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Examining the benefits and barriers for the implementation of net zero energy settlements

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A B S T R A C T

The transition of the Net Zero Energy (NZE) concept from building to settlement scale has been theoretically approached in a number of studies. This paper examines the benefits and barriers associated with the implementation of the NZE concept at a settlement scale, by adopting a comprehensive approach for the design, construction, and monitoring of NZE settlements that was developed in the EU Horizon 2020 ZERO-PLUS project and implemented in four case studies. First, the ZERO-PLUS approach is presented, followed by an analysis of associated benefits and encountered barriers. Next, the roles of different stakeholders involved in the process are identified through stakeholder analysis. Finally, new dynamics that emerge and are critical to the successful implementation of NZE settlements are discussed. The ZERO-PLUS approach leads to achieving NZE settlements with an initial cost that is on average 16% lower than the cost of a typical NZEB, while achieving a net regulated energy consumption of less than 20 kWh/m^2/year and renewable energy production of more than 50 kWh/m^2/year. The implementation of NZE settlements revealed two main issues: 1) the external barriers that were raised by the planning policies and regulations; and 2) the challenge of managing and integrating the needs and requirements of project stakeholders. To overcome these barriers while reaping the benefits of the approach, the management of such projects needs to focus from the outset on the establishment of a project management structure that will ensure the coordination and integration of various stakeholders. The use of a standardized collaboration protocol from the preliminary design stage is recommended to facilitate future projects. Simultaneously, regulations need to be updated towards facilitating NZE settlement implementation.

1. Introduction

The business-as-usual scenario of energy use has significant impacts on both people and the environment [1,2]. These impacts include: i) energy dependency with its political and security implications; ii) environmental impacts including pollution and impacts on public health, as well as anthropogenic climate change. Important factors influencing the development of energy use are the constantly growing and urbanizing world population, accompanied by increases in living standards. Building energy use in particular accounts for 30% of global final energy use and plays an important role in energy conservation efforts [3].

As part of the attempts to tackle building energy use in a comprehensive manner, the EU initiated the Energy Performance of Buildings Directive (EPBD) that prescribes milestones for curbing energy use in buildings [4,5]. Subsequently, the Net Zero Energy Building (NZEB) concept emerged, comprising two main strategies: minimizing the need for energy use through energy-efficient measures, and adopting renewable energies [6]. The NZEB concept is rather vague, allowing for the adaptation of a broad (and not necessarily broadly agreed upon) set of calculation methodologies [7–10], as well as (in the case of the EPBD) adjustments according to national constraints [5]. Nevertheless, the NZEB concept has been adopted in national policies and regulations worldwide [11].

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The methodology and boundaries selected to calculate the energy balance can influence the resulting NZEB status [9]. Building size, building use, and building height are factors that have been found to impede the achievement of NZEB [12,13]. Furthermore, it is often easier to achieve net zero energy (NZE) use in low-rise / low-density developments through locally employed renewables (e.g., photovoltaic panels) [14], yet the future of settlements is urban, often of a high-rise / high-density type [15]. As photovoltaics (PV) are the most commonly selected renewable energy system (RES) for NZEBs [12,16], the location and size of the building can influence the potential for renewable energy generation that is available in order to achieve the NZE balance.

Another challenge that could discourage NZE investments at the single building scale is the initial investment cost. On this topic, researchers have investigated cost-optimal solutions for NZEBs [17–19]. Though a cost-optimal solution could be achieved, in some cases this was at an energy performance level far from the high-efficiency level expected for NZEBs [18,19]. Higher performance levels could only be achieved with higher investment costs [18]. A study in Denmark indicates that in order to be cost-effective, NZEB design and detailing should reduce energy demand to a minimum. The remaining energy demand can then be supplied by renewable energy sources [20]. Costs also depend on parameters such as the climate, which affect renewable energy generation potential and building energy performance. In certain climates, the life cycle cost (LCC) of zero energy buildings can be higher than the baseline [21].

The challenges faced by single NZEBs can be overcome through a community approach [16,22–24]. Creating neighborhood or urban energy centers can allow those centers to capitalize on the opportunity for synergies that are not available at the building level, such as controlling, diverting, and storing energy produced from different sources and regions, as well as feeding into the electric grid or buying from it [25–28]. Built-up masses with well-integrated renewable energy generation at the neighborhood scale, locally managed and interconnected with the broader energy infrastructure, have advantages in terms of achieving NZE use. But a practical realization of this approach requires coordinated regulation and legislation, planning and design, construction, commissioning, operation, and management.

1.1. Net zero energy communities

Similarly to NZEBs, the net zero energy communities have very low energy needs that can be covered by RES [29]. A number of studies in literature examine the potential of zero energy communities. Zero energy communities in literature are mainly approached theoretically, through simulations, examining the potential of existing communities to become zero energy [23,24] or presenting studies on new developments [30–32]. These communities are either composed of residential buildings only [24,28,33] or comprise various building types [30–32]. While the definition of the net-zero energy community given by Carlisle et al. [29] includes not only building energy use but also transportation and industrial energy use within the community, existing studies focus on building energy use.

RES adoption is a prerequisite for achieving zero energy targets. As a result, many studies investigate optimal sizing and economic feasibility of RES systems for zero energy communities. When integrated into a high energy performance community, RES solutions combined with storage can result in a positive energy community [30]. Among the parameters that influence RES integration in a community, there are location, density, size, and microclimate of the community [23,33].

Kim et al. performed a techno-economic analysis and sizing study of a district heating and renewable energy system for a mixed-use net zero energy community in South Korea [31]. The optimal sizing and techno-economic feasibility of a PV power plant for a rural community in Pakistan are presented by Rafique et al. [34]. Both studies conclude that economically viable solutions exist that can also offer significant emissions reduction. A multiple-criteria decision framework has also been proposed for supporting decision making during the planning of a RES system for a zero energy community [35].

The potential of a zero energy settlement in Greece has been evaluated by Ascione et al. [32]. The authors studied a settlement comprising various types of buildings (i.e. residences, hotels, and commercial buildings). Although on a single building scale the high energy demand buildings, like hotels, could not easily achieve zero energy, on the settlement scale, zero energy could be achieved, indicating that the zero energy concept can be extended from single buildings to building complexes.

Mittal et al. studied the potential of a community to achieve zero energy through consumers' participation in a community solar program. By simulating various scenarios of RES, in varying pricing options and varying community interactions, the researchers concluded that the development of community thinking through increased interactions is key and can lead to high levels of electricity covered by RES adoption within the community. Furthermore, it was highlighted that many stakeholders need to coordinate and support the adoption of policies that allow the implementation of community solutions [24].

1.2. Aim

The literature so far on zero energy settlements is mainly theoretical, in that it does not present experience from realised projects. The goal of this paper is to analyze the potential benefits and barriers for the implementation of the NZE concept at the settlement-scale, based on realized case studies. The analysis is based on the results and the experience gained in the ZERO-PLUS project ('Achieving Near Zero and Positive Energy Settlements in Europe using Advanced Energy Technology'), for the design, construction, and monitoring of NZE settlements [36–38]. The present paper contributes to the literature by presenting the ZERO-PLUS approach, which is a comprehensive and holistic approach, as well as the lessons learned from its implementation.

1.3. Outline

In the following sections, the ZERO-PLUS approach is first presented (Section 2). The analysis of associated benefits and encountered barriers follows in Section 3. Through a stakeholders' analysis, the groups of stakeholders that were involved in the implementation of the ZERO-PLUS approach are identified (Section 4). Finally, the relation of the stakeholders to the benefits and the barriers is discussed with reference to the new dynamics that emerge and are critical to the successful implementation of NZE settlements (Section 5). The paper concludes with Section 6, highlighting the findings and gaps that remain to be addressed.

2. The ZERO-PLUS approach

ZERO-PLUS is a comprehensive, cost-effective approach for the design, construction, and monitoring of NZE settlements. The ZERO-PLUS project is aimed at reducing the cost of achieving NZE requirements by implementing the NZE concept at a settlement scale [37]. The ZERO-PLUS approach has three phases – design, construction, and occupancy – each having its own set of activities and associated tools (Fig. 1).

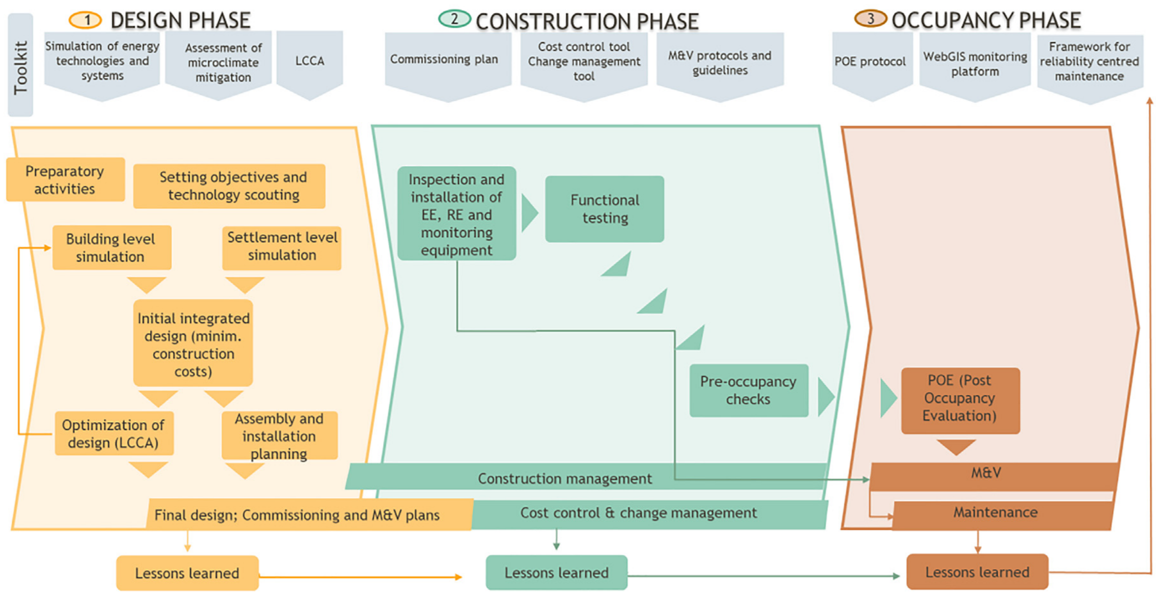


Fig. 1. Graphic representation of the ZERO-PLUS approach.

The **Design phase** comprises the planning of the settlement and the design of the buildings. With the use of simulation tools, energy generation and consumption projections are produced first at the building level, and then at the settlement level to define the energy performance, considering a certain set of candidate technologies [39]. The microclimate of the settlement is assessed to determine the future needs of each building, and together with the building-level assessments, this informs the design of indoor and outdoor living spaces [40]. After an initial integrated and holistic design, optimizing building thermal-energy-environmental efficiency and minimizing construction costs, an additional assessment is carried out using Life Cycle Cost Analysis (LCCA) tool, to determine the costs incurred by operating the energy and environmental systems chosen for the settlement (Fig. 2) [41]. Four types of costs are taken into consideration in the LCCA tool (initial costs, operational costs, maintenance costs and end of life costs). Due to uncertainty regarding those costs, three values are included for each (lower bound, most likely value and upper bound), and their Present Value is calculated for 50 years. Iteration and eventual changes in the initial set of technologies are performed in order to optimize both performance and cost.

The final activity of the design phase revolves around the development of the design, commissioning, and Measurement and Verification (M&V) plans. The building commissioning plan includes the final selection of monitoring devices to be installed, provides installation guidelines for the energy and environmental systems and details the tendering process to be followed for the management of construction to be timely and within budget. The M&V plan describes the processes that will be followed for measuring and verifying the actual performance of the ZERO-PLUS case studies. Considering the complexity and the various aspects of the process, the M&V plan is structured in three phases matching the project development phases in order to ensure a robust M&V and reliable results (Fig. 3).

At every step of the **Construction phase**, collaborative and synchronized work between construction actors is ensured by following the detailed commissioning plan prepared in the previous phase. A Change Management tool enables the identification, examination, and modification of every proposed change to the design of the building. The tool prevents discrepancies in construction resulting from a lack of communication between different actors and allows optimizing the as-built energy and financial per-

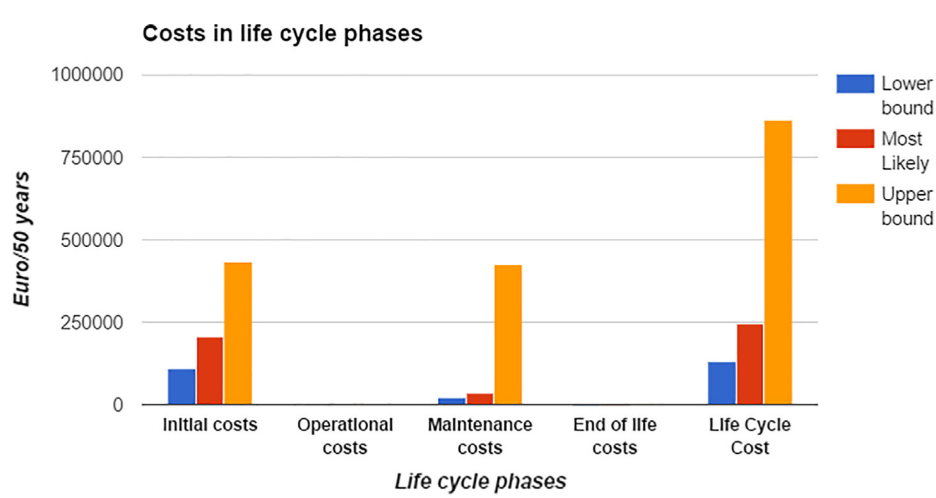


Fig. 2. Example of an output of the LCCA tool.

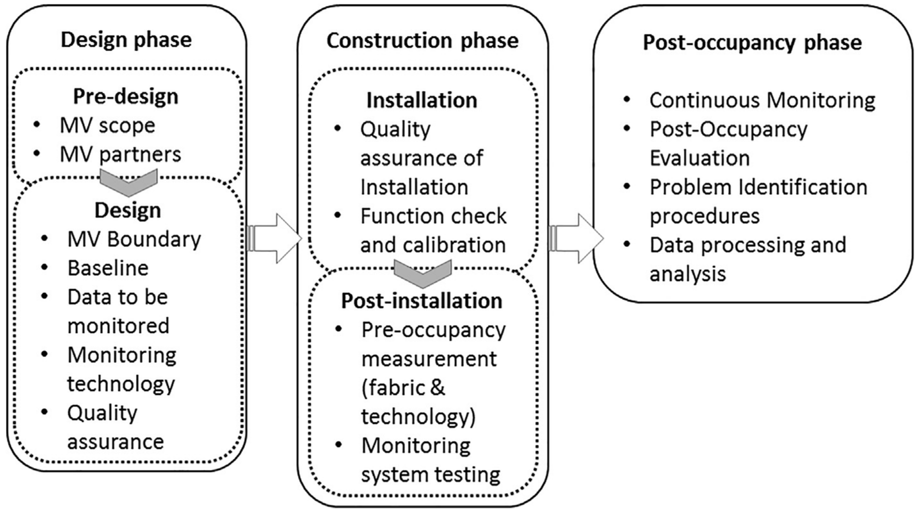


Fig. 3. Measurement and Verification (MV) plan of ZERO-PLUS for the Design, Construction, and Occupancy phases.

formance of components. As the construction of the building progresses, the energy-related technologies are installed following the guidelines laid out in the commissioning plan. Once the installation of energy systems is completed, functional testing takes place to ensure any deficiencies are handled according to the commissioning plan. Checklists are provided to construction contractors and developers to facilitate this process ahead of the Occupancy phase. Pre-occupancy checks are then carried out by the construction supervision team, which verifies the complete and correct installation of monitoring devices, energy measurement devices, weather stations, and routers collecting energy load data at the building and settlement level. Further tests are conducted to assess the thermal and physical performance of the building structure for heat loss, permeability, and u-value.

After the start of **Occupancy**, data on thermal/visual comfort and indoor air quality is captured by short- and long-term sensors fitted on and in every building and through surveys with the building users. Energy generation and consumption are also captured through dedicated monitoring equipment. The documentation, collection, and analysis of performance data at the building and settlement level are enabled using a WebGIS platform [42], which is accessible by all stakeholders involved in the ownership, operation, and maintenance of the building. Using a Post-Occupancy Evaluation (POE) protocol, the analysis of the generated data enables optimal maintenance of the buildings and settlement. At the settlement level, an energy management dashboard can track energy generation and demand. To facilitate this process, residents are provided with a Welcome Package to introduce them to the innovative technologies, the monitoring system, and the WebGIS platform enhancing their quality of life, and supported by a dedicated rescue team.

3. Implementation of the ZERO-PLUS approach

3.1. The ZERO-PLUS case studies

In the ZERO-PLUS project, the approach described in the previous section was implemented in four case studies, located in Cyprus, Italy, France, and the UK. Table 1 summarizes the locations, types of buildings, and technological solutions adopted in each case study. Through its implementation in different climatic settings and types of residential buildings, the adaptability and applicability of the concept have been demonstrated. A different combination of technologies was installed in each case, adapted to each settlement's climate as well as to the achievement of the goals defined for the project from the outset, related to energy, environmental, and financial aspects. The list of energy conservation, energy generation, and energy management technologies in Table 1 is the optimal combination for each case study with respect to the above-mentioned aspects.

3.2. The benefits of the ZERO-PLUS settlement-scale application

The ZERO-PLUS approach is a comprehensive and holistic approach to the design, construction, and operation of NZE settlements. The expected benefits of ZERO-PLUS settlement-scale applications are as follows:

i. *Provision of a clear roadmap for achieving compliance with European regulations for energy efficiency in buildings:*

The EPBD transposition on the national legislation has led to large discrepancies between the definitions of low energy buildings in different European countries [43]. Moreover, the achievement of the targets set by the EPBD and other EU directives require a significant adjustment of the building industry. As a response to this, ZERO-PLUS details the process for achieving the goal set by the EPBD, according to which every new building (public or residential) must meet NZE standards. The performance after implementation of the ZERO-PLUS approach is expected to meet the planned targets (i.e. achieving a net regulated energy consumption of less than 20 kWh/m^2/year and a renewable energy generation of more than 50 kWh/m^2/year). However, due to the ongoing M&V in the first year of occupancy, the actual performance results of the ZERO-PLUS case studies are not yet fully available.

ii. *Optimization of energy performance through optimized technology design and the optimized integration of renewable energy and energy management measures in the settlement:*

In ZERO-PLUS, a combination of energy conservation, energy generation, and energy management technologies have been adopted. Energy and cost analyses were carried out in order to select the optimal combination and size of technologies to minimize their life cycle cost, while optimizing their energy performance. To this end, a Life Cycle Cost optimization tool was developed and applied [41]. The expected optimized performance of the technologies adopted in each case study has resulted in

Table 1
Overview of the case studies in which the ZERO-PLUS approach was implemented.

Location	Type of buildings	Energy conservation	Energy generation	Energy management
York, UK	Detached and semi-detached dwellings	- Insulation	- PV system on the roof	- Batteries for the management of electricity demand from PV and off-peak reduced rate charging - BEMS system with a learning thermostat
Granarolo dell'Emilia, Italy	Villas	- Composite cool thermal insulation on walls and roof	- PV system on the roof	- Storage and inverter system - Load control - BEMS system
Voreppe, France	Social housing apartment block	- Insulation	- PV system on the roof - Electrical and thermal solar panels on the roof - Connection to district heating network (biomass)	- Thermal energy stored in hot water tank - Energy regulation (low temperature at night)
Nicosia, Cyprus	Prefabricated container system	- Solar air conditioning system - Composite cool thermal insulation on walls	- Combined heat and power generation system	None

yearly energy savings of up to 82%, and a reduction in initial costs of 17–26%, when compared to the reference case (per country) of a typical NZEB (Table 2). It should be noted, however, that these figures are preliminary, as the analysis of the data from a full year of monitoring is still ongoing.

iii. *Economies of scale leading to opportunities for lower initial investment costs and lower maintenance costs:*

A settlement-level approach opens up opportunities for economies of scale. This intermediate community or neighborhood scale appears to be an ideal compromise between the advantages of either urban or single building scales in energy planning, due to the advantages of limited complexity on the one hand, and to the opportunities for energy and cost efficiencies at a larger scale on the other hand. As a result, lower investment costs as presented in Table 2 can be achieved. Moreover, the "balance of system" costs that encompass components other than those directly providing energy conservation and generation, such as components for energy storage, distribution, and smart energy management, can be reduced through the use of solutions that are customized and optimized for a settlement and implemented at a large scale. These will replace bespoke technologies that are difficult to integrate.

iv. *Increased efficiency and reliability of the system through the application of communal energy generation and management technologies:*

Increased efficiency can be achieved through innovative energy management technologies (e.g., smart demand responsive energy management systems) that utilize real-time data and predictive models to reduce the need for less efficient power sources. Among the cluster of technologies applied in ZERO-PLUS, energy management technologies, including energy storage and smart energy management, contribute to the management of dynamic energy loads and resources at the community level. The energy management system adopted in the UK case study, for example, has been estimated to result in a 5% reduction in heating fuel consumption.

v. *Access to the expertise required for the design, construction, and maintenance of advanced technologies, as well as of innovative building and settlement design solutions:*

By focusing on the settlement-level instead of on single buildings, the ZERO-PLUS approach aims to bring together settlement planners, building designers, technology developers and suppliers, energy efficiency and renewable energy experts, contractors, and building owners who work together from the earliest stages of project conception to optimize the NZE settlement design. Due to economies of scale, this approach enables the hiring of experts for a fee that is affordable to target markets such as large developers and housing associations, something which would not have been possible in the context of a single-building project.

vi. *Improved microclimate conditions through urban design solutions leading to a reduction in energy demand and CO_2 emissions:*

In ZERO-PLUS, renewable energy generation technologies and settlement servicing technologies and materials are modelled at the settlement level, together with simulations of microclimatic conditions. This also informs the climate-sensitive design of outdoor common spaces and results in improved energy efficiency as well as thermal comfort. Microclimate mitigation strategies can contribute to further annual energy savings up to 5% [40].

vii. *Energy savings and enhanced quality of life for the end-users:*

Advantages for the end-users (occupants, owners, maintenance companies, and utilities) include energy savings; increased energy security; ease of carrying out maintenance activities, resulting in time and financial savings; and enhanced quality of life through

Table 2
Preliminary cost reduction and energy savings in ZERO-PLUS compared with a typical NZEB.

	Italy	UK	Cyprus	France	ZERO-PLUS target
Investment cost reduction	24.8%	17.8%	17%	26.7%	>16%
Yearly energy savings (Percentage)	77.0%	82.6%	29.0%	81.6%	–
Yearly energy savings (kWh)	20,598	53,500	2,860	96,432	

improved performance of the buildings (e.g., temperature, air quality, noise, etc.).

3.3. Barriers encountered in the implementation of the ZERO-PLUS approach

The goals that had been defined for the project were fully achieved in all the case studies. However, some barriers were encountered that made the implementation of the approach more challenging. These barriers were systematically identified and categorized through a survey conducted among the project participants. The identified barriers can be divided into two main groups as follows:

i. Regulatory barriers, related to local and national planning processes and regulations, that may potentially discourage, limit, delay, or prevent the implementation of NZE settlements. These include, but are not limited to, barriers related to long-term urban planning, obtaining building permits, and the approval of communal and hybrid renewable energy systems.
ii. Project management-related challenges that result from the novelty of the approach, which requires collaboration and the alignment of a diverse project team. These include barriers related to the assembly of the project team, to the slow adaptability of the project team to cooperate in unexpected circumstances, the diverse Key Performance Indicators of the parties involved in the design, construction, and maintenance phase of the project, the integration of existing and new technologies, reaching agreement among different owners in the settlement, and obtaining the cooperation of the residents.

3.3.1. Policy and regulatory barriers

3.3.1.1. Long-term urban planning. There is a need to align the ZERO-PLUS approach with existing long-term urban plans, which are initiated and prepared by local and/or national authorities. This limits the opportunities for the application of the approach to those instances in which the plans happen to allow it if the authorities cannot be convinced to change plans to accommodate the ZERO-PLUS approach.

For example, the initial design of the French case study in the ZERO-PLUS project included a combined wind and solar energy generation system. The construction of the building had already started when plans for a future development next to the French case study were announced. The position of this development in relation to the French case study will have a major impact on the wind flow patterns on the rooftop of the French case study. In effect, the installation of the wind turbines in the French case study had to be cancelled and all of the energy to be produced by solar energy technology. The technology eventually installed was a Multifunctional Roof Edge, an innovative rooftop PV installation by the same technology provider – Anerdgy AG (Fig. 4). However, alignment between the local urban plan and the ZERO-PLUS approach in the early stages of design would have prevented this problem from happening.

A similar problem occurred in the Italian case study, where the wind turbine, which was initially planned to be installed on a mast within the common area of the two villas of the settlement, had to be substituted with PV panels, due among other reasons to the potential reduction of energy generation caused by the new wind flow pattern associated with the presence of additional buildings (which were not yet planned at the case study's design stage) within the settlement.

3.3.1.2. Building permits. If local planning authorities are not familiar with the approach and involved in its application from the outset, this will increase the risk that they will be reluctant to approve its implementation or that their limited understanding of the project may cause important delays in receiving the building permits. Furthermore, local authorities are often bound by national regulations in terms of approving designs and issuing permits.

A specific example of this barrier in the ZERO-PLUS project occurred in the UK case study, whose design initially included a mast-less wind turbine that would be directly installed on the roof of a building. This customized solution was preferred over a wind turbine on a mast due to its cost-effectiveness as it did not require much infrastructural support such as a mast, foundation, and cabling. However, problems appearing in the building permit application phase led to the risk management decision of moving the wind turbine to a mast next to the building. This solution would require separate permission for the wind turbine, thus de-risking the approval of the building permit.

3.3.1.3. Regulation of communal energy systems and connection of hybrid renewable energy systems to the grid. National regulations may not allow energy sharing schemes at the neighborhood level. Additionally, utility companies may not be willing to approve communal energy generation and management systems, requiring those systems to be connected to only one specific household, thus eliminating a major component of the ZERO-PLUS approach.

This barrier arose in the Italian case study of ZERO-PLUS, where the installation of a combined wind-solar energy system at the settlement level for community use was not allowed due to national restrictions on shared systems connected to the national electric grid. Indeed, at the time of the design phase, it was not yet allowed in Italy to introduce a residential microgrid and share the produced energy among different buildings and residential units. Since then,

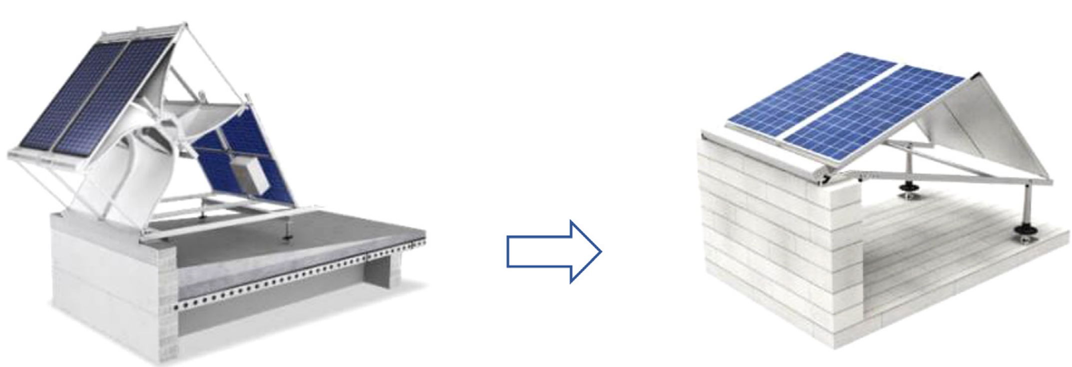


Fig. 4. Evolution of the design of the rooftop energy system by Anerdgy AG.

this has changed following the recent approval of a new regulation by the Italian Government, which allows the sharing of renewable energy within settlements according to the European directive on the promotion of RES.

Similar constraints may prevent the connection of innovative hybrid renewable energy systems to the electrical grid. According to the current Italian regulation, a wind-solar hybrid renewable energy system (e.g. the integration of the wind turbine with the PV panels originally designed to produce energy at settlement level in the Italian case study) can be connected to the national electric grid from the same connection point only through two separate and non-simultaneous connection procedures (one for the PV system and one for the wind turbine). This would have caused an excessive delay in the connection of the system. This was another reason why the wind turbine was substituted by equivalent PV panels and the implementation of the hybrid system was discouraged.

3.3.2. Project management challenges

3.3.2.1. Team alignment. Access to expertise for realizing the concept of NZE settlements is one of the drivers for implementation. However, assembling the experts into an aligned team with good understanding and communication, in order to tackle the various aspects involved in designing, constructing, and monitoring a zero energy settlement, can be challenging. Small companies, such as those involved in ZERO-PLUS, can be challenged by the complex communication networks among the various experts (i.e. construction stakeholders, including architects and building designers, technology providers, and facility managers), especially on innovative aspects of the design and construction, and among non-experts such as the end-users, when involved in the project since the design or construction phases.

In the Italian case study, difficulties in the initial communication between the construction company, technology providers and suppliers, energy and monitoring experts, and tenants were due to a number of factors including diverse individual goals, a different level of involvement and motivation in achieving the project goals, and the use of different communication tools. One of the most evident delays occurred in the design and implementation of a long-term indoor monitoring station. The lack of experience of the construction company with monitoring stations made coordination and communication with the monitoring experts difficult. In addition, the dedicated "rescue team" that provided support for the monitoring was located far from the construction site, which further delayed problem-solving.

3.3.2.2. Integration of technologies. Communication barriers between different consultants, between consultants and technology providers, or between those providers and construction companies, may create difficulties in the integration of novel technologies in local systems and supply chains. This barrier may occur because of a lack of timely information sharing between the stakeholders.

For example, the implementation of a Concentrated Photovoltaic (CPV) solution in the French case study was prevented due to the lack of an appropriate interface (inverter) with the local grid. The French electricity grid is three-phase while the CPV technology had a monophase inverter. The technology provider made an extensive market research, but an appropriate inverter that would offer the required flexibility in connecting the CPV modules to each of the three phases was not found. As a result, the installation of the CPV in France had to be cancelled. It is worth noting that this challenge revealed an opportunity for the technology provider, who is considering developing such an inverter in the near future.

Another example occurred in the UK case study, where the installation of a wind turbine solution on a mast was prevented due to the difficulty of finding a local intermediate installer to assemble the mast and the wind turbine and assume responsibility for the final product. Although the system was considered technologically robust, the mast and the wind turbine were two different products. Due to the lack of installers in the UK, and the distance from the technology provider's headquarters, moving forward with this system proved challenging and installation of the wind technology was cancelled.

3.3.2.3. Agreement among different owners. Potential difficulties may arise in finding common agreement among owners of homes in the settlement. Challenges range from agreeing on energy sharing to agreeing on the design, use, and maintenance of common technologies.

A specific example is the risk of significant delays such as those that occurred in the Italian case study in the installation of the weather station and the wind-solar hybrid renewable energy system, both for common use, due to conflicting owners' opinions regarding their location. The visual impact of the wind turbine in the common areas of the two villas was one of the reasons this installation was not well received by one of the building owners, who also expressed his preference for conventional renewable energy technology (i.e. PV panels) so that in case of failure he would not have to deal with a unique technology provider. Once the decision to opt only for PV panels was made, a common car shelter covered by the PV panels was proposed, but no agreement was found between the two owners on where to locate the common care shelter. The impasse was solved by installing the PV panels for the common use of energy equally on top of both villas' roofs. On the other hand, the decision on where to install the meteorological station was rapidly made when one of the building owners gave permission to install the station on top of his roof due to his interest in having the microclimate around his villa monitored.

3.3.2.4. Cooperation of occupants. In a large project, in which the occupants of the homes have not been involved from the outset in the decision-making process, some residents may be reluctant to accommodate and use novel technologies with which they are unfamiliar.

A specific example of this barrier was the difficulty in obtaining the owners' approval for the installation of the short-term and long-term indoor monitoring system in the two Italian villas. Both owners were not comfortable with having sensors in their homes, and with being continuously monitored. These installations required multiple interventions of external technicians to set, connect, and reconnect the sensors to the WebGIS platform. This, along with multiple visits for Post-Occupancy Evaluation, reduced the patience of the owners, putting at risk their cooperation and willingness to positively respond to requests for further visits.

4. Stakeholder analysis

The realization of the benefits of NZE settlements is in the hands of the stakeholders involved in the design and construction of the settlements. Similarly, in relation to the barriers, it is crucial to identify the stakeholders and their role in creating and/or overcoming each barrier. The stakeholders can be divided into two main groups: i) external stakeholders that are indirectly involved in project development, and ii) internal stakeholders, who are directly involved in project development.

4.1. External stakeholders

The ZERO-PLUS external stakeholders were the planning authorities and utility companies that dictated specific requirements for the approval of the submitted designs. These requirements are a result of the legislation, planning policies, and energy policies that are in place in each country and directly affect the implementation potential of design strategies and technologies (Fig. 5).

The external stakeholders mainly interact during the pre-design and design stages (Fig. 6), when design decisions are made. In ZERO-PLUS, the external stakeholders mainly affected the design development by causing changes and therefore delays in the progress of the design, and consequently delays in the start of the construction. These delays were related to the approval of the innovative technologies. The time-consuming process of obtaining certificates of conformity as well as the uncertainty of final approval led to certain technologies being excluded from the design and replaced with other market-ready technologies.

4.2. Internal stakeholders

The internal stakeholders are the members of the project team and are involved throughout all the project phases (Fig. 7). In ZERO-PLUS, the internal stakeholders were consultants from academia (on energy, monitoring, and IT), technology providers (developers of innovative technologies for renewable energy generation and energy management), project owners, the design team, and the construction team. In certain case studies, the occupants were involved in the project development as well. Therefore, it has become evident that for the design, construction, and management of such projects, an expanded team is needed (Fig. 7).

Focusing on the involvement of the internal stakeholders in each project phase, feedback was obtained from the ZERO-PLUS partners in a structured way through the use of questionnaires. The pie chart in Fig. 8 shows the level of involvement of each stakeholder in the project. This level of involvement is calculated by summing up the number of project phases in which each stakeholder was involved, and the number of communication links with other stakeholders. The pie chart represents the replies obtained from the UK, Cyprus, and Italy. In the French case study, the owner's representative was replaced thrice throughout the project and, as a result, did not have a full picture of the project development.

While the project owner and technology providers show a slightly higher level of involvement, most internal stakeholders are almost equally involved. This further highlights the need for expanded yet integrated teams that work in alignment throughout the project. The coordination of such a team and of the interactions among the stakeholders is a challenging task. It should be handled by a Project Manager who has a broad overview of the project. This conclusion is addressed in more detail in the next section.

A mapping of the communication network of internal stakeholders, as recorded for the Design, Construction, and Monitoring phases of the UK case study, is shown in Fig. 9, with their level of involvement represented by the size of the nodes in the network. The mapping confirms that most members of the project team were involved throughout the project and that a complex network of communications is created among the internal stakeholders. The results for the other case studies were similar.

5. Discussion

There are multiple benefits to opting for NZE settlements, as ZERO-PLUS has demonstrated through the design, construction, and monitoring of four case studies across Europe. However, there is an equally long list of barriers that challenge the implementation of this approach, and hence potentially hinder the realization of benefits. Furthermore, as the previous analysis revealed, there are multiple stakeholders and stakeholder interactions involved in the implementation of the NZE settlements. Table 3 summarizes the benefits, barriers, and challenges that were identified in ZERO-PLUS, in relation to the project phases and involved stakeholders.

Due to the nature of the ZERO-PLUS approach, numerous stakeholders were involved in all phases of the project, working together and continuously exchanging updated information. The benefits of this collaborative management approach reside in the increased ability of actors to simultaneously design the settlement and plan its construction, which results in cost reductions and lower energy consumption of the completed building. In addition, greater energy efficiency and economies of scale can be achieved through a transition from single NZE buildings to NZE settlements in which the energy loads and resources are optimally managed at the settlement level [44]. Obviously, the operational phase cannot be disregarded as it accounts for the highest percentage of energy demand. This requires the smart operation of the building by the building user, which presupposes informed, educated, supported, and collaborative users. Essentially, the implementation of NZE settlements faces two main issues: 1) the external barriers that are raised by the planning policies and regulations; and 2) the challenge of managing and integrating the internal stakeholders.

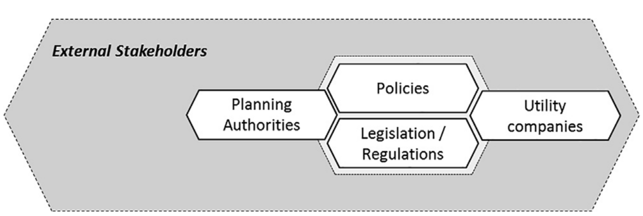


Fig. 5. External Stakeholders involved in the implementation of the NZE settlements.

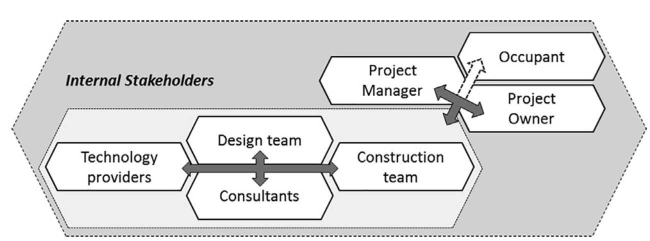


Fig. 7. Internal Stakeholders involved in the implementation of the zero energy settlements.

Fig. 6. Involvement of external and internal stakeholders in the project phases.

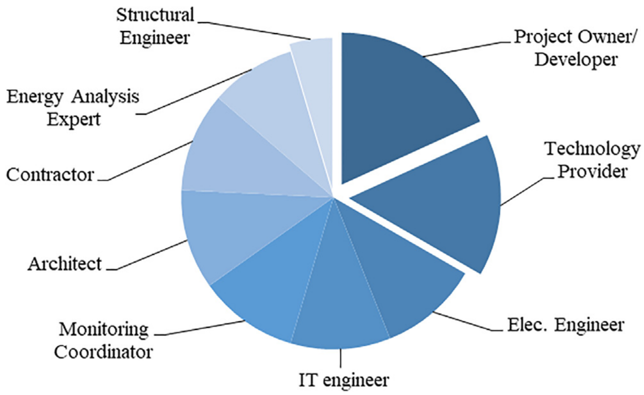


Fig. 8. Combined level of stakeholders' involvement.

5.1. Policy and regulations

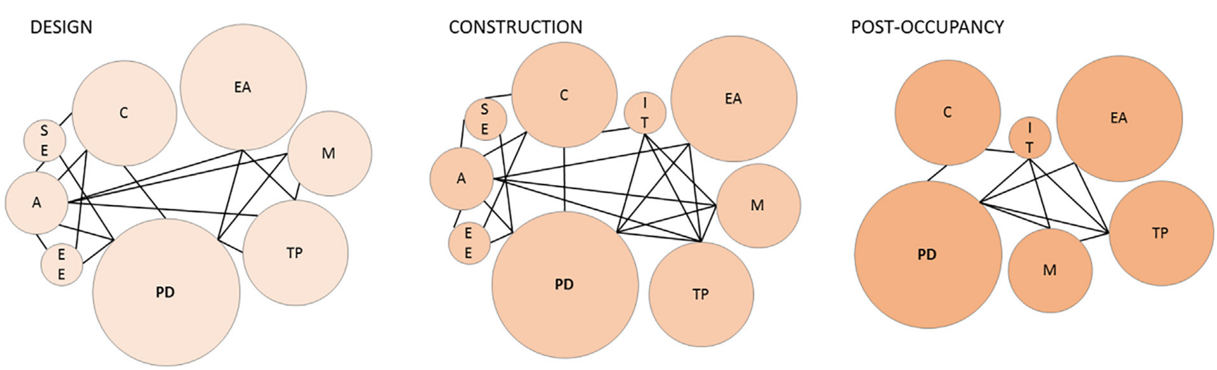
Worldwide, regulations and standards have been adopted towards the wider implementation of net zero energy buildings [11]. However, there seems to be a lack of coordinated policies and regulations for the implementation of communal solutions towards net zero energy settlements [24]. This has been a prominent barrier experienced in the implementation of ZERO-PLUS. Therefore, in view of transitioning from single buildings to settlements, policy and regulations stakeholders need to be aligned with the design components (innovative technologies, shared energy schemes, communal energy management) that enable such transition.

To this end, the policy and regulation framework needs to incorporate provisions that expand from single buildings to settlements, by introducing guidelines, protocols, and by-laws which will facilitate, enforce, and supervise the implementation of such concepts and aims. This expansion will motivate stakeholders such as energy companies in developing and allowing renewable energy sharing programs.

5.2. Project management

5.2.1. Project management structure

As the stakeholder analysis revealed, coordination and integration of the internal stakeholders and their interactions need to be ensured, and would preferably be handled by a Project Manager who has a broad overview of the project. Since integration is a key requirement, traditional project management structures are not applicable. The traditional approach to design and construction is characterized by fragmentation, where various building design and construction professionals are introduced at different stages and probably are working on separate goals [45,46]. This fragmentation also hinders the project's quality management [46]. Integrated Design Process and Integrated Project Delivery put an emphasis on the close collaboration of all involved stakeholders from the early planning stages and throughout design and execu-



A – Architect; **C** – Contractor; **EA** - Energy Analysis Expert; **EE** - Electrical Engineer; **IT** - IT Engineer; **M** - Monitoring Coordinator; **PD** - Project Developer; **SE** - Structural Engineer; **TP** - Technology Provider

Fig. 9. Stakeholder involvement and communication network in each project phase (in the UK case study).

Table 3
Project stakeholders and related benefits and barriers, as identified in ZERO-PLUS.

Project phase	Stakeholders involved	Aspect	Benefits	Barriers
Design phase	Internal and external stakeholders	Urban planning	Improved microclimate conditions through urban design solutions	Local long-term urban planning might obstruct design intentions
		Building permit approval	Clear roadmap for compliance with regulations for energy efficiency in buildings	Reluctance to approve design when authorities are not familiar with the concept
		Communal energy solutions	Increased efficiency through communal energy generation and management technologies	Existing policies and regulations on energy sharing schemes
All phases	Internal stakeholders	Project team	Access to the required expertise	Assembling the experts into an aligned team with good mutual understanding and communication
		Technologies	Optimization of the energy technologies at a settlement level	Difficulties in integrating the technologies in local systems and supply chains
		Owners	Economies of scale lead to lower initial investment costs for owners	Finding common agreement among owners
		Occupants	Energy savings and enhanced quality of life for the occupants	Lack of cooperation on the part of some occupants

tion, in order to achieve optimum design and performance with optimum time and cost management [47]. Integrated Design Process and Integrated Project Delivery lead to the emergence of new forms of project management and contractual agreement to support the new forms of stakeholder collaboration [47–49]. Essentially, in this new form of collaboration, the owner is a key and committed stakeholder throughout the project [47,48]. This is confirmed by the ZERO-PLUS experience, where the Project Owner/Developer had a high level of involvement and communication links. The execution and coordination of an integrated design and project delivery can be assisted by a series of tools that support integrated project management. In ZERO-PLUS, a Cost Control Tool, a Change Management Tool, and a Risk Registry were created to support project coordination and management.

5.2.2. Technology experts and innovative technologies

Technology providers have emerged as prominent members of the stakeholder team for the creation of NZE settlements. The achievement of NZE targets requires the use of technologies for energy conservation, energy management, and energy generation. Similarly, at the settlement level technologies need to be integrated to achieve the ZERO-PLUS targets. Therefore, both at the building and the settlement level, technology providers need to be part of the team and communication network early on for optimum technology integration and integrated design performance evaluation. After installation and commissioning, continuous monitoring of the technologies is part of the settlement-level monitoring.

5.2.3. Continuous monitoring and learning

Continuous monitoring is essential for performance evaluation and energy management. As a result, the roles of the Monitoring Coordinator and IT Engineer are part of the stakeholders' team. The Monitoring Coordinator leads overall planning and implementation of monitoring, including measurement and sensor specifications, design of the monitoring schema, monitoring equipment placement, and monitoring quality control procedures. Consequently, the Monitoring Coordinator needs to be involved in most phases and form multiple communication links, with the Project Owner, The Energy Analysis Expert, the Electrical Engineer, the Contractors' installers, the Technology Experts, and the IT Engineer. The IT Engineer (or Data Engineer) is the developer of the platform where the monitored data are being recorded and also forms a series of interactions to ensure the correct function of the monitoring schema and the data logging platform. Participation of these roles in the stakeholders' team and the related interactions are imperative for high performance zero energy buildings and settlements since monitoring has become an integral part of design and operation.

5.2.4. Ownership and occupancy

When discussing a settlement development, the Project Owner/Developer is the client and a leading stakeholder who needs to be highly involved in the process. However, the Project Owner is not the final home-owner and occupant. In the UK case study, the Project Owner is the developer of a community and the eventual manager of the community. In this case, the home-owners and occupants buy the residences with the monitoring equipment and settlement energy generation technologies already installed. In other cases, such as in the Italian case study, the project developer included the buyers and eventual home-owners and occupants of the residences in the design process. Consequently, there is different involvement of the final owners or occupants (and possibly non-involvement), depending on how the project developer operates.

The level of cooperation of occupants may be affected by perceived rather than actual systems complexity, by technophobia, misunderstanding and misconception, lack of interest in the new technologies and the potential they provide, or simple laziness [50]. However, requested occupant cooperation is not limited to the operation of the building as a sustainability-oriented system, but involves also their willingness to allow and facilitate periodic surveys and share personal information and data with researchers as part of POE. The necessity of all this is clearly delineated in the Welcome Package of this project, and the *raison d'être* of some seemingly intrusive questions is explained in the standard questionnaire administered during the surveys. Yet there is always the potential of the occupant losing interest in such cooperation along the way, or just getting tired of being asked time and again the same questions (morning, noon and evening, for specific days of each season). Whereas all may have a potential interest in saving on running expenses by properly operating their dwellings, some may influence the design process or even the choice of specific items. It is necessary that all such groups become aware of the common interests [51] as opposed to potentially contradicting ones [51,52].

All this implies that the success of the POE's vital part in the analysis of building performance and usability, as well as improving design and construction practices through user feedback, depends heavily on the user being thoroughly informed and aware, educated, and motivated [53–55]. Such predisposition of the occupant and subsequent behavioral adjustments may account for significant variance in heating, electricity and water consumption, as reported by [56]. Informed and positively predisposed occupants have been shown to have a much wider range of forgiveness and tolerance towards the actual performance of green buildings [57], a significant parameter in the success of sustainability-oriented design and construction

6. Conclusions

This paper presents a comprehensive approach for a settlement-level application of the NZE concept, which includes dedicated processes, tools, protocols, and technologies. The need for an approach that supports the realization of NZE settlements stems from the understanding that the business-as-usual scenario of energy use is unsustainable, yet that the costs of changing this scenario remain a formidable factor that needs to be tackled. The ZERO-PLUS approach provides important benefits that can support the implementation of NZE settlements in a range of climatic, technological, and cultural settings. The benefits include improved microclimate conditions, compliance with energy regulations, increased energy efficiency, and lower investment costs, as well as access to the experts required to implement the approach. The ZERO-PLUS approach provides the roadmap for achieving net zero energy settlements while lowering initial costs by 16% when compared with a typical NZEB, and achieving a net regulated energy consumption of less than 20 kWh/m^2/year. Significant barriers were also encountered in the implementation of the approach. These included barriers related to external stakeholders (such as existing urban plans, policies, and energy-related regulations), as well as to internal project stakeholders (such as communication, integration, and collaboration issues). The main solutions to these barriers include:

- Development of policies and legislation that will allow implementing such plans, not least by providing the flexibility needed to allow the inclusion of new technologies developed post-legislation.

Establishment of a project management structure that will ensure the coordination and integration of the stakeholders from the very beginning and that will involve both project owners and residents.

CRediT authorship contribution statement

A. Mavrigiannaki: Formal analysis, Writing - original draft, Writing - review & editing. **G. Pignatta:** Conceptualization, Investigation, Writing - original draft, Writing - review & editing. **M. Assimakopoulos:** Writing - review & editing. **M. Isaac:** Writing - review & editing. **R. Gupta:** Writing - review & editing. **D. Kolokotsa:** Writing - review & editing. **M. Laskari:** Writing - review & editing. **M. Saliari:** Writing - review & editing. **I.A. Meir:** Writing - original draft, Writing - review & editing. **S. Isaac:** Conceptualization, Investigation, Methodology, Writing - original draft, 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.

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Appendix A. Supplementary data

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