	100%	113.7%	−429,411	3.52%
	Con.11	522,102	79,160	345,931	100%	115.5%	−711,894	2.71%
	Con.12	522,984	78,279	345,050	100%	115.7%	−997,154	1.99%

With regard to the insulation levels, it can be seen that current relevant Greek building regulations (Case A) appear to be adequate for attaining a positive energy performance in just one system configuration (Configuration 10); maximum PV capacity (550 kW_p) is required to achieve the electrical self-supply target. Increasing the levels of insulation results in Case B achieving slightly higher technical performance. Due to the reduced energy consumption, the self-supply component imposes a greater share in the energy balance, resulting in a slightly higher degree of self-supply for all configurations of Case B compared to Case A. This results in an additional configuration, during which the technical (DE_T and DE_E > 100%) and financial (NPV > 0, IRR > 5%) set targets are met with a smaller PV capacity (Configuration 6 with 525 kW_p PV capacity). Increasing the energy efficiency of the building fabric therefore provided the flexibility to reduce the size of the PV system and still meet the positive energy requirements.

On the other hand, Case C scenarios present the best technical performance, due to the reduced energy consumption of the buildings. However, they are not cost-effective, mainly due to the increased cost of triple glazing compared to the standard double glazing used in Cases A and B. Increased insulation levels result in reduction of the peak load and, consequently, the size of the heat pump. Nevertheless, these savings are not adequate to justify the additional investment cost for replacing the glazing and increasing the insulation. The use of a larger PV system that will lead to increased revenues from the electricity exports can be considered; however, the potential to increase the PV capacity is limited due to the roof space restrictions.

5.2. Near Zero Energy Retrofit District

The scenarios for the NZE retrofit district presented in Table 6 are evaluated according to the same technical and financial criteria. Results of the analysis are presented in Table 9 below.

Table 9. Summary of results for the near-zero energy neighborhood scenarios examined. Results where all criteria are met are presented in bold.

	Electricity Own-Use (kWh)	Electricity Imports (kWh)	Electricity Exports (kWh)	Self-Supply (Thermal)	Self-Supply (Electrical)	NPV (€)	IRR (%)
Con. 1	123,767	307,113	428,624	100%	54.5%	398,187	8.2%
Con. 2	**306,314**	**124,544**	**246,031**	**100%**	**82.7%**	**287,913**	**7.0%**
Con. 3	**354,475**	**76,412**	**197,890**	**100%**	**95.9%**	**104,553**	**5.6%**
Con. 4	356,373	74,511	195,986	100%	96.5%	−103,940	4.4%
Con. 5	357,271	73,611	195,084	100%	96.8%	−312,977	3.4%
Con. 6	119,651	311,226	353,845	100%	46.3%	363,900	8.1%
Con. 7	294,326	136,553	179,107	100%	68.6%	249,292	6.8%
Con. 8	**336,447**	**94,431**	**136,994**	**100%**	**77.6%**	**62,681**	**5.4%**
Con. 9	337,763	93,115	135,686	100%	77.9%	−146,119	4.1%
Con. 10	338,864	92,016	134,587	100%	78.2%	−355,045	3.1%
Con. 11	114,559	316,294	279,993	100%	38.2%	329,066	8.0%
Con. 12	279,417	151,417	115,083	100%	54.9%	209,163	6.6%
Con. 13	313,617	117,235	80,910	100%	60.4%	18,235	5.1%
Con. 14	314,840	116,010	79,687	100%	60.6%	−190,620	3.8%
Con. 15	315,944	114,907	78,586	100%	60.8%	−399,542	2.8%

In order to evaluate the various configurations examined, a minimum level of self-supply for considering 'near-zero' performance needs to be determined. A degree of 75% is set as a reasonable threshold. The results indicate that a certain degree of autonomy is required as configurations without electrical storage do not meet the near-zero target, despite the fact that they are the most attractive options in economic terms. Furthermore, it is also apparent that none of the configurations in-between 11–15 that have a 250 kW_p total PV capacity (corresponding to approximately 2.6 kW_p available per house delivering on average about 4100 kWh annually) are able to meet the 75% self-supply target. This suggests that the A+ rating that considers 2.2 kW PV_p capacity is not sufficient for achieving the near-zero energy neighborhood target, as defined here. This highlights the need to update the definition and provide specific guidelines for near zero-energy buildings, as well as to establish a definition for near zero energy districts, if a truly near-zero energy performance is to be achieved.

Oversizing the battery for achieving a degree of autonomy greater than 1 day has limited value in terms of technical performance. For example, considering 1.5 days of autonomy instead of 1 day delivers only an additional 0.6% at maximum for all PV capacities considered, with a significant reduction in economic performance. Considering 2 days' autonomy was not financially viable in any case. Therefore, the optimum battery size is that providing day autonomy between 0.5 and 1. The size of the PV system is required to be 300 kW_p at minimum. The self-supply requirement is met with both 0.5 and 1 day of autonomy at the higher capacity of the PV system (350 kW_p), by Configurations 2 and 3, respectively. When the 300 kW_p PV system is considered, the battery size is required to be

1100 kWh, providing 1 day of autonomy, in order for the 75% electrical self-supply threshold to be exceeded (Configuration 8).

Therefore, Configurations 2, 3 and 8 meet the required technical and economic criteria. These configurations present a simple payback period ranging from 13.3 to 15.6 years or a dynamic payback period (i.e., considering an annual increase in energy prices and discount rate 5%) from 9.7 to 12.2 years. The resulting emissions reduction from these solutions varied between approximately 795 tonnes to 893 tonnes of CO_2.

5.3. Building Level Analysis

The analysis of the specific measures is also considered at the building level. Financial performance of the retrofit measures to a single dwelling is investigated when (a) these are applied individually (which is predominately the case for retrofit projects of privately owned houses), and (b) when they are applied to a house as part of a larger community energy upgrade project. The purpose of this study is to highlight potential advantages that each household can benefit from, due to economies of scale achieved, when the retrofit measures are applied as part of a community scale project rather than individually. It is also envisaged that the findings will stimulate the interest of local communities in investing in energy upgrade measures.

The analysis was conducted for the two typical types of houses representing the blocks of the neighborhood, i.e., mid-terrace and end-terrace. Configuration 8 (Table 8) that meets the near-zero energy criteria at the community level is used as case study: In this configuration, a 300 kWp PV system with 1100 kWh battery capacity providing one day's autonomy to the district is used. This corresponds to approximately 3.15 kW_p PV and 11.5 kWh battery capacity on average, per house. Three following scenarios were then investigated:

(a) Conducting the energy upgrade of the house as part of a district energy upgrade scheme as discussed in the previous paragraphs, i.e., increased insulation of the building envelope (walls, roof and windows) and roof-mounted PV with battery storage. Heating and cooling is provided through the district heating and cooling network. The cost of the PV system is set to €1000/kW_p, and the cost of the battery equal to €400/kWh. The capital costs of the GSHP and the DHN for each house are approximately €4200 and €6850, respectively.

(b) Conducting the energy upgrade individually using the same technologies and considering the same levels of PV utilisation, i.e., insulation of building envelope, ground-source heat pump for heating and cooling and roof mounted PV with battery storage. The same PV and storage capacity are considered; 3.15 kW_p PV and 11.5 kWh storage capacity. The cost of the PV system is again assumed to be €1000/kW_p. The cost of the battery and the GSHP for an individual house are €6000 and €15000, respectively.

(c) Business-as-usual retrofit, i.e., insulating the envelope to current building regulations and considering conventional equipment for heating (heating oil boilers) and cooling (A/C units). No PV system is considered. The cost of boiler and A/C units is set to €1500 each.

The energy prices considered are the same as previously (Table 7). The capital and operational costs for each scenario and house type are presented in Table 10.

Table 10. Capital and operational costs of the BAU and the NZEB scenarios at the neighborhood and building level.

	BaU Scenario		NZEB–District Level		NZEB–Building Level	
	Capital cost	Operational cost	Capital cost	Operational cost	Capital cost	Operational cost
Mid-terrace	€10,676.93	€1310.96	€26,469.03	€111.98	€31,826.93	€97.72
End-terrace	€12,879.19	€1446.04	€28,671.29	€145.47	€34,029.19	€129.79

Results of the financial evaluation are presented in Table 11. In both cases, savings are greater for the end-terrace house type. The increase in capital cost for the near-zero energy retrofit is almost

2.5 times that of the BaU retrofit when the measures are applied as part of a larger community scale scheme; when measures are applied individually the increase in capital cost is almost three times that of the BaU retrofit. Results suggest that investing in a NZEB as part of a wider community scheme is a more attractive option than doing so individually, since it is financially viable. On the other hand, it appears that when these measures are considered only at the individual building level the increased capital cost is hardly compensated for by the reduction in operational costs; the investment is not considered viable for the mid-terrace house, while it barely meets the financial criteria in the end-terrace house.

Table 11. Economic evaluation of the NZEB measures applied at the at the building level for the typical terrace and end-terrace building.

	House Type	Simple Payback Period	Dynamic Payback Period	NPV (25 years)	IRR (25 years)
NZEB collective	Mid-terrace	13.2	9.6	€1010.84	7.1%
	End-terrace	12.1	8.6	€2370.82	8.0%
NZEB individual	Mid-terrace	17.4	14.3	€−3900.95	4.4%
	End-terrace	16.1	12.7	€306.59	5.1%

6. Conclusions and Lessons Learnt

The feasibility of the development of a newly-built positive energy district and the retrofit of an existing district to near zero energy performance levels is examined in this paper. The analysis is conducted within the framework of the IRIS project that supports European cities to deliver, among others, upgraded energy services to their citizens in an effective and sustainable manner. The main objective of the work is to identify the technologies and the combinations of these technologies that can achieve the stringent requirements of zero or nearly-zero emissions, while also being financially viable investments. It is envisaged that the work presented here will act as a roadmap for planning and developing additional energy communities in Greece.

The design approach to the highly efficient energy communities considers high levels of building fabric efficiency, renewable energy production and storage (PV, battery and GSHP), as well as the energy efficient delivery of thermal energy (district heating and cooling). The measures considered are able to meet the technical and financial criteria set. This is the case when:

- Increased insulation levels are applied. In the case of the near-zero retrofit district, increasing insulation to a higher standard than required by building regulations is a pre-requisite for complying with the current definition of NZEB. With regard to the new-built district, again, technical performance is better when insulation is slightly higher than required. The degree of electricity self-supply is 3% higher for the same configurations of technologies when increased insulation levels are considered (from 104.6% in Case A—Configuration 10, to 107.6% in Case B—Configuration 10). Furthermore, due to the reduced energy consumption, there is an additional configuration in Case B meeting the technical and financial criteria with reduced PV capacity (Configuration 6). However, care should be taken when considering increasing the levels of fabric efficiency. Replacing the double-glazed windows with triple glazed ones is not considered a viable option based on the results of the analysis.
- Electrical storage providing approximately one day of autonomy is used. This is the optimum configuration in order to deliver the necessary levels of self-supply and be financially viable. In the case of the new-built neighborhood, the positive energy criteria are met only when considering 1500 kWh of electrical storage. In the existing retrofit neighborhood, the respective criteria are met mostly when 1100 kWh of electrical storage are used, corresponding to one day of autonomy. Requirements are also met in a scenario with smaller battery size, 550 kWh, however

technical performance is significantly improved when considering the higher capacity (DE_E 95.9%, compared to 82.7% for Configurations 3 and 2, respectively).

- Increased PV capacity is considered. In both case studies, results suggest that the district performance is optimum when the highest size of PV system considers the limitations imposed by the available roof areas. Higher PV capacities result in shifting the energy balance positive in primary energy terms and increased revenues.

Additionally, the benefits for the occupants of participating in an energy community scheme, rather than performing the energy upgrade on an individual house basis are demonstrated, in an attempt to stimulate the interest of stakeholders for investing in energy community schemes. The need to update the definition of near zero buildings for the uptake of truly near-zero energy buildings and communities is also highlighted. Finally, it should be noted that the technologies considered here are selected from a pool of technologies based on their suitability for the Greek context. Additional research investigating the feasibility of other renewable energy and energy efficient technologies will facilitate the development of energy communities and support the transition towards carbon neutrality.

Based on the experience gained from this study and the limitations identified, it is suggested that similar research studies in the future can benefit greatly from monitoring existing buildings, in order to feed robust data in the simulation software and increase the reliability of the results. If this is not possible due to limited resources or the degree of intrusiveness to the residents' homes, other means of data collection may be used: interviews with the occupants, questionnaires and analysis of energy bills (electricity, fuel) can be used for a better representation of the occupancy profile and the energy consumption in the simulation software. Furthermore, dynamic building simulation software and software specialized in specific technologies have the potential to increase results accuracy, should the resources become available and the project maturity allow for their use. It should be noted, however, that the accuracy of the results relies again on the quality of input data. This highlights the value that monitoring or data collection can add on the simulation study.

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Abbreviations

A/C	Air-conditioning unit
BaU	Business as Usual
COP	Coefficient of Performance
DE_E	Degree of Energetic Self-Supply (electrical)
DE_T	Degree of Energetic Self-Supply (thermal)
DHC	District Heating and Cooling
EE_C	Electrical Energy consumption
EPBD	Energy Performance of Buildings Directive
EPP	Economic Payback Period
ERI	Energy related investment
FC	Follower city

GHG	Greenhouse Gas emissions
GSHP	Ground Source Heat Pump
IRR	Internal Rate of Return
IS	Integrated Solutions
KPI	Key Performance Indicator
LH	Lighthouse city
LPE_E	Locally Produced Energy (electrical)
LPE_T	Locally Produced Energy (thermal)
NPV	Net Present Value
NZE	Net or Near Zero Energy
NZEB	Near Zero Energy Buildings
NZED	Near Zero Energy Districts
PE	Positive Energy
PV	Photovoltaic
RES	Renewable Energy Sources
SEER	Seasonal Energy Efficiency Ratio
SoC	State of Charge
TAC	Total Annual Cost
TE_C	Thermal Energy consumption
TT	Transition Track

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