Locating 'smartly' the Net-Zero Energy District. An analysis through ten European case studies

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ABSTRACT

Transforming cities to deal with the threats of the climate change remain a major challenge. In this context of arising interest of territorial impacts, reducing energy consumption is an important target. During the last years, the *'zero energy idea'* was introduced in individual buildings. The paper proposes the development of a simplified, simulation and scripting district evaluation tool (U-ZED) for urbanisation strategies on a multi-criterion context to frame the urban typo-morphological structure of a Net-Zero Energy District (NZED). The tool explores the linkage of the beneficial influence of urban structure and patterns to the achievement of the increase in energy efficiency and the zero energy standards by examining the feasibility in a larger territorial scale (district). The purpose of the paper is, therefore, to identify the principal drivers of the 'optimal location' to ensure the zero energy standards and applications on-site. The tool develops the constraints towards the feasibility of its application and compiles the key parameters to synthesise the 'smart location'. Up to now, an extensive literature review through a diagnosis of ten European cases established four urban exemplar-simplified models. This work highlights the opportunities of extending the boundaries of the zero energy concept to a district and opens future research perspectives.

KEYWORDS
Case-study, District, Energy, Location, Smart, Tool, Zero

INTRODUCTION

Background – Research problem

The rapidly growing world energy use has already raised concerns over supply difficulties, exhaustion of energy resources, heavy environmental impacts, climate change, etc. During the last two decades, primary energy has grown by over 40% and CO_2 emissions by 43% [1]. Over 60% of the global energy demand is consumed in contemporary cities by increasing the energy requirements of the users [2]. On the other hand, buildings occupy a key role among the major contributors to energy consumption and GHG emissions [5,6]. In such a context,

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the objective for energy performance and sustainable development on city districts remains a challenge [5]. Responding to this, Commission's Roadmap indicates the reduction in GHG emissions by around 90% by 2050 comparing to 90s levels and sets out a legislation regulatory framework (i.e. directives, EPBD recast, etc.) towards this direction [6].

The zero energy concept has gained international recognition in literature but still, its definition is not yet standardised. Although existing definitions around the 'zero energy idea' are commonly articulated around an annual energy balance equal to zero [7], numerous differences exist in several definitions depending on the diverse elements (i.e. policy targets, connection to the grid, etc.) to address the goal of energy efficiency. The feasibility of this objective addresses primarily at the retrofitting of the existing building stock. Up to now, the concept focusses more on an individual and autonomous building aiming at more sustainable, long-term and concrete applications [3] neglecting phenomena incurred in larger territorial units (i.e. district or even city), such as the mobility, etc.

The current research study investigates the opportunity to extend the 'zero energy' concept to larger territorial scales by proposing a simplified simulation for urbanisation strategies of its urban structure with zero energy attributes. Although, the idea can be conceptualised to a district in a similar manner as the buildings by articulating its main energy uses (i.e. building energy consumption, transportation, etc.) the concept remains complicated and challenging. Dealing with the zero energy idea in a district unit and structuring its 'optimal' typo-morphological elements completes the existing approaches relating to 'zero energy' context. This paper discusses a methodological approach of a theoretical model to locate 'smartly' and strategically a district to achieve zero energy solutions. This implies innovative approaches towards an interdisciplinary planning that will highlight the importance of the zero energy concept and aid the city stakeholders and planners to define the structures of city districts and deal with this challenge at the spatial planning processes. The purpose, thus, is to present a contribution towards a better understanding of urban development path to be introduced towards a strategic location for future city districts.

Objectives

The main objective of this study is to provide the 'optimal' location of the zero energy district via a simplified simulation and scripting tool (U-ZED) based on the contextualisation of the urban structure of the NZEDs. The concrete research objective is the development of an interactive tool for the determination of the urbanisation strategy for 'smart' districts via key parameters and factors.

Precisely, the **objectives** of the executed work include:

- The **diagnosis** of sustainable urbanisation strategies in response to the literature review of the state-of-the-art and on-site analysis.
- The **feasibility** of the zero energy concept's expansion from the individual building to a district.
- The **development** of a district evaluation tool for an 'optimal' and simplified urban model(s) to define the NZED's location within the introduction of key parameters, criteria and indicators that influence its attributes.
- The **presentation** of the 'optimal' (exemplar) simplified urban models of NZED urban structure and location.

Methodological approach

The concept of the energy balance is the starting point for the U-ZED theoretical model. A first approach of the methodological steps of the U-ZED tool is elaborated in accordance with three axes: the **'smart location'**, the 'smart typology' and the 'smart morphology' to estimate the opportunities for the development of the 'optimal' simplified urban models. In this paper, we focus our research on the first axis of the study ('smart location').

The location of the 'Net-Zero Energy District' is fundamental and consists the first step in its urban analysis. The issue of implantation is related to the question of "where" we will locate the district with zero energy criteria and corresponds at the demands of continuity with the existent urban city form and the accessibility to the public transport. The identification of a site for the implantation of a 'Net-Zero Energy District' reveals an interactive procedure [8]:

- The combination of the intention of the community to develop a 'Net-Zero Energy District' in a particular sector. The application of the planning process to identify the strategic axis of the urban development according to the urban local planning sets the objectives of construction and expresses the policies of public transport.
- The combination of a first consultation with the districts' residents (end-users) and the stakeholders. The residents' attitude concerning the energy consumption is also a key factor for the achievement of zero energy objectives.

Generally speaking, the implantation of a NZED is related to two (2) main axes:

1. The continuity with the existent urbanisation, which minimises the environmental impacts and the depletion of natural resources.
2. The proximity to transport services and the connectivity with the network assigned to soft transport modes as an alternative choice and reduction of carbon emissions.

The planning of a NZED coordinates in a dynamic way the following components [8]:

- The response to demographic change with a range of accommodation adapted to different circumstances and aspirations in a spirit of social and functional balance.
- The creation of a diverse district through the employment encouragement and the impulsion of dynamic uses (commercial, etc.).
- The promotion of 'short distances', the development of alternative modes of transport (encouragement of public transport instead of car use) and the intermodal mobility.
- The choice of renewable energy sources and techniques, materials and components for eco-design and eco-construction.
- The creation of alternative sanitation systems and rainwater management.
- The protection of landscape and approach to natural diversity.

Introduction of the notion 'smart ground'

Along with the application of the zero energy idea in a district scale as the previous analysis indicated, the study carries out the significance of the 'smart ground' implying the importance of locating 'smartly' a district to achieve the 'optimal' Net-Zero Energy District. Before the installation of any innovative technological realisation or application in a district, the 'smart ground' considers 'intelligently' the location to ensure its context.

The pyramid is based on the 'optimal' location for the accommodation of the zero energy systems and the application of their techniques. To these principles, the role of residents' participation to maintain a fully engaged sustainability and strategic planning already from the earlier conception of a NZED as an urban project is significant (Fig. 1):

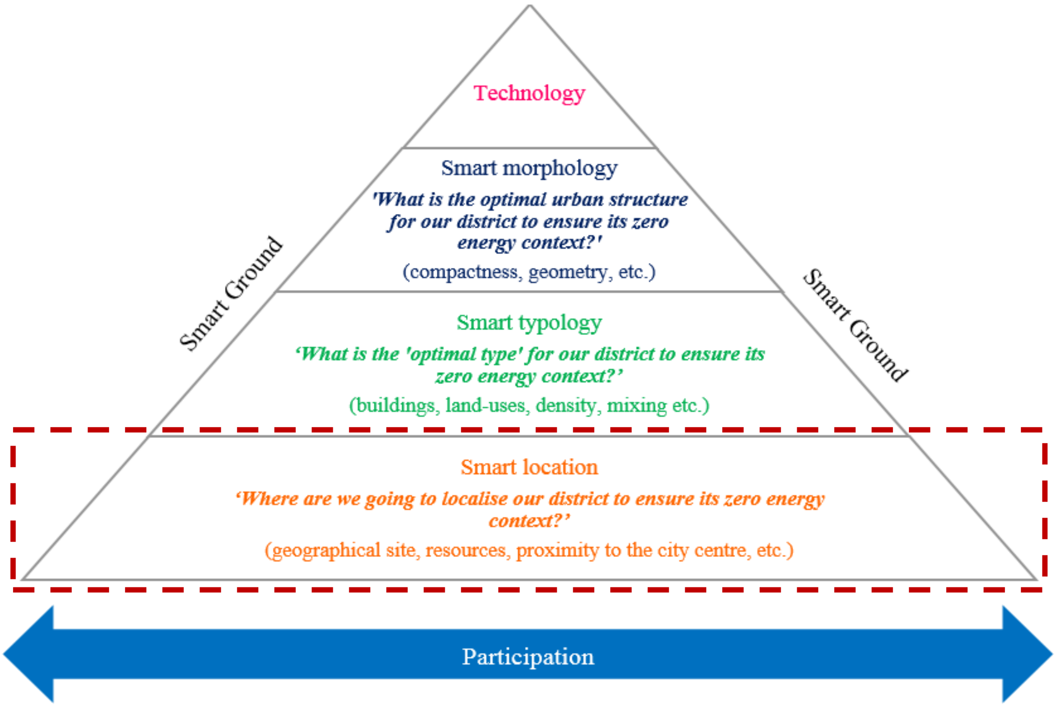

Figure 1. Introduction of the notion of 'smart ground' for the description of a NZED

Recapitulation of methodological steps

To begin with, the study as an initial step includes a state-of-the-art-analysis of the previous existing approaches in districts with interesting and sustainable context. Defining the research objectives and questions ensue the analysis of key criteria/factors (i.e. potential of natural resources, density, mixing, etc.) that define the district with zero energy attributes. Beyond this, four (4) districts: *BO01 (Malmo), Kronsberg (Hannover), Eva-Lanxmeer (Culemborg)* and *Pic-Au-Vent (Tournai)* (related to their lessons-learnt and experiences) have been considered as 'exemplar' to have the potential and the opportunities for a zero energy 'transformation'. The cases aggregate particular typo-morphological characteristics of their structures as 'smart grounds' as we will analyse in a subsequent section. Briefly, the methodological approach and the description of the steps of U-ZED tool includes:

1. Problem Definition: description of the problematic and the research motivation
2. Previous work & Literature Review: 'scanning' on the previous work analysis and the existing literature review regarding the ideas of 'zero energy', 'district evaluation', etc.
3. Research objectives and questions: definition of the research questions and objectives of the analysis
4. Case studies and Analysis: description of ten representative European case-studies with a sustainable context in a multi-thematic approach.
5. U-ZED district evaluation tool: development of the methodological tool (U-ZED) for the zero energy district approach.
6. Conclusions/Future Work: an overview of the main conclusions of the work and ideas for further work.

DEFINITION OF A NET-ZERO ENERGY DISTRICT

The problematic of the 'territorial scale'

A comprehensive problematic that the study had to deal with the appropriate 'territorial scale' to identify zero energy solutions. The strategy of the identification of the urban scale for an effective energy planning has to take into account the fact that it has to be executive in strategic decisions of the planning process and that coherent with the global objectives in a 'city level' to ensure a more integral diagnosis. Due to the complexity of the zero energy context, the first step of the problematic is the identification of the 'optimal' territorial scale of the analysis in a manner that the diverse aspects as considered as a cohesive whole. Table 1 provides the most interesting attributes of the diverse territorial 'scales' in a comparative analysis in an effort to define the 'appropriate' level for zero energy applications [9]:

Table 1. Sustainability themes and problematic of the territorial scale

Territorial scale	City	District	Building
Urban system	Urban structure Land-uses Street network Mobility policies	Urban structure Land-uses Street network Mobility policies	Land-use Connections with public transport Mobility policies
Environment	Waste Emissions Energy production Energy consumption Water management	Waste Emissions Energy production Energy consumption Water management	Waste Emissions Energy production Energy consumption Resources use Microclimate Outdoor comfort Indoor comfort Water management
Society and economy	Biodiversity Access to culture Work Equity Safety ICT	Biodiversity Access to culture Work Equity Safety ICT	Biodiversity Access to culture Access to services Health Safety ICT

Zero Energy Concept and Definitions

In scientific reviews, the zero energy objective is originated by the buildings' definition by proposing calculation methodologies or tools at their patterns and construction design with greatly reduced energy demand. D'Agostino et al. [10] state the significant importance of the zero energy concept and the emergency to be introduced at a district level. EU with the EPBD and its recast and a package of additional regulation introduce specific measures towards the reduction in energy consumption in the building and district level. The timeline for the NZEBs implementation (EPBD) is illustrated in Figure 2.

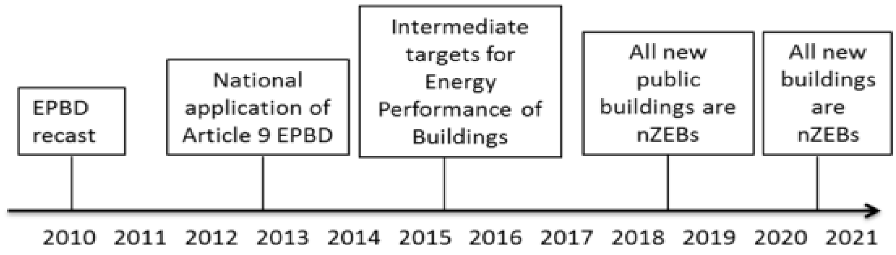

Figure 2. Timeline for NZEBs implementation according to the EPBD recast [10]

The discussion around NZEBs has more focused in the last decade especially on some aspects that still need to be properly defined. The main arguments are schematised in Fig. 3 and are related to: *physical boundary, period and type of balance, type of energy use, metric, renewable supply options* and *connection to energy infrastructure*, etc. [11]. By analogy to the building, Kilkis [12] describes the context in a district level as the district which includes buildings that produce as much energy at the same grade (or quantity) as consumed annually introducing the term (Net-Zero **Exergy** Buildings). Kilkis in [13] conceptualises the idea of zero energy on 'exergy' including the summation of energy flows with diverse exergy levels and the indifference to the usage of energy resources. Thus, the concept of zero energy in a building is the counterbalance of production and consumption in an annual basis with the aim to resolve mismatches in exergy levels at the internal and the external environment of a building with zero energy attributes.

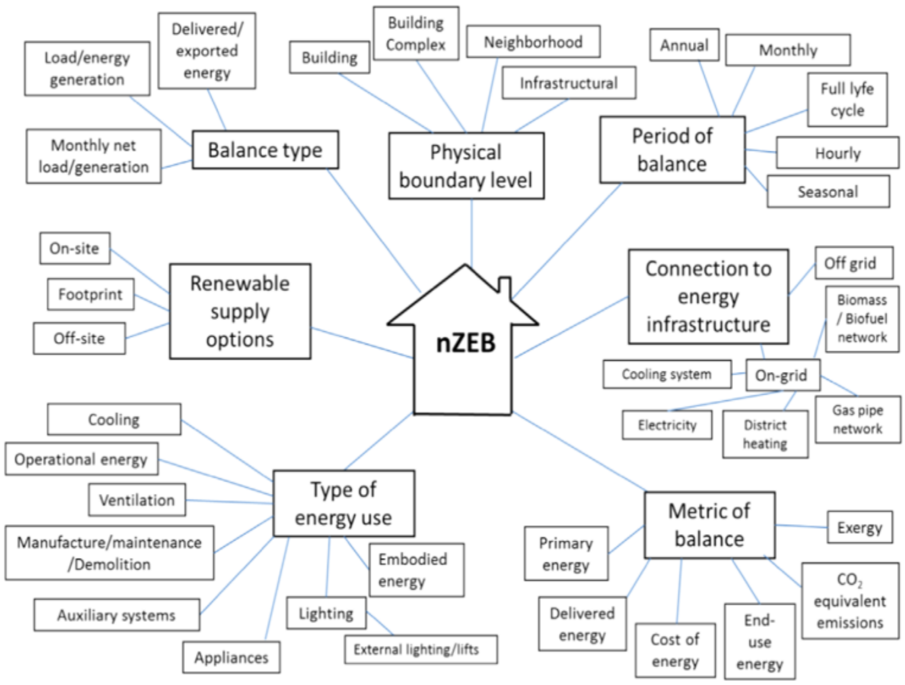

Figure 3. Arguments around the NZEBs [10]

Generally speaking, a NZEB refers to a building with a zero or negative (net) energy consumption (energy balance) over a typical year (annual basis). It implies that the energy demand for heating and electrical power is reduced. It also normally implies that the grid is used to supply electrical power when there is no renewable power available and the building will export power back to the grid when it has excess power generation. This 'two-way' flow results in a net-positive or zero export of power from the building to the grid. The objective is not only to minimise the energy consumption of the building with passive design methods but also to design a building that balances energy requirements with active energy production techniques and renewable technologies (PVs, solar thermal or wind turbines, etc.) [14].

Besides, the achievement of a low (or even zero) energy depends not only on the energy balance of the building stock but also on its holistic urban metabolism including the human factor [3]. Despite the particular interest of NZEBs, *the research of the concept on the individual scale of the building as an autonomous entity neglects the significance of phenomena linked to larger territorial scales concerning the efficiency and performance of renewable energies, the impact of the transportation system, etc.* [15].

Net-Zero Energy District

Role of the district

Despite the particular interest of a district, the research of the zero energy objective up to now is focussed on the individual scale of the building as an autonomous entity by ignoring the significance of phenomena linked to larger territorial scales [15]. Besides, the achievement of a low (or even zero) energy district depends not only on the energy balance of the (existing) building stock but also on its holistic urban metabolism including the **human factor** and its users' attitude.

Districts are a subset of the city and one of its constructive elements with physical and administrative boundaries structured in accordance with historical, cultural, urban or other criteria usually surrounded by the infrastructure through its expansion. This territorial level appears interesting in operational and multi-thematic context as a 'city micrograph' to identify the patterns of the zero energy concept [16]. Districts are compact enough to concentrate resources and well-situated to experiment with specific practices the urban and the built environment. In a district, it is possible to evaluate the characteristics of the urban structure and its complexity but also to 'interpret' the socio-economic environment, the distribution of its functions and activities, the diversity of the building households, etc. [9]. Jalala [17] states that zero energy projects are more worthwhile and efficient in a district scale to provide energy techniques for renewable systems that are not available in individual buildings.

From the authors' point of view, the **district**:

- It is a scale particularly interesting within its interconnections and interfaces among the diverse components at a larger scale than a building (Fig. 4).
- It deals with the challenge of both developing innovative and energetically performative urban structure and concurrently retrofitting the existing building stock.
- It is understood and an 'urban block' with diverse key parameters of its 'internal' and 'external' environment.
- It is considered in a systemic approach (Fig. 4).

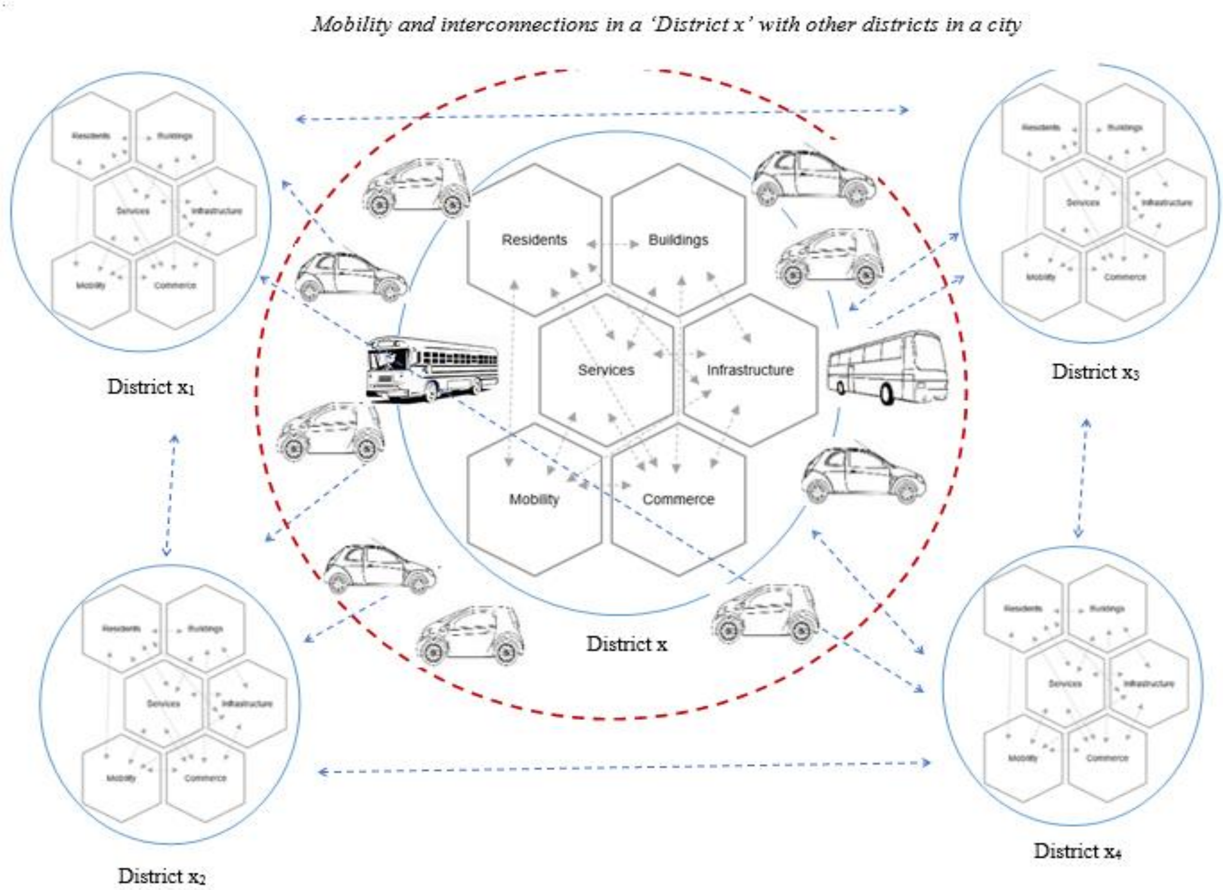

Figure 4. District approach, interconnections with 'internal' and 'external' environment

The term 'Net-Zero Energy **District**' is an innovative concept still in progress growing prevalent during the last years and it is still restricted at the scientific literature review. Juusela et al. [18] figure the role of the urban agglomerations as widely recognised and as a key role in reducing emissions and energy consumption. In line with changes in energy systems, research into the energy performance of the built sector is broadening its objectives in the district territorial level. U-ZED district tool highlights the significance of increasing the boundaries of energy analysis and achievement of the zero energy attributes to a district via a procedure of territorial evaluation.

Cortese and Higgins [19] state that a Net-Zero Energy District is a group of buildings with a stated goal of achieving the zero energy idea. Carlisle et al. [20] define the Zero Energy Community as *the community with reduced energy requirements (covered by renewable resources) by increasing energy efficiency*. Todorovic [21] defines the Zero Energy Community (ZEC) as the *'community with greatly reduced energy requirements'* and includes energy not only for residential buildings but also for other infrastructure [22]. Polly et al. propose four (4) design principles for the NZEDs:

1. Maximisation of building efficiency by improvement of the building envelope (i.e. using techniques of wall and roof insulation, highly efficient windows, etc.).
2. Maximisation of the solar potential, buildings' design and standards to enhance the solar access.
3. Maximisation of the use of renewable and natural resources.

4. Establishment of load control systems for buildings and districts to accommodate the renewable energy supplies (i.e. wind turbines, etc.) and to support the district's interaction with the electric grid as a whole.

Todorovic [22] states respectively the question of the 'zero carbon city' and the role of the simulation tools towards the 'zero energy city'. In terms of renewable energies at a district level, the studies tend to include more the solar potential of the existing urban zones from the point of view of solar panels without including the energetic consumption of buildings [23]. The impact of the urban structure at the energetic consumption due to the mobility introduced primarily at the study of Newman and Kenworthy [24]. Steadman [25] develops in a theoretic view the relation of the energy consumption and the urban structure via the criteria of the urban form and the density and concludes that the 'dense' city districts reduce their energy consumption.

Jalala [17] states that the Net-Zero Energy District delivers as much energy to the grids as it uses from them with the use of renewable resources by achieving a high energy performance. The buildings considered as autonomous entities by neglecting the importance of phenomena related to larger territorial scales (i.e. district, city, etc.). Marique et al. [3] describe the NZED by analogy with the 'Net-Zero Energy Building' as a district in which the *'(primary) annual energy consumption for buildings and mobility demand*'. The idea articulates three (3) main energy uses: (a) the building energy consumption, (b) the production of on-site renewable energy and (c) the transportation consumption for the daily mobility demands. Perhaps the two most frequently cited definitions in current literature are 'net-zero site energy' meaning that a site produces (at least) the **same** energy as it uses (annual basis) and 'net-zero source energy' [26].

Transforming the energy performance of individual buildings is indeed an important step towards the zero energy idea in a district scale. However, the application of zero energy techniques is not possible nor realistic in every building in the district and the goal is feasible for a large perimeter of buildings but not for all of them. Kallushi et al. [27] state the strategy of achieving a NZED depending on the scale, ranging from only, a few buildings to larger and complex districts (see simplified models). Yet, developing a NZED deals with many challenges and difficulties as it requires particular infrastructure, which is often difficult to be connected to the existing grids and networks. Another difficulty is the 'phasing' as it demands the installation and application of energy systems that have to be 'tested' before their implementation. This fact is not always feasible in urban projects like the district development. Every zero energy project is basically depended on the occupants' participation so its success depends upon the continuous efforts towards the residents' awareness and sensitivity [17]. For this study the 'Net-Zero Energy District' is understood and considered in a ***'systemic approach'*** (Fig. 5), where the energy consumption and production are balanced on an annual basis:

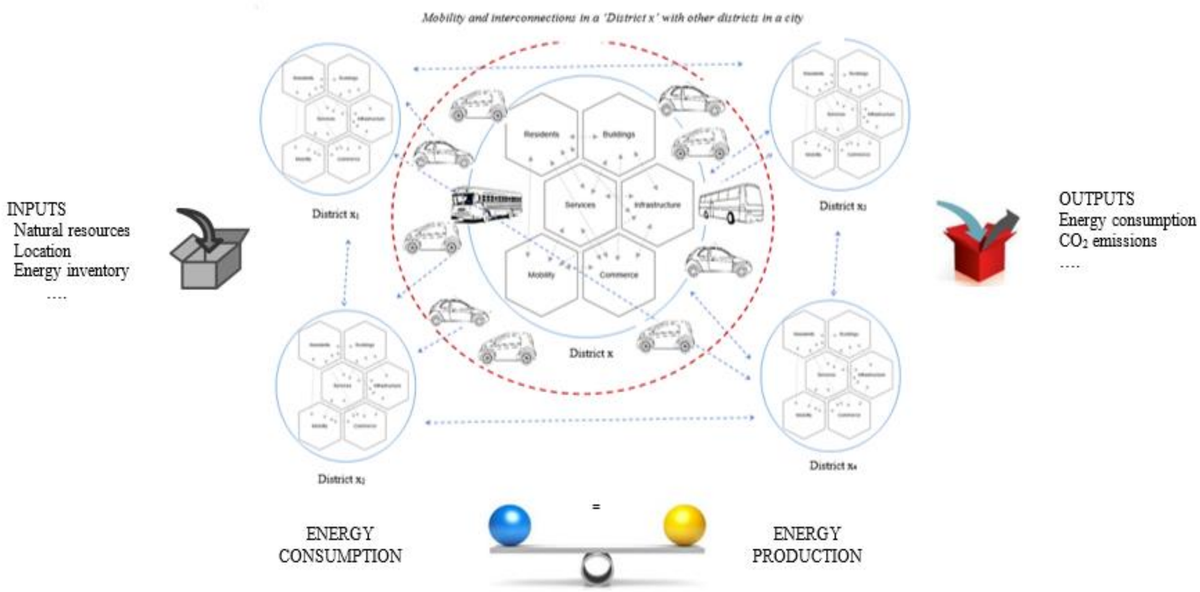

Figure 5. Net-Zero Energy District in a systemic approach

U-ZED DISTRICT EVALUATION TOOL

In this context of the evaluation procedure, further research on the principles and criteria to assess the potential of zero energy retrofitting and validate an assessment tool (i.e. U-ZED) to meet the requirements of zero energy district reaching a high level of energy autonomy by optimising its urban strategic planning, three pillars are introduced (Fig. 6) :

Pillars of U-ZED evaluation tool

The first methodological step of the U-ZED approach is the definition of the indispensable pillars for the zero energy objectives in a district level.

Pillar 1. Optimisation of residents' energy requirements

The primitive principle for a NZED to minimise the residents' actual requirements in energy including the mobility (car dependency) and the buildings' energy consumption.

Pillar 2. Energetic hybridisation

Analysis of the site potential, the energetic systems, the technologies and the techniques to apply and to 'hybridise' the capacity of the diverse natural (and renewable) resources to ensure the local energy production and correspond to the actual residents' needs. The pillar encompasses the analysis of the site potential, the technologies and the techniques to apply to the implementation of the zero energy concept in the district as well as their viability in a long-term context. An energetically autonomous district 'hybridises' the capacity of the diverse resources to ensure the local energy production and corresponds to the actual users' requirements.

Pillar 3. Organisation of energy storage

Indispensable pillar of a NZED evaluation. In the definition of an energetically autonomous district, the recourse on energy storage is imperative. Thus, it demands energetically efficient and autonomous systems for the energy distribution in function with the peak periods of consumption to achieve the 'optimal' balance.

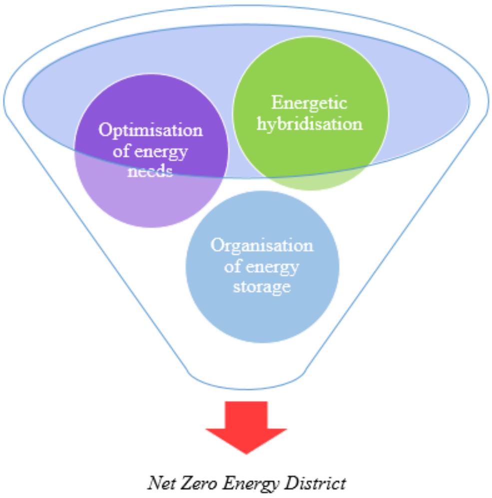

Figure 6. Pillars of evaluation (U-ZED tool)

Diagnosis of ten European case studies

The analysis focusses on the representative European case studies selected with an 'eco' character due to the information availability, their geographical criterion (Europe) and the publication of their first lessons-learnt (Fig. 7):

Figure 7. Presentation of ten case studies of European eco-districts

Smart location

The initial question for the establishment of the zero energy idea in a district is the 'location': ***'Where are we going to locate our district to ensure its zero energy context?*** The implantation of the 'Net-Zero Energy District' is fundamental and consists the first step in its urban analysis.

In particular, the **criteria** included in the research study for the 'smart' implantation of a NZED are:

Resources

The proximity of the natural resources and the reduction of energy consumption is probably the aspect the most important to 'labels' a district as 'net-zero energy'. The focus on renewable energies enables the minimisation of the environmental impacts and the less dependency on fossil and gas emissions [28]. This parameter is crucially important for the definition of a NZED regarding the selection of the 'optimal' geographical site (i.e. close to the natural resources or the city centre, etc.).

Girardet proposes the concept of the 'urban metabolism' to explain the use and the role of the natural resources in a district [29]. The principal problem for the district is to correlate this metabolism to economise the resources and recycle them as far as possible (i.e. recuperation of storm water, etc.). The energy consumption follows the same principle towards its reduction with a rational use of natural resources and their transformation [30].

Density

Ewing and Rong [31] note that the choice of residential dwellings is strongly related to the urban structure. Using path analysis, the authors conclude that residents in sprawling counties tend to live in large, single-family detached dwellings and both lead to higher residential energy use [32]. The criterion of 'density (residential)' is twofold: (a) the compactness – key parameter for the definition of the urban morphology from an architectural viewpoint – and (b) the population or residential density (number of inhabitants or units per ha). The criterion of 'density' is central to the urban strategy of a NZED to limit the car dependency and economise the land use. Highly dense districts restrict the distances by increasing the proximity and fostering at the same time the public transportation.

Obviously, the parameter of 'density' is an effective tool that responds to mobility issues. The analysis of the selected case studies proves that 'high density' and compactness belong to principal characteristics of a NZED with the aim to overcome the problems of the urban sprawl. The reorientation of the urban sprawl and the zoning with the concentration of land uses is arousing for the development of the new districts and even more for the NZED [30]. Typical examples of 'dense' (eco) districts are presented in Fig. 8a-b:

(a) (b)

Figure 8 (a-b). Examples of two aspects of the criterion of 'density' in (a) Vesterbo (Copenhagen), (b) Vauban (Germany) (from left to the right) [30]

The concept of a 'strong (high)' density is 'translated' negatively as it is associated with socials or behavioural dysfunctions. For this study, the criterion of 'density' is considered necessary but not sufficient for a NZED definition and it should be studied in combination with other key parameters (i.e. connectivity, accessibility, mixing, etc.). Table 2 presents part of the advantages and disadvantages for a highly dense district:

Table 2. Advantages and disadvantages of a highly dense district

Advantages of a high density (+)	Disadvantages of a high density (-)
Small distances	Less green zones
Reduction in transport needs (encouragement of public transport and less car use)	Increase in circulation in high dense zones
Protection of agricultural land uses	Potential of perturbation in land uses
Preservation of biodiversity	….
Reduction of energy consumption	
Reinforcement of functional mixing	
…..	

Combining the criterion of 'density' with the implantation, a solid basis is defined as meeting the goals of a net-zero energy urban planning. The definition of minimum density thresholds depends on the context in which the urban project operates. According to Teller and Marique [33], a minimum threshold of 30 units per hectare enables the realisation of the district sustainability's objectives, located in poles, where land pressures are high. This minimum threshold is increased to 40 units per hectare in districts situated near to stations and city centres. In central villages, the threshold is 20 units per hectare. These values are considered as the minimum thresholds and they are revised depending on the varied situations and the possibilities offered as well as the environment and the surroundings of the district. Vasant et al. propose a mixture of high and low buildings for a NZED as an 'optimal' urban structure, which improves the ventilation conditions as too many high buildings affect unsuccessfully the access of natural lighting and the daylighting [34].

Madlener and Sunak [35] indicate the criterion of density in relation to the Urban Heat Island (UHI) effect. Compact and dense urban agglomerations absorb and retain the solar irradiation and increase the temperature. Despite this, a highly dense city district has advantages compared to less compact areas with regard to energy demand. Indeed, dense development patterns reduce infrastructure demands and the car dependency combined with the criterion of functional mixing, etc. As population density increases, public transportation becomes more effective, so per capita consumed fuel is much lower in the high dense developments. Urban density also affects urban ventilation conditions, as well as urban temperature; urban development with a high density of buildings suffer from poor ventilation and high temperature. Briefly, denser district patterns maximise the energy efficiency and satisfy the social and environmental requirements in the district. Thus, *less dense districts are not recommended for NZEDs* as they consume more energy and compose a sprawl urban structure. On the other hand, compact urban structures have advantages for energy distribution and transport system designs and are preferable for NZEDs.

Mixing (functional and social)

After the introduction of the mixed uses in a district, as one of the elementary criticisms on modernist city planning, a second important moment in districts has been the idea that the concentration of people and activities in more 'compact' urban structures contribute to lower the energy consumption and improve the energy efficiency in urban agglomerations [36]. In a broad sense, the mixed-use context is the combination of residential and non-residential activities and functions on the basis of a multi-functional territory to achieve uniform distribution of the population and the residential development in spatial conditions [37]. Mixed-use (or heterogeneous) areas enhance the compatible land uses in close proximity and decreases the car dependency between residential by intending to [38]:

- Promote a variety of dwelling typology and a range of densities to accommodate diverse housing requirements.
- Provide residential uses to proximate to commercial (or other) services.
- Foster pedestrian-oriented activity nodes by providing a mix of uses in compact areas.
- Lead to land-use optimisation by using public space.

The mixed-use context of a district compiled with reference to the:

- 'Functional mixing': The proximity and diversity in the functions of a district – including the infrastructure and the services – reduces the distances and increases the mild public transport. Teller et al. propose that at least one function supplementary to an existing to be developed in a perimeter of 700m around the site of the district during its urban strategic programming. The objective is twofold: (1) to avoid the mono-functional residential district and (2) to avoid the competences among the diverse land-uses in the district [33].
- 'Residential and non-residential mixing': The diversity of residential and non-residential dwellings is compelling for a NZED.
- 'Social mixing': In combination with the 'functional' and 'residential and non-residential mixing', the 'social mixing' is required for the zero energy context. In the framework of a NZED, it is preferable to envisage a district with a minimum of social housing concerning the residents' requirements.

Connectivity with surroundings and other districts

The physical connectivity (boundaries) is a point that corresponds to the different connections with this point. In the NZEDs' case, this corresponds to its connection with the public transport, which consists an important point at its identification. According to Salmon [39], the well-connected districts to the city centre consider an average distance from 2-3km, while for the suburban districts the preferable distance is calculated between 3-8km from the centre to the closest and between 10-15 km farthest. This point requires the implantation of the NZEDs close to public transport networks creating multi-modal centres and alternative transport connections (bus, train, cycling, etc.) [30]. The spatial planning of the NZED and connectivity are, therefore, intrinsically linked [33]. According to SOLEN (Solutions for Low Energy Neighbourhoods) project [40], the relation of connectivity for different services for a 'well-connected' district are defined as follows:

For train service:

- *Good*: Presence of an IC/IR station less than 2km from the site/area and/or the presence of a station L to less than 1km of the site/area.
- *Medium*: Presence of IC/IR station within 2-5km around the site/area and/or the presence of a station L in a radius of 1-3km of the site/area.
- *Low*: No IC/IR station within 5km from the site/area.

For services by bus, tram and metro:

- *Good*: Passage of at least 34 buses a day at stops located within the perimeter of 700m around the boundaries of the district/site. (One bus serving several stops within this scope recognised only once the two directions of traffic recorded).
- *Medium*: Passing bus under 34 but over 16 daily buses at stops located within the perimeter of 700 meters around the boundaries of the district/site.
- *Low*: Sixteen-bus pass or less per day with stops located within the perimeter of 700m around the boundaries of the district/site.

For the mixed functionality:

- *Good*: Presence of at least five functions distributed in at least three categories (shops over 400m², shops, utilities, services, equipment and recreation), in the scope of 700m around the boundaries of the district.
- *Middle*: In all cases that are neither good nor poor.
- *Low*: Presence of fewer than five functions distributed in less than three categories within the perimeter of 700m around the boundaries of the district.

The systemic approach of the district is encouraged by a 'good' connection (i.e. public transport, close to city centre, etc.) with its surroundings. Linking the grid of districts contributes to improving them in a longer term, the social relationships and the quality of life in the internal and external environment of the district. If the land availabilities are present close to the district's site, then the conception (design) of the net-zero energy planning (in terms of buildings, road network, etc.) favour also a future expansion in line with it.

RESULTS

Simplified NZED models

In the previous analysis, the concept of NZED in a systemic and a multi-criterion approach indicated the criteria into consideration for the 'smart' location to achieve zero energy attributes. Following the state-of-the-art-analysis, U-ZED 'evaluates' the ten case-studies (Annex I) in terms of three pillars defined previously as NZED potentials. Four (4) urban projects considered as exemplar for their transformation into the net-zero energy concept: BO01 (Malmo), Kronsberg (Hannover), Eva-Lanxmeer (Culemborg) and Pic-Au-Vent (Tournai). Their analytical description in relation with the three levers of evaluation and criteria is a preliminary but interesting step for the definition of NZED 'optimal' typo-morphology. The focus on *renewable energies* enables the minimisation of the environmental impacts and the less dependency on fossil and gas emissions. For a NZED, the 'optimal' location is considered between 3-10km from the *city centre* (criterion of *'proximity'*) in a distance of +/- 1500m from the railway station with the possibility to be served by public transport in a radius of 700m. Note also that the 'smart location' is considered in relation to the interfaces of the neighbouring districts by combining the residential with alternative functions by integrating a range of diverse services and avoiding mono-functional or mono-zoning districts.

The results of the four simplified NZED models are presented in Table 3. Analytical information about the 'smart location' of the exemplar simplified urban models in Fig. 9.

Table 3. 'Smart' location of four exemplars NZED models

Case-study	Distance from city centre (in km)	Public transport (m)	Proximity to natural resources (y/n)	Type of natural resources
Type A: *BO01, Malmo*	3km from the city centre (Malmo). Strategic location nearby the sea and close to the railway station	500	y	Solar, wind, geothermal, biogas, gas. Wind turbine, solar tube, panel collectors and heat pump. Development 100% of local, renewable energy resources
Type B: *Kronsberg, Hannover*	10km from the city centre	300	y	Solar, wind
Type C: *Eva-Lanxmeer, Culemborg*	1,4km from the city centre	300	y	Solar, wind, geothermal, biogas
Type D: *Pic-Au-Vent, Tournai*	1,5km from the city centre	n/a data(1)	y	Solar

Type A: BO01, Malmo

Malmö is the third biggest city in Sweden and it is located in the middle of the Öresund region. A bridge completed in 2000 link Malmö to Copenhagen within 45 minutes. It is situated 3km from the centre of the city of Malmo, a previous industrial zone. Its location is strategic due to its proximity to the sea and the railway station. The inhabitants are encouraged to use environmentally friendly modes of transport. Pedestrians and bicycles have priority in the area and it is car free. Bus stops are within 500m's distance from the residential dwellings. Generally speaking, the district is well served by the public transport with a service of commuting available (a distance of 500m max of every bus stop).

Type B: Kronsberg, Hannover

Kronsberg is a new-constructed eco-district in Hannover of mainly agricultural land at the city margins. The district is located in the South East of the city and represented the last

[1] Remark: the district of 'Pic-Au-Vent' is **not** well-served by public transport, the frequency of the bus line 88 is not adequate for the residents' requirements (every two hours)

remaining area in Hannover suitable for a large-scale building project. Situated at the periphery of the city (10km from the city centre) at the south-east, laying at the ancient agricultural grounds, Kronsberg is found near the park of Expositions and the International – Universal Exposition of 2000 and it covers the connection between the ancient district of Bemerode and the Exposition site.

Type C: Eva-Lanxmeer, Culemborg

Eva-Lanxmeer is a social-ecological district of 24ha built on a former farmland surrounding a protected drinking water extraction area as an example of an integrated approach towards the sustainable planning. The district is located near the Culemborg railway station 1.4km from the city centre and it is well served by the public transport (a distance of 300m max of every bus stop).

Type D: Pic-Au-Vent, Tournai

Pic-Au-Vent is an on-going pilot project of passive architectural bioclimatic design located in the city of Tournai, Belgium in a distance of 1.5km from the city centre. In terms of proximity, the district is not really well served by the public transport. The access to the district is quite difficult (bus every 2 hours and distance of 4.5km from the railway station).

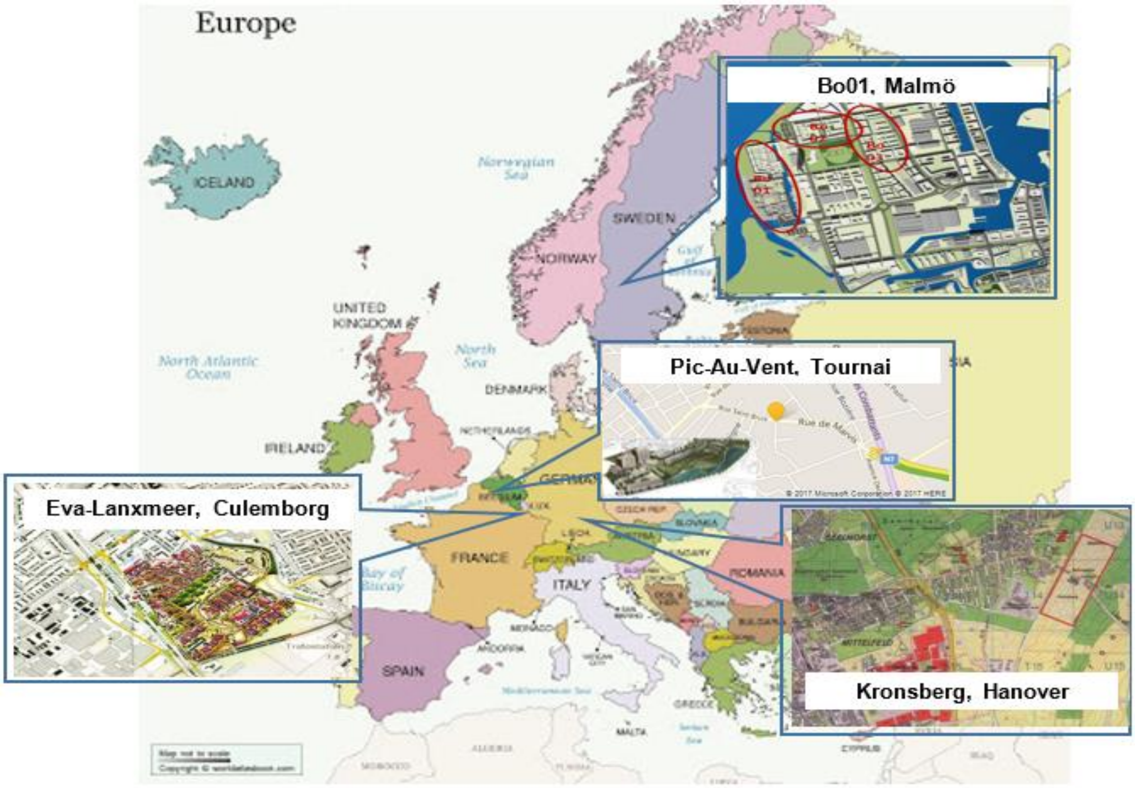

Figure 9. Geographical 'smart location' of the four (4) exemplar simplified district models

The four paradigms above indicate the significance of the 'smart location' to the NZED definition mainly in terms of the proximity of renewable resources and connectivity (city centre, etc.). The analysis of the possibilities to implement the NZED concept per location is the initial step including technical, social and potentially financial constraints. The attributes of a district's location (i.e. potential of natural resources, etc.) meet the requirements of the successful concept and its implementation to future districts.

CONCLUSIONS

Implementing Net-Zero Energy Districts is a sense of responsibility towards future generations implying new lifestyle and mentality. This paper refers to a NZED community in a systemic approach with interventions of its external and internal environment and not only as a cluster of buildings and infrastructure and indicates the difficulties for its implementation in real cases. The district evaluation by the U-ZED tool of ten European cases discusses the importance of the 'smart location' as an initial procedure before the accommodation of the energy systems that introduce the zero energy concept in a community.

Up to now, a research methodological study is developed to contribute to the establishment of a simplified, scripting and simulation tool (U-ZED) tool for the definition of the urbanisation strategies and simplified urban models with zero energy attributes. A critical selection of key parameters and criteria (and sub-criteria) that influence the structure of a district in response to the reduced energy consumption is defined as an initial step in accordance with the three prerequisites of the 'smart ground'.

To conclude, in a more general perspective, a first methodological approach and a diagnostic analysis in three axes (optimisation of energy requirements, energetic hybridisation and organisation of energy storage) estimate the opportunities and the feasibility of applying the zero energy concept in a district within a 'parametrical' and 'multi-criterion' frame in regards to the 'smart location', the 'smart typology' and the 'smart morphology'. The ***goal*** of the study contributes to the establishment of a simplified, simulation and initial tool (U-ZED) for the definition of the zero energy district on the basis of contextualisation of its urban structure. The tool explores the linkage of the beneficial influence of urban structure and patterns to the achievement of the increase in energy efficiency and the zero energy standards to contribute to the existing literature on the 'zero-energy' objective in the individual building by exploring its feasibility in a district.

The 'success' of a NZED implementation depends on an integrated and holistic vision and strategy with a starting point of the buildings but also of the external connections of the neighbouring districts and the city as a whole. The concept, thus, depends not only on individual technologies but also on well-executed planning, integrated standards, design-involving users, and their daily needs in the district.

In a more general perspective, the study deals with the challenge of the development of a tool and an urbanisation strategy to complete the existing assessment methods and extend their boundaries from building to district with the main concern to define the context of sustainable and long-term districts dealing with the challenges of climate change and its disastrous impacts.

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ANNEX I

Evaluation of ten case-studies by U-ZED tool

District	EVALUATION : CONCLUSIONS			
	Pillar 1. *Optimisation of needs*	*Pillar 2.* *Hybridisation of energy systems*	*Pillar 3.* *Organisation of storage*	**EVALUATION AS A NZED**
HAMMARBY, SWEDEN	The actual energy needs of the district (buildings, transport, etc.) are almost 3 times higher than the initial estimations. This fact, naturally, reduces the proportion of consumption covered by the local production of renewable energy	The hybridization of energy is reduced and it is based on its majority on solar energy. This problematic is particularly caused due to the choice of the district's location, which is far from the energy potential or inventory (obstacles for the combination of RES)	There is no particular storage system in the district for the energy. However, the district's needs are covered at 90% by renewable energy through the mixing of off-site energy forms	Apart from the three (3) pillars that are considered in terms of the NZED's definition and framework, the transport policy adopted by the district's stakeholders has been adequate and effective representing the 80% of the residents' commuting. As a result, a significant reduction of CO_2 emissions is remarked linked to transport
	Despite the fact that some areas (e.g. transport) reach the goals of energy autonomy, generally speaking, the district of Hammarby **is quite far from the concept of net-zero energy**. The ambitions of the combinations of energy needs' optimization, of low energy hybridization and the organization of energy storage, are not truly achieved.			
BO01, MALMO	The objective of energy supply based entirely on renewables and a local production only seem to have been achieved according to the information published on site performance. Particular attention should be given in the case of demand increase and to the relevant resources' management.	The energetic hybridization is achieved in an interesting extent by the combination of the energy inventory, potential, and resources on the site.	Interesting storage systems for its organization	The district corresponds in an interesting extent to the strategic axis of the NZED optimizing the occupants' needs with the energetic hybridization (exploitation of potential and renewable energy resources) using systems for the organization of the energy, water, and waste. Combining with these achievements, a mobility plan for the encouragement of the green mobility is installed leading to an important CO_2 reduction
	The results of the district approach evaluating them in accordance with the systemic methodology and the three thematic axes prove its energy independence and the achievement of the majority of its initial goals as an 'eco-district' but also it consists and **interesting example of a district close to the goals of the NZED**.			
ECO-VIIKKI, FINLAND	Problematic the calculation on actual electricity and water consumption due to the building typology and occupants' behavior The optimization on transport needs is not achieved	The energetic hybridization is not achieved. Focus only on the solar gain	No specific system is organized for the storage in the district except for the recuperation of storm water and the natural passive ventilation	Evaluating the district of Eco-Viikki according to the three (3) pillars that frame the NZED, significant deficiencies are remarked.
	The results of the analysis of the Eco-Viikki district in the framework of a NZED prove that further policy targets should be reoriented towards its energy autonomy and independency. As a consequence, the case of Eco-Viikki district **is far from being considered as a NZED**.			
BEDZED, UK	Partially achieved initial goals concerning the optimization of energy needs (adequate satisfaction level concerning part of the services provided)	The energetic hybridization is partially achieved (only a combination of solar energy with photovoltaic panels is encouraged while the cogeneration system is abandoned. This becomes worse taking into account the fact that the potential inventory is inadequate	No particular system for the energy storage is registered at the district but interesting technologies for the reduction of water consumption are used	Evaluating the district regarding the three levers of the systemic approach of the NZED as considered, important deficiencies and problematics are remarked (mainly the obstacle at the organization of the energy storage)
	The district of BedZED has as its initial and principal key goal the zero carbon policy, an interesting target in terms of sustainable urbanism. Despite this fact and the relevant energy autonomy that the district gains, the main conclusion is that it remains **far from being characterized as NZED** as the energetic hybridization is low and there is a deficiency in the organization of energy storage.			

<table>
<tr><th rowspan="2">District</th><th colspan="4">EVALUATION : CONCLUSIONS</th></tr>
<tr><th>Pillar 1.
Optimisation of needs</th><th>Pillar 2.
Hybridisation of energy systems</th><th>Pillar 3.
Organisation of storage</th><th>EVALUATION AS A NZED</th></tr>
<tr><td rowspan="2">SOLAR VILLAGE, ATHENES</td><td>The initiative of the eco-village is the optimization of energy needs by using innovative technologies and particularly active and passive systems and principles of the bioclimatic architecture</td><td>The project tries to test 17 different combinations of active and passive solar energy systems with conventional heating systems in favour of the Mediterranean climate</td><td>No particular system for the energy storage is registered at the district</td><td>Evaluating the district regarding the three levels of the systemic approach of the NZED as considered, important deficiencies are remarked with the most important the lack of organization of energy storage</td></tr>
<tr><td colspan="4">The district of Solar Village, despite its innovative technologies and interesting concept, is <u>widely far from being characterized as NZED</u> as energetic hybridization is low and mainly because of the fact that there is no organization concerning the energy storage.</td></tr>
<tr><td rowspan="2">VAUBAN, FRIBURG</td><td>The optimization of energy needs for the occupants of Vauban is partially achieved. In terms of mobility, the adoption of the policies and targets seem interesting but the main problem remains the lack of quantitative data from its conception.</td><td>The energetic hybridization in Vauban is restricted but effective. Different systems are combined regarding the passive concept and the renewable energy resources.</td><td>There is no organization concerning the energy systems but interesting technologies about the recuperation of storm water and the transformation of waste to biogas are adopted.</td><td>Evaluating the district in accordance with the three pillars of the systemic approach of the NZED, significant problems are noticed (mainly the organization of energy storage but also the partial optimization of the occupants' needs).</td></tr>
<tr><td colspan="4">The district of Vauban covers only the second pillar of the systemic approach of the NZED (hybridization of energy systems) with crucial deficiencies to the others so it remains <u>far from being characterized as NZED.</u></td></tr>
<tr><td rowspan="2">KRONSBERG, HANOVRE</td><td>The optimization of energy needs in Kronsberg is achieved to a good extent. The balance sheets of housing and water consumption are good and the occupants declare a satisfaction level.</td><td>The energetic hybridization is quite effective with the combination of the wind potential and the installation of various systems (cogeneration, photovoltaic, solar panels, etc.)</td><td>The organization of storage is achieved in terms of energy and water and covers a significant part of the occupants' needs.</td><td>Evaluating the district of Kronsberg regarding the three pillars of the systemic approach of a NZED, the main conclusion is that important parameters are covered and reach the autonomy in energy.</td></tr>
<tr><td colspan="4">The district of Kronsberg is an interesting example of an eco-district that goes through the analysis of the three pillars and presents innovative actions towards the goal of the NZED. As a consequence, the district can be considered as <u>a good case-study for a NZED</u>.</td></tr>
<tr><td rowspan="2">GWL-TERREIN, AMSTERDAM</td><td>The planning and design of the district with the principle of car-free optimizes the occupants' needs in terms of mobility. However, the non-availability of data (for the actual needs but also their achievements) put constraints on the accuracy of evaluation conclusions concerning this pillar.</td><td>Despite the fact that various systems are used (focus on cogeneration, insulation, etc.), the inexistence of the energy potential limits the energetic hybridization in the district.</td><td>The organization of storage is partially achieved concerning the water (recuperation of storm water, etc.) and waste (composting, collecting and reuse) systems but not in the case of energy.</td><td>Evaluating the district of GWL-Terrein in accordance with the concept of NZED, significant deficiencies are remarked at the totality of its pillars.</td></tr>
<tr><td colspan="4">GWL-Terrein is an interesting exemplar eco-district of car-free but, however, it still remains <u>widely far from the characterization of a NZED</u>. If its stakeholders desire its transformation, further work should be given to the totality of its actions.</td></tr>
<tr><td rowspan="2">EVA-LANXMEER, CULEMBORG</td><td>The pilot project of Eva-Lanmxeer meets the occupants' needs in residential dwellings despite the difficulties of its territory (former farmland) as well as it is well served concerning the green mobility. However, the lack of certain data regarding the actual needs on energy needs (heating, electricity, etc.) put restrictions at the accuracy of the evaluation conclusions of this pilar.</td><td>The energetic hybridization is achieved in an interesting extent for Eva-Lanxmeer (focus on the combination of passive systems, photovoltaics, etc.), while systems are striving towards the balance of zero energy.</td><td>The organization of storage is achieved providing the district with an energetic autarky.</td><td>Evaluating the district regarding the three pillars defined for the NZED approach, noticeable remarks are registered with the most important concerning the second pillar (systems strive towards the balance of zero energy).</td></tr>
<tr><td colspan="4">Eva-Lanxmeer is an example of sustainable urbanism with <u>perspectives to be transformed into NZED</u>. Stakeholders proved that despite the difficulties, the district is able to meet the occupants' needs and promote actions towards the district's autonomy (storage, systems with a zero energy balance, etc.).</td></tr>
</table>

District	EVALUATION : CONCLUSIONS			
	***Pillar 1.* Optimisation of needs**	***Pillar 2.* Hybridisation of energy systems**	***Pillar 3.* Organisation of storage**	**EVALUATION AS A NZED**
PIC-AU-VENT, TOURNAI	The optimization of occupants' needs is achieved at a good level (bioclimatic design and 22 zero energy buildings). Reduction of energy consumption. Difficulties in district's accessibility. Problematic for the accurate evaluation the lack of data regarding the actual needs.	No specific energy inventory or potential. Energetic hybridization satisfactory with the combination of gas boiler and thermal solar panels. Focus only on solar energy.	Good organization of storage in terms of energy and water (recuperation) but problematic in waste collection and composting.	The district of Pic-Au-Vent is a pilot project with a bioclimatic design with steps towards the net-zero energy balance (already 22 of its dwellings are constructed following this direction). The project is ongoing and it has remarkable perspectives.
	Evaluating the district of Pic-Au-Vent with the criteria of the systemic approach of the NZED, we conclude that the project reaches a sufficient level its ultimate objectives. It can be considered as **an interesting example of a NZED** considering some improvements to take into account (e.g. the organization of waste composting, etc.).			