Linking energy efficiency and renewable energy to upscale positive energy districts

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Abstract

In recent years the EU has been moving towards a more decentralised structure, as the energy landscape evolves and the importance of communities being key to decarbonising Europe is recognised as crucial. Positive energy districts (PED) use the energy efficiency first principle coupled with green technology and renewable systems to achieve decarbonised neighbourhoods. This paper introduces the concept of Positive Energy Districts and shows how to handle energy performance targets by moving beyond individual buildings towards a district level. This is a relatively new endeavour in both scientific research and realised projects. One route towards this could be to have the minimum energy performance requirements imposed by the EPBD also be applied to a cluster of buildings in a specific district. In practice, this means setting legal requirements that enable communities to become zero or positive energy districts (for example through municipal or regional requirements). From a financial point of view, a zero-energy district (ZED) or positive energy district (PED) project needs to be investible whilst providing the municipality and district-dwellers with low-carbon solutions that provide co-benefits to the citizens and local authorities (such as, inter alia, better wellbeing and health, job creation, increased GDP and tourism). In order to assess potential cost and benefits, this paper finds the EPBD's cost-benefit calculation methodology for the setting of minimum energy performance requirements can be utilised on a district scale by aggregating the individual buildings.

Introduction

Humanity is highly vulnerable to looming changes in climate. The United Nations Intergovernmental Panel on Climate Change's latest report gives mankind no more than a decade to cut back emissions before irreparable damage is caused to the world's weather systems (IPCC, 2019). It is increasingly apparent that action needs to take place now, and fast, to keep our planet, countries, cities and communities safe and healthy in the future. This vital endeavour cannot simply be waged from a top-down, political, macro approach; community and neighbourhood actions are crucial in the course towards a transformational shift (Saheb et al, 2019).

The Covid-19 global pandemic in 2020 demonstrated the essential importance of strong links between community actions and local and global solutions. The environmental community views the response to the pandemic as an opportunity to press the global reset button and as a watershed for climate action. (Figueres, Tom Rivett-Carnac, Thornton, 2020). The idea of a global reset is encompassed in EU COVID-19 recovery strategies (e.g. the Renovation Wave, The Energy Sector Integration Strategy), the European Commissioner for Energy, Kadri Simson stating (European Commission, 2020, 'We must use this moment as an opportunity to accelerate the progress towards our climate neutrality goal. The Green Deal will be at the heart of that plan and energy will have an important role to play.' The next 10 years are critical to curbing emissions and transforming Europe into "the first climate-neutral continent" by 2050 (European Green Deal, 2020). In the European's Commission 'Clean Energy for All Europeans', communities and citizens are central to the decarbonising strategies for 2050 (RESCoop, 2017). The EU's Strategy for Energy System Integration envisages the evolution of the energy landscape towards 2050, as policies promote change towards increased decentralisation and distribution.

From an energy perspective, the process towards a decentralised, district approach presents openings for the achievement of cost-effective levels of high-energy efficiency and renewable energy systems. At a district level, efficiency measures on individual buildings lower the overall neighbourhood energy demand, while additional district level technologies, such as renewable energy systems, local energy networks and energy storage, can offer very cost-effective solutions, thus establishing a performance guarantee in carbon savings and promoting investor confidence (Nematchoua, 2020 and Webb, 2019).

The aim of this paper is to understand the optimal management of energy performance targets through a change in emphasis from individual buildings to a district level. This is a comparatively fresh approach in both scientific research and realised projects. Practically, legal obligations to promote and assist communities in becoming ZED or PEDs are needed at city or regional level. In addition, a ZED or PED project needs to be investible and to provide the community and stakeholders with low-carbon solutions plus co-benefits to the citizens and local authorities (such as, *inter alia,* better wellbeing and health, job creation, increased GDP and tourism).

To assess potential cost and benefits, this study finds that the aggregation of individual buildings can enable the use of the EPBD's cost-benefit calculation methodology for the setting of minimum energy performance (MEP) requirements at a district level. This refers to both energy efficiency assessment and RES measures on-site and nearby to reach minimum or cost-optimal energy performance and the inclusion of district level renewable energy.

Objectives and Methods

This paper considers the performance needs of an energy district and investigates ways of setting positive district targets in relation to energy efficiency and renewable energy. The main objective of this study is to suggest a methodology to aid developers and policy makers in establishing cost-optimum positive energy districts. The approach proposes the adoption of the EPBD's cost-optimal calculation methodology for performance targets. This strategy can be employed by a range of stakeholders, communities, developers and local, national and EU level policy makers. Primarily, the study discusses performance aspects and guides local municipalities, urban planners and national policymakers by providing a roadmap for use in designing: national level: A policy to legislate and enable PEDs and district level: An individual PED project.

The study adopted a three-layered approach, founded on expert knowledge and the scientific literature published since the recent 2000s. More than twenty stakeholders working in the field of energy efficiency and renewable energy and specialising in energy districts were interviewed. Additionally, a review of the scientific literature was carried out to examine possible methodologies for handling minimum performance requirements at district level. Finally, the interviewed experts reviewed and commented.

The specialities of the interviewees are broad ranging and geographically diverse. Participants have experience in the field of building energy efficiency, renewable energy and experience in ZED/PEDs projects policies or financing, this includes; Global implementers of policy in the fields of EE and RE; Researchers of current methodologies for ZEDs and renewable energy communities; Developers of building codes across Europe; Developers of building codes across America (ASHREA and ICC); Developers of localised or national nearly zero energy projects; Members of EU ministries handling building regulations; Third party experts from Non-Governmental Organisations working on energy efficiency and renewable energy in buildings; and Industry stakeholders.

The literature review examined around fifty papers and recently published findings – peer reviewed studies in journals, case studies of low carbon districts, energy modelling tools for energy districts, grey literature from websites, databases and reports from sources such as Research Gate, Google Scholar, Science Direct and Horizon 2020 projects. Furthermore, the interviewees furnished many of the reports and online sources and the interviews fed into the literature review.

Literature review

The process of establishing a zero or positive energy district involves consideration and identification of the diversity of the energy interplays in the buildings' different energy performances and production capabilities. This opens up the possibility of sharing the neighbourhood's energy needs, costs and resources (Amaral, 2018b). Thus, a ZED can provide much more scope for optimisation than a single building (Sameti and

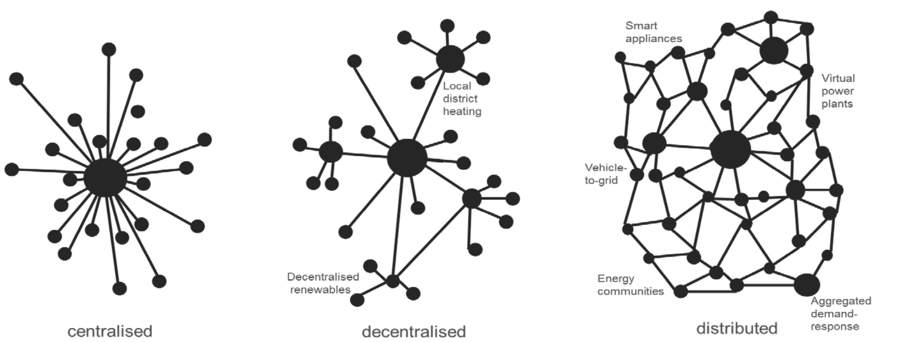

Figure 1. Centralised to distributed systems (including EU policies). Source: Hoos, 2020.

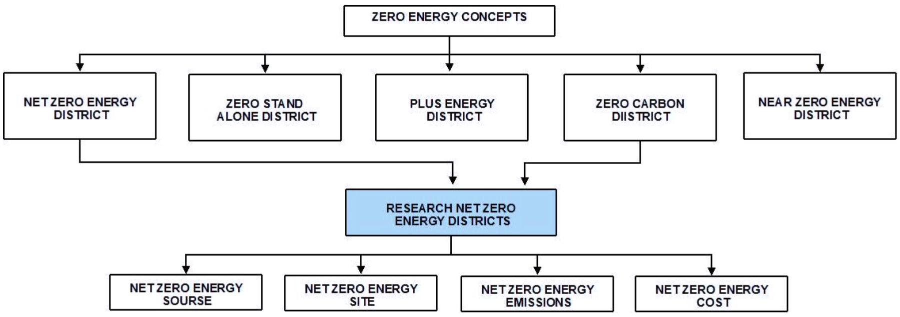

Figure 2. Zero Energy District Concepts. Source: Laustsen, 2008.

Haghighat, 2018). Building systems can be specifically designed and can have tailored load profiles to enable the high utilisation of carbon-free renewable sources, such as wind and photovoltaics (PV) for the electricity demand and heat pumps, thermal waste, geothermal, solar thermal, etc. for the heating and cooling demands (Olgyay and Campbell, 2018). Furthermore, a district can use "energy cooperation" or "energy pooling" to enable communities to own their local renewable energy.

Thus, the PED/ZED approach can address many of the concerns raised by individual NZEBs, it permits better-managed demand and flexibility in generation and the mutual influence of buildings and their surround urban areas enhance their energy performance based on being about to use the renewables available on-site or nearby (Koutra et al 2017). For instance, districts can use a range of energy resources and, due to a larger area, are more flexible. However, increasing the scale of intervention from building to district will make energy performance assessment and design factors more complex (Eržen, 2017).

Envisioning the district will show clusters of buildings of varied typologies and energy profiles powered by renewable energy farms and building integrated RE systems, all connected to centralised and/or aggregated storage facilities and smart distribution networks. Districts should also make provision for future technical advancement in electrical and energy equipment, these might encompass; Local climate change over time requiring more AC or heating; Energy systems such as the replacement of cogeneration units; Social changes such as increased/decreased energy needs and demographics; and Vehicle fleets changing in terms of infrastructure and electrification.

Primarily, a zero or positive energy district necessitates that the all stakeholders collaborate to develop the best-fit solution for their community to enable citizens and authorities to play their part in finding solutions to the climate crisis. With an enabling policy framework, communities should be able to develop their own district concepts (Williams, 2016). The interactions between different building typologies and RE systems of an energy community/district require that future revisions of the EPBD and building codes should include such enabling frameworks to support different districts to optimise their ZED transitions (Sameti and Haghighat, 2018).

Although the terms 'zero energy' and 'energy community' are in use, no absolute definition is contained in current European legislation. In spite of this, there are many tools in the CE4E package to assist citizens, local communities and national authorities to develop these districts (in particular REDII, EPBD, EED) (Hoos, 2020). Furthermore, the 2019 Green New Deal puts a strong emphasis on citizens and communities, for example in their *Climate Pact* and *Renovation Wave Programmes.*

To this date, the only district or community definition can be found in the REDII, that states a **'renewable energy community'** means a legal entity: a) which, in accordance with the applicable national law, is based on open and voluntary participation, is autonomous, and is effectively controlled by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity; b) the shareholders or members of which are natural persons, SMEs or local authorities, including municipalities; c) the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits.

In the EPBD, the definition for a NZEB is "a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby" (Directive 2010/31/EU, Article 2(2)). This definition could include these concepts at a district level. Similarly, most scientific publications and definitions of a ZED consist of these very same components (Jalala, 2016, Laustsen, 2008, Cortese & Higgins, 2014, A2PBEER, 2014, seen in the list below Figure 2.

The EPBD's long-term building renovation strategies' (LTRS) objective is the "transformation of existing buildings into nearly zero-energy buildings" (Article 2a, EPBD). As part of this, Article 2a says the Commission has promised to "collect and disseminate, at least to public authorities, … information on schemes for the aggregation of small-scale energy efficiency renovation projects … best practices on financial incentives to renovate from a consumer perspective". This aims to mobilise investment for aggregated renovation projects.

Essentially, a ZED is a group of buildings (a city district, community, village, cluster of buildings or campus) with the declared ambition of achieving zero or positive energy, producing at minimum an equal amount of primary energy as they consume and whose remaining energy demand is met by onsite or nearby renewable energy. The concept of a ZED can also be described thus, Net Zero Energy Districts, Plus Energy District, Zero Carbon District, Nearly Zero Energy District (Laustsen, 2008), as per Figure 2.

Each of the definitions has similar meanings, however they differ thus: Plus Energy Districts: supply more renewable energy to the grid than they use, producing more renewable energy than they consume. Net Zero Energy Districts: deliver the same amount of energy to the supply grids as they use from the grids, and do not use fossil fuel for heating, cooling, lighting. These districts are connected to the national grid for backup and energy exchange. Zero Stand Alone Districts: are not connected to the grid and are independent in generating their own renewable energy supply with the capacity to store energy in storage systems such as batteries. Zero Carbon Districts: do not use energy from any carbon dioxide emitting sources (e.g. biomass, biogas excluded) and over the course of a year will either be carbon neutral or positive energy, they produce enough energy so that their energy demand is always at most zero. Nearly Zero Energy Districts: have a very high energy performance but do not always reach a zero-energy target over a year, most of the remaining energy demand is provided by onsite or nearby renewable energy. Using the EPBD, the REDII and scientific research as a basis, a PED or a ZED is an area with defined borders that:

- Is based on open and voluntary participation, autonomous, and effectively controlled by its citizens.
- Whose primary purpose is to provide environmental, economic or social community benefits.
- Has an overall energy balance of zero or positive over a year.
- Has buildings with very high energy performance, complying with applicable minimum energy performance requirements and local building codes.
- Has buildings with a nearly zero or very low amount of energy demand.
- Has its building demand covered to, at least, a very significant extent by renewable energy sources.
- Where renewable sources are produced on-site or nearby.

As aforementioned, an energy community requires that all stakeholders buy into, engage with and cooperate to develop the best-fit solution to enable citizens and municipalities to play their role in the energy transition. This implies that social innovation, including behavioural change, must be considered and transformed to deliver ZEDs. It is not sufficient to merely amplify when upscaling from a building to a district level. Some requirements will remain the same, others will have to be modified or added.

To achieve a ZED, the community should have the objective of a zero, or positive energy balance. The timescale this depends on several factors. Planners need to calculate the overall energy demand of the district and match this with renewable energy systems, single building units and whole district energy plants or farms (Ala-Juuselaa et al, 2016 and Admaral, 2018). The design must take account of residents' needs and consider the district as a whole. Factors to be considered include; The district's boundaries; The location of the district; The geographical and urban morphology of the district (the form of the settlements); The building characteristics in the district; The characteristics of the district/building occupants; The energy demand before and after energy efficiency measures; The natural resources available for maximising the use of onsite and nearby renewable energy; and The balance between the energy production and energy consumption (including buildings, production of on-site renewable energy).

When developing a ZED, it is vital to consider the factors that make up the energy balance and how they interact to ensure the target can be met. However, it is important to note that the reduction of energy and carbon are not the sole drivers. In the Sustainable Development Goals of the United Nations and the objectives of the EU's CE4E and Green New Deal packages, the objective is to ensure that the measures also benefit consumers, growth, jobs and the planet (Becchio et al, 2018).

DEFINING DISTRICT TARGETS: METHODOLOGIES FROM LITERATURE

This section outlines and describes the approaches developed by other researchers and projects to define a PED. The list is not exhaustive but offers a basis for understanding and has been key to the generation of this paper's methodology. The reports demonstrate the importance of an accurate evaluation of the district energy demand for use as a baseline. Many of the studies below give procedures for the calculation of this, thus enabling designers to project district energy performance when ZED measures have been put in place. Table 1[1] shows each strategy's objectives, metrics, design parameters and methodologies.

Koutra et al. 2018The studies examined from a district level have been used to produce a variety of models to simulate improvement in overall energy and carbon performance of the district. For this paper, methodologies using a holistic approach and taking account the territorial scale of the district have fed into the recommendations and conclusions of this report. Studies utilising the EPBD as a basis for establishing district level targets were crucial in developing a simple methodology to enable communities to develop accurate performance targets for PEDs/ZEDs.

Interview outcomes

The specialist interviews provided a wealth of innovative ideas for methodologies. Despite this variety of approach, experts concurred that performance targets are required for individual buildings as well as the district as a whole. The suggested performance targets ranged from zero or positive energy overall, which would permit some flexibility through trading between buildings (allowing some buildings to be less efficient and other to be energy providers), to stringent component-by-component targets. Some of these possible solutions included district performance targets based on:

1. The EPBD's cost-optimisation methodology.
2. Monitored data.
3. Cost-optimisation through energy modelling or tools.
4. Energy Balancing – transactional trading system between buildings.
5. A positive energy district, not a zero-energy district.
6. Multiple benefits coupled with cost-optimality calculations.

1. Full citations can be found in the reference section.

Table 1. Methodologies, Tools and Metrics of Zero Energy Concepts.

Purpose	Method	Metrics/ Type of Energy	Parameters considered	Sources
Adaptable and affordable Systemic Public Building and District retrofitting Methodology	Tackle retrofitting from the building and district scale. Analysis of the target building/district to characterise the current conditions through Key Performance Indicators, which are compared to benchmark values in order to identify the relevant technical retrofitting gaps. Different units are proposed to establish the amount of expected reduced emissions.	(Ton CO_2). CO_2 (g/kWh). CO_2 (g/kWh). GHG (CO_2, N_2O and CH_4) (NO_x, SO_x)	Buildings: heating, cooling, ventilation, appliances, cooking, DHW. Transportation: distance, means of transportation, relative consumption rate. High performance envelope retrofitting, smart windows, smart lighting. District heating based in smart grid functionality and integration of heating and cooling, deploying adaptable and affordable solutions.	A2PBEER 2018
Cost-optimal energy renovation strategy for a building during its whole life cycle	Life cycle cost (LCC) optimisation software.	Annual energy demand of the building after renovation	U-values of the building, air change rate, indoor and outdoor temperatures, costs and performance for different components and energy efficiency measures, energy prices and the real discount rate.	OPERA-MILP, 2017
Mobilisation of innovative design tools for refurbishing of buildings at district level	Guidelines for energy performance assessment in step wise district-level energy refurbishment. Looking at Potential technological alternatives for building refurbishment, Energy saving potential in the district, GHG saving potential in the district, Potential use of local renewable energy in the district and Refurbishment cost on district level.	CO_2, kWh/m², €	Enables the comparison of different alternatives of RES systems, holistic energy-system design at district level, activation of refurbishment effective design management.	MODER, 2015
Highest possible energy saving for districts, considering the global costs and market barriers	Classified the existing residential building stock & developed refurbishment scenarios with energy efficiency measures, global costs and subsidies. Developed a calculator sheet to combine the several results and to achieve urban scale cost-optimal refurbishment solutions based on user defined scenarios.	Minimum energy performance	Energy efficiency measures. District heating/cooling systems and installation of renewable energy technologies in addition to the ones installed on-site.	T Zachariadis · 2018.
Assess the energy performance of various energy concepts for settlements	Software tool, the District Energy Concept Adviser. The calculation core is the German procedure for single building energy performance certificates (standard DIN V 18599) and was extended by calculation methods for local central energy systems.	Final and primary energy demand, the CO_2 emissions and the renewable energy rate.	Defines district based on archetype buildings with a fixed geometry but adaptable building envelope quality, building-wise service systems, local central energy systems (e.g. local district heating and cooling systems) and energy generation from renewables.	Energiekonzept-Berater für Stadtquartiere, 2021
Support urban decision makers in assessing district energy at the early planning stage(s)	Using Spatial Planning (GIS): Unofficial District EPC. Benchmarking district final and primary energy based on the proportion of residential and non-residential buildings in the district.	Final and primary energy	Same standard as the single building energy performance calculations.	IBSA, 2018
Provide a platform for displaying geo-coded EPCs	ENERFUND provides the base map is an open data map and ratings for each address to help identify areas for deep renovation. Based on a set of parameters.	EPCs, no. of certified installers, governmental schemes running, etc.	Geo-coded EPCs.	ENERFUND, 2019

The table continues on the next page … →

Table 1. Methodologies, Tools and Metrics of Zero Energy Concepts – continuation.

Purpose	Method	Metrics/ Type of Energy	Parameters considered	Sources
Deep Retrofit Pilot Programme	Policy measure requiring renovations to Building Energy Rating (A3 standard).	Primary energy use per unit floor area per year (kWh/m²/year)	Deep retrofit works. Whole house solution with a fabric first approach.	SEAI, 2017
Energy demand for heating and cooling of neighbourhoods	Dynamic simulations (EnergyPlus). Study of energy demand for heating and cooling of neighbourhoods according to housing units' shape.	Total annual energy use. kWh/y	Buildings' shape, density, site layout.	Hachem, Athienitis, Fazio 2012
Design parameters on energy performance of neighbourhoods	Dynamic simulations (EnergyPlus). Analysis of the impact of design parameters on energy performance of neighbourhoods.	Total annual electrical energy use. GWh	Buildings' energy performance level (local statistics), density, district typology, CBD relative location, streets' design.	Hachem 2016
Assessment of the impact of urban form on districts' energy needs	Buildings: sum of energy consumption for heating, cooling, ventilation, appliances, cooking, DHW + Transportation: Energy consumption for daily mobility.	Primary energy. kWhp/m²/year	Buildings: heating, cooling, ventilation, appliances, cooking, DHW. Transportation: distance, means of transportation, relative consumption rate.	Marique & Reiter 2014
Evaluation of overall energy demand of existing neighbourhoods	Buildings: Energy Performance Index for each building +. Transportation: transport energy indicator +. Outdoor lighting: electric energy consumption per unit area of public space.	Primary energy for heating. kWhp/m²/year	Buildings: opaque and transparent envelope surfaces. Transportation: distance, means of transportation, number of trips. Outdoor lighting: number and type of lamps.	Fichera et al 2016
Development of a methodology for evaluating NZED's	Dynamic simulations (URBANopt).	Electricity use for heating and Cooling. kWh	Buildings: orientation, window-to-floor ratio, envelope characteristics, airtightness. Solar potential: orientation, roofs slopes, avoid building-to-building shading.	Polly et al 2016
Evaluation of energy consumption of different neighbourhood scenarios	Dynamic simulations (ENVI-met).	Electricity use for cooling. kWhp/m²/year	Urban layout pattern, street width, street orientation.	Sosa et al 2018
Development of a methodology for evaluating NZED's	Function of Users, Buildings, Infrastructure, Industrial Activities, Mobility, Other requirements.	kWh	Buildings: heating, cooling, appliances, DHW.	Koutra et al. 2018

7. A life-cycle approach to a carbon neutral district.

A popular and viable approach amongst the interviewees was the application of the EPBD's cost-optimality methodology to each building and the subsequent aggregation of this to district level, thus both enabling building-based renewable energy on the building plus onsite or nearby renewable projects to be incorporated into the cost-optimality calculation.

The specialists all agreed that individual buildings should have an individual minimum performance target, to be set via use of measured data or the use of reference buildings, as encapsulated in the EPBD methodology. Using these targets, an aggregation exercise can be carried out to determine the overall district performance target.

The experts proposed that individual building targets are set based on a minimum performance level from cost-optimality calculations. In some areas, these may already be a available from local building codes. The interviewees also proposed that, in future, the cost-optimality calculation include life-cycle analysis of costs and carbon reductions of the measures undertaken and also include the multiple benefits to the community, economy and environment.

All interviewees were in accordance that the Energy Efficiency First principle should guide the process, roughly speaking, this implies that the district should not aim for nearly or net zero, but positive energy and carbon neutral. It is tricky to achieve an exact "zero" and the positive energy goal will speed up the transition to carbon neutrality.

Approach to developing a Positive Energy District

A district being a community of buildings, as targets can be developed for distinct buildings, it is feasible to combine these to achieve a district target in kWh/m^2/year. From interviews and the literature, this research has generated a strategy for the definition of a district energy performance target. This methodology sets out the steps to enable the development of a cost-optimum positive or zero energy district. The approach enables the least costly ("cost-optimal") route to meet zero or positive-energy targets. To meet the EU Green Deal and the Paris Agreement targets, the following should be taken into account when developing a PED or ZED:

- Fulfil the EE requirements of the local building code
- Optimise EE versus RES
- Optimise the supply of the remaining demand by onsite RE (in district)
- Optimise the supply though a separate grid system

Individual district targets can be defined in such detail as developers wish, for example, simply by aggregating all individual buildings in the district and dividing by floor area to give a whole district building target. To meet EPBD requirement, buildings should adhere to the local building code's minimum energy requirements. Developers would then have a picture of the district's demand before and after the energy efficiency measures and what further RE (onsite or nearby) needs to be supplied. The district would therefore have an "optimal" targeted performance and related renovation measures/packages rather than a "minimum" energy performance (Olgyay and Campbell, 2018). The overview of the key steps in this methodology are listed in Figure 3 and described in the following sections.

Points 1–3 are to be based on the building EPCs and other available district data. Fundamentally, a district's energy performance (EP) target should follow EPBD outlines and local building code legislation and a "lowest-cost" or "cost-optimum" energy performance can be calculated and combined to find the kWh/m^2 for the group of buildings, this should include renewable energy. Examining alternative district level energy system solutions will potentially be complex due to the range of different system components (combination of energy efficiency levels, building integrated systems, shared systems, energy storages, connections to energy networks and grid, smart control, etc.). Some important points regarding this novel methodology are:

- The macroeconomic cost-optimality calculations are crucial in determining the district target linked to an EE and RE strategy, these specify the societal multiple benefits. However, return on investment is likely to be more important to the private sector and project developers than the "optimal-performance" for society. Therefore, linking these macroeconomic aspects to private sector interests is important.
- The approach may be perceived as complex due to the potentially high number of technological combinations.
- The data for these calculations probably exist but are dispersed.
- This 8-step process has been developed for policy makers; however, the real estate sector should be consulted to ensure that the process is feasible.
- Therefore, case studies should be undertaken in a range of countries to explore the practicality of the methodology, and to allow fine-tuning of the approach.

STEP 1: DISTRICT BASELINE STUDY

In order to understand the role and interplay of buildings in the district, a baseline study should be undertaken of the building stock (Deakin and Reid, 2018). This assessment should include; District boundaries; Climate properties; Type and number of buildings; RES potentials for buildings and the district; Period of construction; Building locations; Distances and shading patterns; and District energy system configuration.

The ways in which the design parameters can be adjusted depends largely on the characteristics of the buildings, whether the district is formed of new builds or is an urban regeneration area with old stock, or a mix of old and new. The development of an existing district will not permit a great deal of change of the design parameters, however, the intervention points can be highlighted during the baseline study of the district. For the overall transformation of a district, there are three key perspectives, the thermal performance of buildings, user behaviour and alteration of the operation of buildings and user behaviour and enabling new energy technologies and infrastructure.

These roles are interconnected and crucial to ensuring cost-effective zero-energy system solutions. The characteristics of

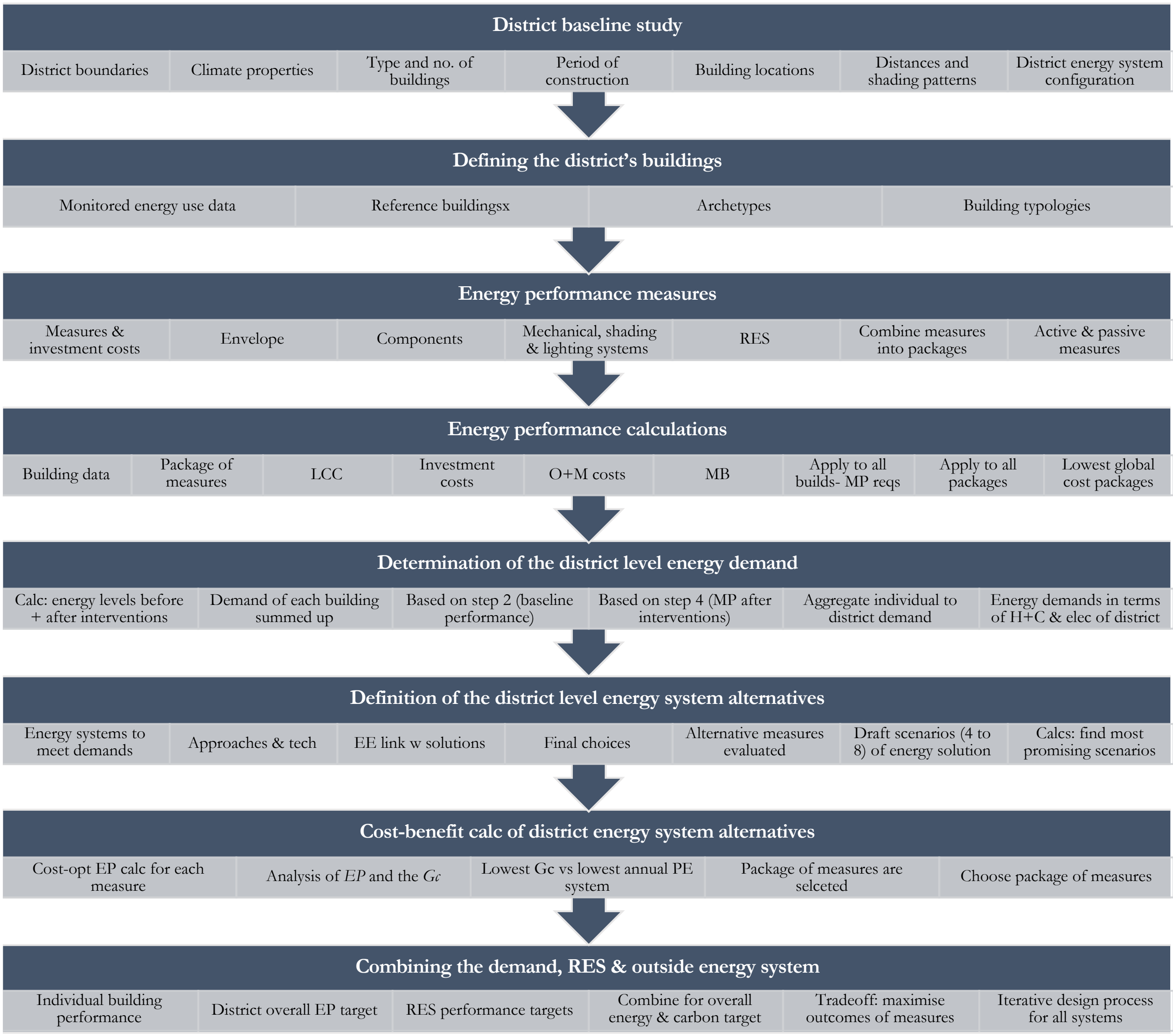

Figure 3. Steps to Developing a PED Strategy.

the district must be clearly understood by developers. The district boundary must be defined to ensure that data is accurate and that building system energy flows can be estimate. The level of data required for the baseline assessment is linked to ensuring a "smart" location and "smart" morphology (Deakin and Reid, 2018). Climate and weather conditions, natural resource potentials and locations, land uses, meteorological data and the functional autonomy of the district must be taken into account. Developers should also consider density (both residential and population), orientation and the spatial urban design and the compactness of the district (Kılkış and Kılkış, 2019).

At this point, a rough calculation of the energy consumption of the baseline case should be undertaken to enable evaluation of the success of the ZED measures.

STEP 2: MAP THE EXISTING BUILDINGS IN THE DISTRICT

In the district's building stock, there will be a range of building typologies, ages and sizes. There are various methods of analysing these to establish the energy performance measures to be undertaken, including: monitored building energy use data, reference buildings (real examples), and building typologies (corresponding to common buildings). It is recommended that any monitored data be used, if available, to establish each building's energy consumption (Jassens et al, 2017).

STEP 3: DEFINING ENERGY PERFORMANCE RELATED MEASURES

Part 3 involves the recognition of existing energy-efficiency measures that can be undertaken in the district. After establishing each building's energy performance, a list of measures to improve this can be drawn up, together with their investment costs. Factors such as envelope, components, mechanical system, shading, lighting systems and renewable energy systems should be considered at this point. These measures can be combined into complementary packages.

As in the EPBD and most MS building codes, new buildings should fulfil NZEB requirements. District renovations should adopt similar methodologies. It would be advisable to exceed the building code's requirements and renovate as deeply, to zero or positive energy if possible.

Measures considered can be active or passive, each measure and component will have a different lifespan, and from a cost-optimal perspective it is important that the high-value long-term energy savings are achieved first. Modification of the building envelope is essential to lower energy demand and active systems can then be installed/adapted to the new building demand. Developers must ensure that all strategies are appropriate to the characteristics of the building.

STEP 4: ENERGY PERFORMANCE CALCULATIONS

From the baseline and packages of measures, the cost-optimality calculations can be applied to the buildings to establish minimum performance values. At this stage, any buildings unable to achieve NZE should be identified. They will be compensated for by other buildings in the district and this is be dealt with in step 8. A minimum performance calculation will be undertaken for each identified package of measures, input data will include energy performance as annual primary energy consumption and global costs, including the investment costs, long-term operating and maintenance costs, Life Cycle Assessment (LCA) and the Life Cycle Costing (LCC) and multiple benefits (Becchio et al, 2018 and Kalaycıoğlu and Yılmaz, 2017).

In the cost-optimal calculations, the lowest cost package of measures for each building and aggregated buildings that will provide a positive or zero energy solution will be selected as the "cost-optimal solution". This permits the comparison of different scenarios, technologies and renewable methods. The main outputs for the evaluation are: Global cost, taking into account initial investment, maintenance cost, substitution cost of the current HVAC systems, energy consumption cost and the cost savings of the multiple benefits; Net Present Value (NPV) and Payback Period (PBP), using savings as a cash-flow to recover the investment; Primary energy (PE) consumption and related GHG emissions; Cumulative cost of energy consumption and saving depending on the horizon of calculation (for LCC); Embodied energy and related emissions taking into account materials and energy use (for LCA).

The EU (EU 244/2012) proposes this cost-optimal calculation methodology for establishing optimal levels as a function of costs for the minimum energy performance requirements. The global cost represents the current value of the initial investment cost, operating cost (including energy, operating and maintenance costs), periodic replacement costs, and final disposal costs. Buildings and districts will enjoy benefits, amongst which are: Economic; Energy and social security; Health and wellbeing; and Environmental and biodiversity.

These can and should be included into the cost-optimal calculations and can be added to the global cost calculations. Also, a life-cycle analysis can be made of the components, measures and environmental considerations that are included within the cost-optimality analysis. This establishes the amount and cost of carbon during the lifetime of the project. LCA and the LCC (ISO 15686, 2008) are the established standards to be used for this.

STEP 5: DETERMINATION OF THE DISTRICT LEVEL ENERGY DEMAND

Through calculating the baseline and post intervention of energy levels, the district energy demand can be defined, which shows the energy saving potential of the district. Each building's energy demand will be calculated and then aggregated to reach the total district energy demand.

STEP 6: DEFINITION OF THE DISTRICT LEVEL ENERGY SYSTEM ALTERNATIVES

As the cost-optimal calculations provide the district energy demand, the developers are able to understand and employ the appropriate systems for heating, cooling and electricity. Conceivable approaches and technologies should be evaluated in terms of life-cycle assessment, energy consumptions, investment costs and long-term management costs. There are a range of available options, combining the energy efficiency levels with building integrated systems, shared systems, energy storages, connections to energy networks and grid, smart control, etc., and the final choice will depend on the climatic conditions, individual and district-wide demands, technical capacity, and natural resources within the district.

In terms of thermal district systems for heating and cooling, a broad range of options and technical systems already exist, therefore the measures evaluated by the developers will depend on site-specific opportunities and limitations (Kalaycıoğlu and Yılmaz, 2017).

Developers should examine the following possibilities from the broad spectrum of renewable energy technologies exist in Europe and each MS:

- Large electricity farms including wind, solar, tidal and wave
- Heating and cooling including district heating and or cooling plants, biomass, geothermal; solar thermal, heat pumps, etc.
- On-site building level energy generation including heat pump systems, PV, wind, solar electric, photovoltaic (PV), solar thermal, solar hot water (domestic water heating and space heating), solar ventilation air preheating and geothermal heat pumps.

STEP 7: COST-BENEFIT CALCULATIONS OF THE DISTRICT'S ENERGY SYSTEM ALTERNATIVES

A cost-optimal energy performance calculation can be made for all potential measures to be undertaken. The cost-benefit analysis will analyse the *energy performance* (as annual primary energy use) and the *global costs* (including the investment costs together with long term operating and maintenance costs) (Becchio et al, 2018). The lowest cost option which meets or exceeds the community's energy demand should be selected.

Calculations should be undertaken during the selection process to examine different scenarios for different measures and combinations of measures. Sometimes the district's catchment area might be too small for RES to supply the energy demand required by the community. In this case, it may be useful to consider the community in relation to neighbouring areas. ZEDs and PEDs should not exclude a wider regional approach and the boundary of the district could be reconsidered.

STEP 8: COMBINING THE BUILDING SOLUTIONS, RES SOLUTIONS AND OUTSIDE ENERGY SYSTEM

To achieve an overall energy and carbon target of zero or positive energy for the district the individual building performance, the district energy performance target and the renewable energy systems performance targets should be combined and maximised. For example, step 4 assesses the buildings incapable of achieving a nearly zero energy target and, at the same time, identifies potential energy producing buildings which can compensate through trade-off. Therefore, an iterative design process is required to account for all systems and their interactions, including all associated costs and value streams, minimising the carbon emissions of the district. This step will provide district scenarios, and analysis of the selected positive or zero energy scenarios can be undertaken by the developers in order to find the optimum energy performance at the lowest cost.

The relationship with the outside energy system will depend on the consumption and production peaks of the district. ZEDs or PEDs should not operate in isolation but rather integrate with the wider energy system. They are likely to have overproduction and consumption peaks and developers will have to take these into account when planning the district. The district will have security of supply as backup for peak demand as it will be connected to the grid, and also able to export surplus energy.

SUMMARY OF PED PROCESS

This 8-step approach is an initial endeavour to produce a methodology for the development of district targets and optimisation techniques for use on a range of policy or implementation levels. The approach has used the existing EPBD formula and framework of cost-optimality and applied it to a procedure for districts.

It is crucial to establish the district baseline before target setting, and this will vary with location and climate. Hence community targets will differ; some regions/districts will have the technologies and climate to reduce demand in their buildings while others will have the natural resources enabling the supply of energy. A multi-mechanism approach must be taken in order to find the optimal best fit solution for each particular district, based on the Energy Efficiency First principle. Cost-efficient solutions for each district can be found using the EPBD's cost-optimal mechanism.

Discussion

The literature review and the interviews undertaken in this study came to the consensus that *it is possible to develop cost-optimal energy performance targets for a ZED,* although there are still some barriers to wholesale application. The EPBD's cost-optimality calculation methodology, designed to calculate the minimum performance of individual buildings, can, with some adaptation, allow for minimum district performance requirements to be defined following an 8-step process, resulting in a locally adapted energy performance target of zero or positive energy and an optimised zero or positive energy district solution. As each district is different so the processes for this will vary, depending on the morphology and building typology of the district, for example, it will be more straightforward applied to a new district rather than in the renewal of an existing one.

The 8-steps to developing a district target and finding optimisation solutions are:

1. District Baseline Study
2. Map the existing buildings in the district
3. Defining energy performance related measures (individual building EE and RE systems)
4. Energy performance calculations
5. Determination of the district level energy demand
6. Definition of the district level energy system alternatives
7. Cost-benefit calculations of the district's energy system alternatives
8. Combining the building solutions, RES solutions (building and district level) and outside energy system

This Report provides a fuller understanding of how targets can be set by districts and how policy makers can provide an 8-step methodology, guiding MS and developers on the procedure to develop a PED. The general conclusions of the paper, in line with the views of the interviewees and literature review, are:

- A **methodology for defining a PED target has been defined** based on a general consensus amongst the experts interviewed; this approach was also reinforced by some of the reviewed literature reports.
- The **districts should be positive energy districts** (not nearly or net zero) supported by smart grids and renewable and efficient technology.
- **The energy efficiency first principle is used to guide the district's target,** although it is imperative to ensure RES are included within the district's plans.
- In order to develop a performance target for the district, the **individual buildings within the district should follow the EPBD's methodology** and local and national building codes in order to establish their minimum performance targets.
- For the individual buildings, the **minimum performance targets are to be found either using measured data, reference buildings or archetypes** of the building typologies within the specific district.
- To find the minimum performance in a cost-optimal manner, the EPBD's **cost-benefit calculation methodology can be utilised on a district scale** by aggregating the individual buildings.
- **Renewable energy solutions are to be included** within the cost-benefit calculation methodology at building and district levels.
- In order for the targets to be realistic and investable, **the cost-optimality calculation methodology must take account of the life cycle costs and life cycle carbon of the efficiency and renewable interventions into account** (e.g. CO_2 emissions and costs of each measure), ensuring the carbon footprint of the district is accounted for and is neutral.
- **The multiple benefits of a PED are to be included within these calculations** in order to be accounted for and valued. Not only will this encourage project investment, it will also help the community to understand the benefits of a PED, individually and as a community.
- Going forward, policies addressing the built environment should seek to include a district or portfolio approach, such as the EPBD.

It is important to test this 8-step methodology on actual PED projects going forwards. Practical trialling can be done through collaboration with developers and municipalities planning to undertake such projects. In addition, it could be tested on finalised or PEDs/ZEDs in the development stage to compare results with the final decisions made. If baseline data for case study projects is available, this methodology can be applied, fine-tuned and further developed.

This report elucidates an 8-step process endorsed by building specialists that will allow project developers not only to have a district target but also to be able to develop a district energy strategy. Following the 8 steps will provide the project with a renewable energy and energy efficiency roadmap with a cost-optimal methodology for the design and development of a zero energy or positive energy district.

Zero energy districts are an interesting area for future research and policy making. It is expected that further research will be undertaken building on the experiences and best practices from Member States and taking into account both the revised legislative framework and the upcoming Renovation Wave.

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