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Enabling Positive Energy Districts across Europe: energy efficiency couples renewable energy

Shnapp, S.

Paci, D.

Bertoldi, P.

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Contact information
Name: Daniele Paci
Email: Daniele.paci@ec.europa.eu
Address : European Commission, Joint Research Centre, Via E. Fermi, 2749. 21027 Ispra. VA, Italy

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ABSTRACT

This report aims to understand 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 (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.

1. INTRODUCTION

The United Nations Intergovernmental Panel on Climate Change's latest report states that there are 11 years left to save the planet before an irreversible climate catastrophe is triggered (IPCC, 2019). Increasing evidence shows that the battle against global warming is of greatest urgency and should be fought not only at macro level (global or national) but also at local level: local authorities are required to be an active part of the transformation of energy use and production needed for the survival and well-being of their citizens (Saheb et al, 2019). This year, 2020, the world was confronted with a global pandemic (Covoid-19) that further stressed the importance of community actions being linked to, and supported by local and global solutions. The district scale can be considered as an "*optimal scale to accelerate sustainability, small enough to innovate quickly and big enough to have a meaningful impact.*" (EcoDistricts, 2013).

In his book, 'The 3rd Industrial Revolution', Professor Jeremy Rifkin says, *"our houses must become a power plant using geothermic, solar, wind… even rubbish will be a major source of energy"*. This model is based on a convergence of energy and communication and follows the concept of 'zero energy' that is being regarded in scientific literature, EU and global policies as a way to combat climate warming, alleviate energy demand, prevent the depletion of resources and adopt alternative renewable sources of energy.

A recent report published by the JRC reviewed sixty-one low carbon districts across Europe, providing novel insight into the ingredients used by frontrunner European municipalities (Saheb et al, 2019). The report found that highly energy-efficient buildings were at the cornerstone of every low carbon community, hence the importance of getting the right policy targets in place. Within the European Union's (EU) Directive 2010/31/EU (the Energy Performance of Buildings Directive, from hereon on called the "EPBD"), the concept of Nearly Zero-Energy Building (NZEB) has been defined as "*a building that has a very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*" (Directive 2018/844/EU, Article 2(2)).

The concept of handling and addressing minimum requirements for buildings at neighbourhood level from a cost-optimal perspective is relevant within the scope of the EPBD, although an official approach to this has not yet been explored or defined. However, there is a mention of a district approach within Article 19 of the amended EPBD Directive (EU) 2018/844, requiring the Commission to review the EPBD before January 2026 and to *"…examine in what manner Member States could apply integrated district or neighbourhood approaches in Union building and energy efficiency policy, while ensuring that each building meets the minimum energy performance requirements, …"* (Directive 2018/844/EU). The application of integrated district or neighbourhood approaches could have potential implications for future energy policies.

This report aims to understand 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 (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. This includes both the assessment of energy efficiency and RES measures on-site and nearby to reach the minimum or cost-optimal energy performance and by including district level renewable energy. The approach means that a district scale RES approach will allow for the optimisation of a wider area than an individual building approach. The literature review describes the energy performance and the cost-optimality provisions. The cost-optimality calculation mechanism has features that can include and assess the multiple benefits of a ZED or PED whilst considering using a life cycle assessment (LCA) of the components in order to ensure the carbon footprint of the community is low to negligible, and preferably negative.

2. APPROACH

This Report examines the performance requirements of buildings in the context of an energy district and provides a deeper analysis of how targets can be set. The approach looks into how to develop targets for the different levels within a community (e.g. individual components, building targets or district scale targets) as well as looking into what the energy performance ambition of these levels could be (e.g. energy performance in terms of energy consumption/m2/year and RES supply). The principle aim of this study is to propose a methodology that outlines the broad steps to help developers and policy makers implement a cost-optimum positive or zero energy district. The approach taken allows for the EPBD's cost-optimal calculation for performance targets that can be used by a range of ZED / PED stakeholders, namely; local, national and EU level policy makers, district developers and communities. Essentially, this paper discusses the performance aspects and provides a roadmap for local municipalities, urban planners and national policymakers to use when designing:

1. A policy to legislate and enable ZEDs at national level, or
2. An individual PED / ZED at project level.

The methodology of the study follows a three-tiered approach and is largely based on expert knowledge and published scientific literature since the recent 2000s. Interviews were held with over 20 stakeholders working in the field of energy efficiency and renewable energy and specialising in energy districts. At the same time, a review of the scientific literature was undertaken to identify the potential methodologies for handling minimum performance requirements on a district scale. Finally, the paper was reviewed and commented on by the interviewed experts.

The interviewees come from a range of disciplines, geographical locations, and were selected based on their experience in the field of building energy efficiency, renewable energy and experience in ZED / PEDs projects policies or financing, their experience 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
- Industry stakeholders

The literature review looked at recent reports and other published material, such as: peer reviewed papers 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 and equivalent. Additionally, the interviews fed into the literature review and the interviewees provided many of the reports and online sources. Around 50 papers were reviewed for this report.

2.1 Limitations

With the focus of this study being on how the EPBD can evolve to include PEDs / ZEDs, the report concentrates on the buildings aspect of energy districts. Transport, public spaces and lighting have therefore not been included in the methodology for developing district level targets. Therefore, district targets are derived from the energy use of the building stock and other infrastructural uses, in particular renewable energy. Street lighting normally provided by the local authority is part of a larger infrastructure system and operated independently from buildings. Street lighting can and should be included as part of the energy within the district's borders, however, it has not been considered within this study due to being outside of the scope of the EPBD. Similarly, when developing a ZED project, as per the current EPBD, electric charging points should be taken into account; this has not been undertaken as part of the study. Transportation-related energy demand, including charging points for electric vehicles, is not considered either, since it is mainly determined by other factors (e.g. type of public transport vehicles, number of passengers, peak hours of travelling etc.), which are not related to the subject of this analysis. The mobility concept is not targeted in this analysis; however, the energy storage will be designed differently if charging of vehicles are considered.

The IEA are currently undertaking a taskforce developing their Annex on Positive Energy Districts. Their general approach to defining the targets for PEDs follows the same outline as in this report, however, both methodologies will require for a number of complications to be resolved in order for it to be used by stakeholders, these include:

- **Value of energy**: should kWh of heating and kWh of electricity have an equal value in energy balance calculations? This question is answered in Annex 1 of the EPBD, requiring for the calculation of primary energy to be based on primary energy factors or weighting factors per energy carriers. The primary energy factor converts electricity consumption to primary energy consumption. However, this can lead to problematic results when one considers that producing one unit of electricity in a power plant typically means generating 3 units of thermal energy and wasting 2 units of it through a cooling tower, or similar. This characterises thermal power generation but not all types of generation.
- **Consumption and production peaks**: ZEDs or PEDs should not be isolated energy islands but rather integrated and useful parts of the greater energy system. Since they will have more or less intense overproduction and consumption peaks, how will planning prevent these from becoming a problem for the energy system at large? This complicates planning and optimization because only going for maximal self-sufficiency is likely not the total optimum.
- **Timeframe:** The time phasing implications and duration of a district scale project will need to be understood, for example: the orchestration of which building goes first and last would have to be factored into all considerations associated with the cadence of a district wide programme. Additionally, a developer will have to consider the timeframe for the energy balance: whether this is hourly, daily, weekly, annual or over the whole lifecycle. The planning and optimization problem differs depending on which is selected.
- **Inspections for codes and standards** that support PEDs: Are city agencies and local authorities prepared to support and enable a district model? Are there policy and regulatory mechanisms that might need to be adjusted for a district-wide programme?
- **Community buy-in:** What happens in a situation where there are non-actors or citizens who "opt-out" within the community - do they become free riders? How can the developer ensure all citizens are on board? Hence the prerequisite to have additional tools that support legislation on PEDs such as incentives.

These limitations are important and should be kept in mind and covered when undertaking future ZED / PED studies, and when planning such project. However, the limitations do not hamper the results and conclusions of the study that reinforce the importance of and provide a step-by-step methodology to developing ZEDs and for the inclusion of these in policy and project development.

3. LITERATURE REVIEW

3.1 Political context

The overarching 2015 Paris Climate Agreement lays the political landscape and is the keystone in keeping the global average temperature to 'well below' 2°C, while trying to maintain it at 1.5°C above pre-industrial levels. All Parties involved aim to achieve net zero emissions in the second half of this century. Although 'net-zero energy' is not the goal, one of the EU's contributions to the international agreements is the 2016 "Clean energy for all Europeans" (CE4E) package consisting of eight legislative acts that provide the policy framework, and targets to deliver the energy transition and decarbonise Europe's energy systems. Binding 2030 climate targets have been set in order to decarbonise the EU's energy systems by moving away from fossil fuels:

- At least 40% cuts in greenhouse gas (GHG) emissions (from 1990 levels)
- At least 32.5% share for renewable energy
- At least 32.5% improvement in energy efficiency

Additionally, on the 11th of December 2019, the Commission presented their European Green Deal. The Commission's roadmap for "*making the EU's economy sustainable",* striving to be "*the first climate-neutral continent*" by 2050. The roadmap sets out specific actions by all sectors of the economy to boost the efficient use of resources by moving to a clean, circular economy and to restore biodiversity and cut pollution. The Commission have developed a 'Just Transition Mechanism' aiming to provide financial support and technical assistance to the people and businesses most affected by the transition, mobilising at least €100 billion over the period 2021-2027 (EC, 2020).
Several EU policies pave the way, providing a legislative framework to help MS reach these targets, namely: the Renewable Energy Directive (RES), the Energy Performance of Buildings Directive (EPBD), the Energy Efficiency Directive (EED), the EU Emissions Trading System (ETS), the Effort Sharing Regulation (ESR) and the Electricity Directive (2009/72/EC). Each Directive has specific importance for supporting the development of PEDs / ZEDs and decarbonising the building stock. The summaries of the legislative frameworks and how they link to supporting PEDs are found below:

- The RES requires each MS to adopt its own national renewable energy action plan with sectorial targets and its recast, RED II, sets definitions for 'renewable energy communities' and 'self-consumers' (individuals who produce and consume energy).
- The EPBD paves the way for the reduction in energy demand from buildings across Europe. It requires each MS to develop regulations and packages to improve the energy performance of their buildings, defines the nearly zero energy (NZE) concept and facilitates the cost-effective transformation of new and existing buildings to NZEBs.
- The EED sets the foundations for the Energy Efficiency First principle and establishes a common framework that promotes and mandates energy efficiency improvements in European MS. Its aim is to help businesses, the general public and public authorities better manage their energy consumption. It encourages the adoption of increased efficiency in all stages and sectors of the supply chain and sets binding measures to ensure EU energy efficiency targets are met.
- The ESR regulates the sectors of the economy that fall outside the scope of the EST – namely transport, buildings, agriculture, non-ETS industry and waste. Collectively, they account for almost 60% of total domestic EU emissions. The ESR sets binding national greenhouse gas targets for each MS, collectively amounting to a 30% cut in emissions by 2030 (from a 2005 baseline).
- The ETS is an EU-wide carbon trading market that fixes a 'cap' on GHG emissions for large installations and provides 'emissions allowances' corresponding to tonnes of CO_2. Effort sharing sectors interact with the sectors under the EST, and emission reductions observed by these sectors can be linked to the ETS via instruments that lead to stronger sectoral integration. In the context of ZEDs, examples of such integration are the promotion of electromobility and a more intensive use of district heating (Ecofys, 2018).
- The Electricity Directive establishes common rules for the internal market in electricity, aimed at adapting market rules to increase flexibility and allow for the large-scale integration of renewable

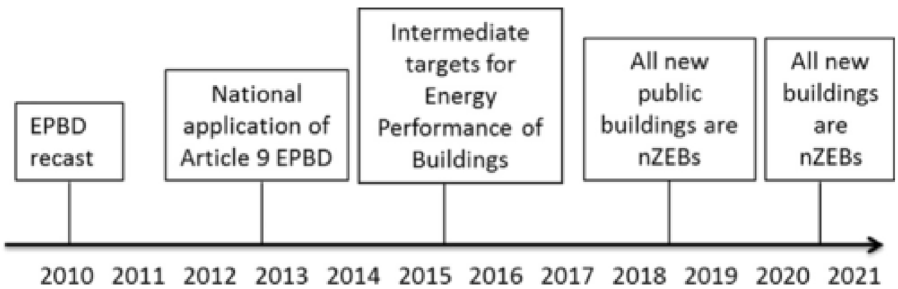
energy, that has become a major market player, This directive ensures free movement of electricity and allows all consumers in all Member States to freely choose their gas and electricity suppliers.

Connections and interactions between the EPBD, EED and RES Directives, complementing and supporting each other is instrumental for Europe's clean energy future. Enabling this, a "Joint Workshop", hosted by the three Concerted Actions[1] (CA EED, CA EPBD and CA RES) was hosted in Barcelona in January 2020. The meeting was set up to find areas of collaboration, connect the dots and exploit the synergies of the different legislative tools of the three Directives. One of the central outcomes of the meeting was the importance of the three directives working together to ensure the correct framework, policies, definitions and tools are in place for wide-spread up-scaling of zero energy communities (ZECs) across Europe.

3.2 Provisions in the EPBD

In EU-policy, the concept of 'zero energy' is clarified in the EPBD, requiring MS to establish NZEBs as the new building standard in building codes or regulations from 2021. For MS, Article 9 of the EPBD requires that:
a) After 31st December 2020, all new buildings are nearly zero energy
b) After 31st December 2018, new buildings occupied and owned by public authorities are to be nearly zero energy. The full timeline can be seen in Figure 1.

Figure 1. Timeline for NZEB implementation according to the EPBD.



Source: EC (2009)

The NZEB concept is linked to an evolution of the 'passive house' standard by minimising demand whilst providing alternative sources of energy and well-balanced 'smart' operations between consumption, production and grid integration (Koutra et al, 2016). While the passive house concept focusses on space heating and the utilisation of passive solar gains, NZEBs introduce an integrated approach to energy efficiency, which includes RES and EE. In the EPBD, a 'nearly zero-energy building' means a "*building that has a very high energy performance... the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby*" (Art. 2). Therefore, a NZEB should have a very high energy performance whose remaining demand is provided by on-site or nearby RES. Article 2 of the EPBD describes the energy performance of a building as being the calculated or measured amount of energy needed to meet the energy demand associated with the typical use of the building, including, *inter alia*, energy used for heating, cooling, ventilation, hot water and lighting.

[1] To assist EU Member States to transpose and implement EU legislation cost effectively, the European Commission funds initiatives known as "Concerted Actions". Concerted Actions are joint initiatives between EU Member States and the European Commission. They provide a confidential, trusted forum for exchange of knowledge and collaboration between national governments and their implementing agencies, helping countries to learn from each other, avoid pitfalls and build on successful approaches.There are currently three Concerted Actions dedicated to the Energy Efficiency Directive (CA EED), the Renewables Directive (CA RES) and the Energy Performance of Buildings Directive (CA EPBD).

The definition of a “very low amount of energy” and “covered to a very significant extent by energy from renewable sources” is, however, left to the MS to determine, following the cost-optimality methodology. This means that each MS defines their own energy performance requirements using the EPBD’s cost-optimality methodology. The cost-optimal performance level is the energy performance in terms of primary energy leading to minimum life-cycle cost. This results in a broad range of energy performance requirements (in m2/year) with differentiating input points; such as primary energy factors, calculation methodologies and energy use. As MS are able to determine their own energy performance requirements, considerable discrepancies exist between MS, and some performance requirements are still quite high (EC, 2016).

While literature on NZEB is already wide and well established (ZenN 2014, Schneider et al, 2019, Hamdya et al, 2017, Hamdy et al, 2017) the ZED concept is newer and only a few studies specifically concentrate on how to extend the zero energy concepts from individual buildings to districts.

3.3 From NZEB to ZED

From an energy perspective, moving beyond NZEBs to ZEDs / PEDs provides opportunities to achieve cost-effective levels of high-energy efficiency and renewable energy systems. This set-up requires holistic and smart planning. Energy efficiency measures on an individual buildings level will reduce the overall demand of the neighbourhood and coupling this with technologies, such as renewable energy systems, local energy networks and energy storage, can offer overall cost-effective solutions. The aggregation of individual measures to a district of buildings provides investor confidence as a performance guarantee in carbon savings is established (Webb, 2019).

When placing a zero or positive-energy objective on a district, the diversity of the energy interplay of the building’s different energy performances and production capabilities provides an opportunity to share the neighbourhood’s energy needs, costs and resources (Amaral, 2018b). Thus, a ZED could offer a larger scope for optimisation than an individual building. The building systems can be specifically designed and can have tailored load profiles that will enable a high penetration 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. Additionally, a district scale can use “energy cooperation” or “energy pooling” to empower communities to own their local renewable energy.

The PED / ZED approach is able to address concerns raised by individual NZEBs – allowing for higher accuracy when measuring energy performance and better-managed demand and generation flexibility. As an example, districts being able to use different energy resources and having a bigger area to “play” with than an individual building site. That said, enlarging the scale of intervention from building to district increases the complexity of the energy performance assessment and design factors (Eržen, 2017).

Looking at the district as a unit, within it, there will be clusters of buildings of different typologies and energy profiles that are powered by renewable energy farms and building integrated RE systems, and are all linked using centralised and / or aggregated storage facilities and smart distribution networks (Ademe, 2010). The districts should allow for future technical advancements in electrical and energy equipment, for example:

- 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.

Essentially, a zero or positive energy community requires that all stakeholders, including citizens, come together and collaborate in order to develop the best-fit solution for and by the citizens and municipalities in order to play their role in the global climate crisis. With the support of an enabling policy framework, the citizens of the communities should be able to develop their district concepts themselves.

3.4 Definitions of Energy Districts

There are several ‘zero energy’ and ‘energy community’ concepts that exist, however, in terms of the legal framework, there is no such definition in current European legislation. Nevertheless, there are many instruments in the CE4E package that can support citizens, local communities and national authorities to develop such districts or communities (in particular REDII, EPBD, EED) (Hoos, 2020). Additionally, the 2019 Green New Deal puts great focus 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;

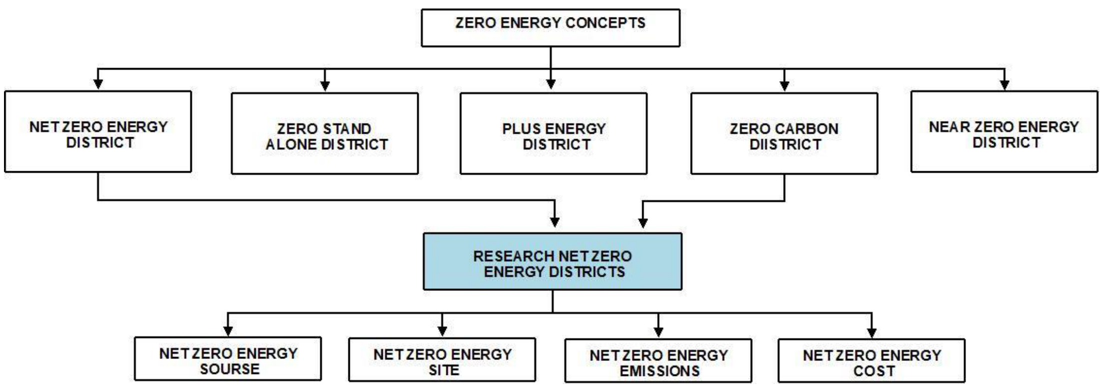
c) the primary purpose of which is to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits.

With regards to the EPBD, the definition used 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 the same concepts when applied to a district scale. Similarly, most scientific publications and definitions of a ZED consist of the very same components (ZedN, 2018, Jalala, 2016, Laustsen, 2008, NBI, 2016, Cortese & Higgins, 2014 Malin, 2010, A2PBEER, 2014, seen in the list below Figure 2.

The EPBD's long-term building renovation strategies' (LTRS) goal 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 is in order to mobilise investments for aggregated renovation projects.

Principally, a ZED is a group of buildings such as a city district, community, village, cluster of buildings or campus, with a stated goal of achieving zero or positive energy, producing at least the same amount of energy as they demand, whose reduced energy demand is produced by on-site or nearby renewable energy. The concept of a ZED can be described or defined in one of the following manners, Net Zero Energy Districts, Plus Energy District, Zero Carbon District, Nearly Zero Energy District (Laustsen, 2008), as per Figure 2 below.

Figure 2. Zero Energy District Concepts



Source: Laustsen (2008)

Each of the definitions has similar meanings, however they differ thus:

- Plus Energy Districts: deliver 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 require any 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 carbon dioxide emitting sources (e.g. biomass, biogas excluded) and over the year will either be carbon neutral or positive energy, therefore they produce enough energy to ensure 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, almost all of the remaining energy demand is provided by onsite or nearby renewable energy.

Looking at the synergies of the directives, it can be seen that an enabling framework exists: using the definition of an NZEB and LTRS from the EPBD to serve as the minimum energy requirements of the district's new and existing buildings, with the definition of a 'renewable energy community' from the REDII able to provide, enable and facilitate the framework for self-forming communities. So, 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, is autonomous, and is effectively controlled by its citizens.
- Who's 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 a very significant extent, or more, by renewable energy sources.
- Where renewable sources are produced on-site or nearby.

3.5 Set up of a Positive or Zero Energy District

In essence, an energy community requires for all stakeholders to interact and collaborate in order to develop the best-fit solution for citizens and municipalities to play their role in the energy transition. This also means that social innovation, including behavioural change, needs to be considered and transformed to deliver ZEDs. There are many non-technical barriers to be overcome, and community engagement is vital to ensure the buy-in of community members.

When upscaling from a building to a district scale, one must not simply replicate the requirements from small to big scale, as the requirements for a cluster of buildings will differ. The challenge is which requirements should stay, which can be modified, which need to be added and which are part of another regime (e.g. indoor environment requirements, which are part of building codes.).

In order to achieve a ZED, the aim of the community should be to have an energy balance that is zero, or positive. The timescales for the zero / positive energy goal will depend on a number of factors. The district planner will need to calculate the overall energy demand of the district and match it with renewable energy production systems, single building units, whole district energy plants or farms (Admaral, 2018). The design of the community will have to take account of the residents' needs and look at the district as a holistic urban system. When designing a PED / ZED, some factors for consideration that will be discussed in greater depth in the following sections 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.
- The balance between the energy production and energy consumption (including buildings, production of on-site renewable energy).

When developing a ZED, it is important to consider the components that are at the centre of the energy balance, where the interconnection of these lie and how they can interact to ensure a zero or positive target can be met. However, it is important to note that the reduction of energy and carbon are not the only drivers in establishing such a district. As per the Sustainable Development Goals of the United Nations and the objectives of the EU's CE4E and Green New Deal packages, the overall aim of both is to ensure that the measures taken to achieve a zero-carbon society are also good for consumers, growth and jobs, and good for the planet. With this in mind, Annex 1, developed by Saheb et al in 2019, provides a list of sustainability criteria to be considered by local actors in order to develop a holistic zero / positive energy district.

3.6 Case studies – a ZED and a policy framework

This section provides a case study of a ZED in Denmark and a policy framework that supports and enables the upscaling of energy communities in Scotland. The learnings from these feed into the advantages and disadvantages section as well as the methodology for designing a ZED / PED.

Avedøre Case Study

A standout case-study of a community project shows some of the advantages of a ZED can be seen in Avedøre, this project demonstrates the benefits of a citizen-lead initiative The Avedøre Green City (AGC) project is based in a south-western suburb of Copenhagen in the Hvidovre Municipality. In Avedøre, the citizens wanted to make their community more sustainable, and due to their because of their lack of knowledge on energy systems they set up a steering committee with a group of stakeholders from area, including the Avedøre Social Housing Association (ASHA), Avedøre Camp, Avedøre Village, Film City, Hvidovre High School, Hvidovre Municipality and Avedøre District Heating (cooperative) (Kransen, 2020). The stakeholder group developed a shared vision with a 'green city' objective and baseline based on UN Goals (3-13, 15 and 17). Centred around the communities' goals, using the communities' morphology, buildings and energy supply and demand information, the steering committee set up a 'manual' with actions and initiatives that was communicated to the local area and residents. The AGC empowered their citizens by facilitating cooperation between different types of organisations, stakeholders and processes. Through knowledge sharing and engagement techniques, the citizens were able to be part of the solution and share the same goal of sustainability. The project ensured that enthusiastic members of the community had the right tools and information to share their knowledge and engage others in the local project.

The AGC community's energy use is defined by being supplied by Avedøre District Heating, therefore the first step the citizens took was to use this to their advantage and transform the system to an optimised two-string DH system with new radiators, ventilation-systems, solar energy storage and heat-pumps resulting in a 10 % reduction in energy use. The second item in their manual was an aggregated renovation of 210,000 m^2 of floor area by insulating the building envelopes, improving windows, using smart-meters and changing the DH from 90°C to 60°C, these measures resulted in a 40 % reduction in energy use. The third and final step the collective took was the development of an energy community using renewables to supply their remaining energy demand, using thermal solar energy supply, PV and BIPV, reducing their energy use by 50 %, resulting in them becoming a zero-energy community by 2040.

The Avedøre Green City project showed that the citizens of a community have a very important role to play, especially when it comes to the renovation of existing buildings. Here, citizens wanted to make their city more sustainable, but due to a lack of knowledge, they were unsure of the steps needed. Once a steering group was established with the relevant stakeholders of the community, the citizens were able to obtain the appropriate tools to allow for their idea to flourish. By collaborating with an onsite district heating company, the citizens and stakeholders were able to develop a three-tier system to reduce demand via reducing energy through renovating buildings and supplying enough energy and heat needed to become a zero-energy community.

Scotland Case Study: legislation and policy package

In April 2019, the First Minister for Scotland declared a Global Climate Emergency and legislated to make Scotland a net-zero economy and society by 2045. The Scottish climate targets steer national energy policy, with the goal of 50% of energy supply being renewable by 2030 and interim GHG emission reduction targets of 75% by 2030 and 90% by 2040. Scotland's Energy Strategy is the driving force behind this legislation with six strategic energy priorities: consumer engagement, energy efficiency, system security and flexibility, innovative local energy systems, renewable and low carbon solutions and oil and gas industry strengths. An advantage to developing ZEDs in Scotland is its top down policy that prioritises local energy systems, moving away from centralised fossil fuel plants and increasing renewables penetration. Thanks to this, the trend of Scotland's energy system is rapidly decentralising, and aims to ensure that 100% of electricity consumption is met from renewables by the end of 2020, compared 75% at the end of 2018.

Scotland has a legacy of strong community engagement in local renewable energy generation that is supported by the Community and Renewable Energy Scheme Programme (CARES), funded by the Scottish Government and managed by Local Energy Scotland (a consortium made up of the Energy Saving Trust, Changeworks, The Energy Agency, SCARF and the Wise Group). CARES support local energy communities and covers local ownership and / or community involvement. CARES is a one stop shop providing advice and support, including financial support to community groups, organisations and rural SME's seeking to develop renewable and low carbon projects. In 2018, the capacity of community and locally owned renewables more than tripled to 697MW, and currently there are approximately 882MW's worth of projects in the pipeline.

The Scottish Government believes that targets help to drive investment decisions and develop supply chains and their National Community Target is for 1 GW of community and locally owned energy by 2020 and 2 GW by 2030. The Scottish Government put a central focus and priority on decarbonisation as the driver for community-led action. As the future of the Scottish energy system transitions to a more decentralised one, they are consulting on a local energy systems policy statement – setting out a series of key principles and outcomes summarised in a framework. The Government see the 32 local authorities (LA) in Scotland playing a major role in their energy transition and are working with the LAs to put in place a statutory requirement to produce Low Carbon Heat and EE Strategies for decarbonising the built environment in their areas. The Scottish Government has set up several programmes and financial packages in order to cater to the needs and support the uptake of energy communities. Up to £5 million was available through CARES in 2018/19 to support the growth of community and local energy in Scotland, with the same amount proposed in the coming financial year (2020).

The overall policy package in Scotland paves the way to empower both local authorities, communities and citizens in developing energy districts. Their targets and policies coupled with the CARES support scheme and financing packages pave the way for Scotland to be a zero-net economy, championed by its communities.

3.7 Advantages & shortcomings of zero energy districts

As both the research and interviews concluded, there are advantages and disadvantages to including PEDs / ZEDs into EU legislation and to implementing zero energy projects on a district scale, as opposed to an individual building scale. Generally, the advantages of a ZED are the positive impacts they will have on reducing the carbon footprint of Europe and empowering citizens and stakeholders to take the lead in their own communities. It is to be noted that regulations are not the only tool that support the uptake of ZEDs. When upscaling ZEDs it is essential to ensure strong community buy-in and commitment, consequently tools that encourage the public by means of incentive or reward scheme also need to be considered by local and national bodies.

An advantage of a ZED is the flexibility a collective group of buildings provide, whereby some buildings may not be able to meet high efficiency levels whilst others may be energy providers. The main downfalls are the possible complexities that will be encountered in the planning, development and monitoring of these districts. Mostly, zero-energy projects are instigated by a community's desire to be more environmentally conscious; such is the case for urban renewal projects and new settlement projects (Saheb et al., 2019). ZEDs provide the energy sector with the link to promote both energy efficiency and renewable energy, both working together to support a zero-carbon world, as opposed to what is often the case; the two industries competing for projects based on the most cost-optimal option.

A list and understanding of the advantages and disadvantages of a zero-energy district were developed based on the literature review, case studies and interviews with experts and are detailed below (Amaral, 2018, Polly et al, 2016, Jalala, 2016, Koutra, et al, 2016, Webb, 2019).

The advantages of a ZED are primarily economic, technical (efficiency), infrastructural, social and environmental, such as:

- Dealing with buildings at a district level allows for a better technical assessment of their combined energy performance and needs by accounting for the buildings' forms, characteristics and urban layout.
- Aggregating buildings within a district introduces the option of larger-scale renewable energy production meaning that buildings can make best use of on site and nearby renewable generation and proximate distribution systems – this allows for cost-effective systems like district heating and wind / solar farms to be used as well as or instead of individual heat pumps and single generators, meaning the fuel source to be switched more quickly and efficiently.
- The renewal of the district can transform a run-down neighbourhood into a valued one, many studies show the multiple benefits of ZEDs, such as:
    - Property value increase - expressed in asset value and net present value of increased rental rates
    - Greater coordination between stakeholders allows for the neighbourhood to work together with a shared goals and objectives and a sense of community that can reduce crime, improve security and improve mental health.
    - Job creation
    - Boosting the local economy, through ecotourism, job creation, improvement of household income, willingness to go out to restaurants / bars in the evening with concomitant links to security.
    - Reduced electricity demand
    - Better local air quality
- Economies of scale and the cost-effectiveness of transactional energy performances allow the district's building owners to reap cost savings. A district-wide program will offer purchasing power and economies of scale for energy efficient passive and active solutions among the participants.
- Large-scale district renovation programmes can help secure investor confidence and unlock project finance under certain pre conditions: performance evaluation and availability of performance data.
- District renovations are easily replicable and could therefore lead to an increased renovation rate for neighbourhoods.
- Greater stakeholder coordination allows for the exploitation of synergies between different buildings and hence allows for suppliers to more easily balance their energy production (for example cooling waste from one building used to heat other buildings).
- Some technologies perform better at larger scale.
- Many services and techniques can be procured that may not be available on an individual building scale, such as wastewater recycling, rainwater harvesting, district heating and cooling, renewable and low impact transportation alternatives, local food production…etc.
- Individual buildings have site constraints and grid requirements that hinder the building orientation to benefit from passive design using solar and wind directions.
- The initial cost of a Zero Energy Building is high and often owners / investors cannot afford it, yet as governments realise fundamental change is needed, zero carbon targets become a societal issue. The gap between the societal need for long term zero carbon targets and the cost of buildings

becoming zero energy being linked to the individual should be filled by governments; *a district level approach allows for this gap to be filled by governments and municipalities.*

The challenges of a ZED are often based on complexities of the design process, regulatory issues and the difficulties of achieving consensus amongst stakeholders:

- Large scale projects mean that more than one building owner and stakeholder need to collaborate and agree upon the overall solution, individual and district level targets, this involves more time and work in the project planning.
- Difficulties may arise in the neighbourhood if a consensus is not reached and could result in some of the inhabitants being unhappy / dissatisfied, which could ultimately prevent the implementation of projects.
- The complexity of approach may be difficult to enforce and may require a third party or stakeholder to be in control of the overall set up and monitoring.
- There may not currently be enough knowledge or skills within the workforce necessary for efficient and effective implementation.
- Giving the responsibility to the whole district could lead to other stakeholders taking less responsibility:
    - Individual building owners / occupiers spending less money to improve their buildings and not adhering to the current building codes. This could essentially lead to a lowering of renovation rate.
    - Construction companies may avoid responsibility for the energy in the district
- A Zero Energy District needs infrastructure development that will allow them to connect with the existing networks that serve the whole city.
- Most district projects are developed and operated in phases making it harder to invest in infrastructure—such as district heating (DH) —that may not be needed in the first phase of development.

With regards to the practical implementation of a ZED, the designers and stakeholders will have many questions to pose and will have to define the ZEDs spatial planning process before the energy planning process, for example:

- How can the energy performance requirements at district level be defined?
- How can an energy balance be managed so that district borders will be unambiguous and high-performance buildings are not be double counted?
- What will a business model for a ZED look like?
    - How can legislation support community-lead business models?
    - How will a district level measure be financed? Who is to provide the grant / loan and guarantee? Who owns the measure?
    - How does the investment pay back?
    - Is DH or local DH a precondition?

In order to avoid some of these constraints, the literature suggests it is important for individual building requirements from building codes to still be applied. Similarly, information on energy performance at building level (in particular in the form of Energy Performance Certificates) remains critical for all buildings.

3.8 Defining district targets: methodologies from literature

Of the papers, case studies, tools and projects reviewed, some suggested methods for developing positive or zero-energy or carbon districts became apparent. The methodologies differ from project to project; from undertaking minimum district performance analyses, using tools to find the cost-optimal solution, using archetypes as inputs into a spreadsheet / tool and aggregating building level performance targets. This section attempts to outline and describe the methodologies developed by other researchers and projects to define a ZED. The list is not exhaustive but provides a basis for understanding the existing methodologies for defining a district target.

The reports and methodologies, described below, have been instrumental in the development of this report's methodology for defining a zero-energy or carbon district. The reports studied for this paper show that the key to developing a district target is an accurate evaluation of the overall district energy demand – the first step is to use a baseline approach to understand the building stock's energy demand. Many of the studies below provide methodologies that can help municipalities or project designers calculate (or estimate or model) the overall energy consumption or demand of the existing or planned districts thus enabling them to know, with the reduction of demand and adoption of renewable energy systems, what the projected energy performance of a district can be. The table below shows each strategy's objectives, metrics, design parameters and methodologies.

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

Purpose	Method	Metrics/ Type of Energy	Parameters considered	Sources [2]
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 CO2). CO2 (g/kWh). CO2 (g/kWh). GHG (CO2, N2O and CH4) (NOx, SOx)	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 2014
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
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
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	Kalaycıoglu & YılmazIstanbul 2017
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 CO2 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	Energiekonzept-Berater für Stadtquartiere

[2] Full citations in the reference section.

			systems) and energy generation from renewables	
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	GIS - Geographical Information System
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, number of certified installers, governmental schemes running, etc	Geo-coded EPCs	ENERFUND
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 /yr)	Deep retrofit works. Whole house solution with a fabric first approach	SEAI
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 y	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 y	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

Source: Adapted from Amaral (2018).

While some of the studies described above remain at the scale of the individual building level, others are looked at from a district level, from which various models, methodologies and tools have been designed to simulate the performance of the individual building in order to improve the overall energy and carbon performance of the district. For the purpose of this study, the reports that take a holistic approach to ensuring the territorial scale of the district is taken into account have been studied in greater depth and their methodologies have fed into the recommendations and conclusions of this report.

The studies that use the EPBD as a basis for the development of a district level target were key, as essentially this report is looking for a methodology that allows for communities to develop performance targets for PEDs / ZEDs, whilst allowing for communities to understand how they can go about developing accurate targets for their districts in a simple and step-by-step manner.

4. INTERVIEWS: Realisation of a PED / ZED target

The interviews with experts in the field of ZEDs provided many innovative ideas for methodologies for the development of performance targets for an energy district. Although the methodologies varied from one another, all experts agreed that in order to ensure a ZED follows its definition of 'an area that reduces demand whilst providing clean energy production', performance targets would need to be set for both the individual buildings within the district and for the overall district itself. The solutions for performance targets ranged from a global target of zero or positive energy that would allow for building flexibility with the development of a transactional trading system between buildings (allowing some buildings to be less efficient and other to be energy providers) to stringent individual component-by-component based efficiency targets (thus allowing for the market to have guidelines for the efficiency of each component). Possible solutions taken from the interviews 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.
6. Multiple benefits coupled with cost-optimality calculations.
7. A life-cycle approach to a carbon neutral district.

One solution the majority of the experts suggested, and that fits with the literature review and case studies analysed on this topic, could be to apply the EPBD's cost-optimality methodology to each building in the district and aggregate this to a district scale. This would include building-based renewable energy on the building scale and onsite or nearby renewable projects into the district's and aggregated building's cost-optimality calculation. Of the 20 interviewees, the majority advised this is a viable approach to the development of energy performance targets of a low carbon district.

4.1 Methods for defining a district target

This section details the discussions and topics raised during the interviews. Each approach sheds a different light on how one might approach developing a district target, often the views shared by the interviewees were in line. One method defined by an expert is described briefly in a footnote below and further developed in an annex, as the approach is already included in the current EPBD.[3]

4.1.1 Target values based on reference buildings

Applying the energy performance methodology at a district level would require for reference buildings to be developed within the specific area of the community. The question that each district developer would need to answer in a baseline study is: is there already a typology for a reference building within the municipality area? If not, research will need to be conducted to develop a typology for the area. Some of the input options that would be fed into the cost-optimal study are:

- Area: size of community
- Location: urban or rural
- What is needed: new builds or renovations

[3] It was suggested that an overall district requirement would be challenging to control with regards to jurisdictional rights and enforcement mechanisms. Hence, a component-level target-based system was proposed at a building-to-building level. The individual districts around Europe would set these standards themselves, based on their climatic conditions, and ensure these were the same or more stringent than national building codes. These standards would be enforced by linking the requirements to the building owners, essentially enacting the EPBD with an additional goal or layer for building components.

- Layout of the district: proximity of buildings
- Size and settings of the district: which buildings will be affected
- Population: how many people inhabit each building and the community as a whole
- Do the inhabitants commute or do they work nearby?

The current methodology can already cover decentralized methods, for example; district heating – this would simply be added into the central equation.

In order to set up targets for a district, a buildings standard and buildings target approach allows for the energy balance to be understood and calculated. The district can use the science behind the minimum performance approach and local building codes to develop an accurate overall district target for the full set of buildings in energy performance per floor area. The overall reference targets would therefore be developed from the EPBD's minimum performance calculation and provide each building within the district with a minimum energy performance target in the form of kWh/m^2/year for different types of buildings (based on the building type and age). These values can then be extracted and adopted into the specific neighbourhood level depending on the type of building within the district. The minimum performance requirements would be used as the defined reference values for each area – thus allowing for subsidies and planning tools to apply to all buildings within the district. This approach follows three steps:

1. Determine reference values for building typologies in district.
2. Minimum performance values of each building determined using local building code / EPBD cost-optimality methodology (EE and onsite or nearby RE connected to the buildings).
3. Minimum performance target for each building aggregated to find the buildings district target in kWh/m2.

4.1.2 Target values from monitored data

Several interviewees preferred a methodology for setting performance targets from monitored data from real buildings, suggesting this is more reliable than developing targets based on reference buildings. This would involve collecting or monitoring energy use data from the buildings within the district or in the same geographical location in order to develop a building performance target. Based on the individual building's performance targets within the district, these can mathematically be aggregated in order to develop an accurate target for the whole district in kWh/m^2/year.
For example, the PED / ZED project lead / community aggregates the sum of each building (residential, offices, schools and hospitals, district dependent) and divides this by the floor area to get their overall district performance target. Although here, building targets are treated in isolation, some of the buildings may be able to perform better than others, thus allowing for performance trade-offs – in this case the developer should take these synergies into account. RE would be integrated into the calculation of each individual building for individual RE systems. The remaining energy needed to reach a zero-energy district would be provided for by an onsite, nearby directly connected RE farm / district heating system. Gaining the data for this calculation may be challenging and hence experts suggest an archetypal data collection approach, described below. This approach follows three steps:

1. Determine buildings' energy demand based on monitored data.
2. Minimum performance values of each building determined using local building codes / EPBD cost-optimality methodology (EE and onsite or nearby RE connected to the buildings).
3. Minimum performance target for each building aggregated to find the buildings district target in kWh/m2.

4.1.3 Target values through energy modelling or tools

For all countries, it is possible to get to a cost-optimum for a district target, this approach can be managed using modelling platforms. The building types of the district can be put into an energy model where the optimization uses data points, reference buildings, renewable systems and carbon costs to calculate the district's cost-optimum. In the EU, modelling is not yet common practice; most individual building projects will not have a modelling exercise, yet, as pointed out by the interviewees, simple tools will allow constructors and designers to understand the cost optimum. One of the key issues surrounding optimisation is that common practice sees an optimisation of either a building or the RES. Whereas what is needed is a system that optimizes a combination of the two, also allowing for the optimisation of multiple buildings. The challenge lies in the financing of the two options that is currently organised differently.

The minimum performance requirements of the whole district would depend on the location, morphology, and typology of the district. In order to take all of these features into account, the developer can look into the planning of the district and make an energy concept connected with a zoning plan that takes the potential of RE systems into account (using PV, ground water, waste heat, etc.) and develop recommendations based on energy efficiency reducing the individual building and district demand and RE supplying the demand. From the supplier side they can recommend the extent RES should be used and from the demand side they go for the minimum energy requirements according to building codes.

A tool can combine the building-wise targets (EPBD assessment) of all buildings in a certain district multiplied with their floor area and divided by the sum by the total floor area to get a target for the district. This works with average energy performance values (for example for measured EPCs). To simplify it, it is possible to separate the buildings into residential and non-residential types.

This will vary from country to country and the results would need to be valid in each national context. Therefore, the approach will differ on a case-by-case basis. It is important to establish a methodology to model the group of buildings and to choose building scenarios for the calculations, alongside the RE solutions and scenarios. National and regional regulations can be used as a minimum condition to achieve PED / ZED levels.

It is to be noted that the problem with district level simulations is that there are many technical systems interacting in different conditions at different time intervals and hence it is a complex simulation problem. When trying to optimize for more than one parameter, the complexity is further increased. In practice, both CO_2 and cost will have to be optimized at the same time. Although there are some promising methodological approaches that exist, this modelling is not currently undertaken routinely. Methods and tools for cost-optimisation would be very helpful for the ZED communities, and are currently being prepared within the IEA Annex on PEDs. A strong local adaption of the models will support the upscaling of ZEDs. The models should be supported by and be able to handle the local or regional building code requirements.

4.1.4 Energy Balancing - transactional trading system between buildings

For a district model – based on a minimum requirement for all buildings - the overall targets need to be zero-carbon to meet the Paris agreement. The role of the district can interact with the nuances of the dense population (new properties, old single-family buildings, commercial buildings) to allow for leeway. On a community level, the options for energy efficiency and renewable energy transitions increase as the portfolio increases. As some buildings in the portfolio will not be able to be very efficient (cost-effectively), whereas others will be positive energy producing buildings, thus an energy balance will allow each to compensate for the other. In order for this to work, a community grid is needed to allow for bigger variations. A transactional / internal trading system between buildings allows for some renovations to be less deep whereas some buildings and RE systems give back to the grid. Ultimately, a baseline would be set at the district level – minimum energy performance – and all the buildings would add up to positive or zero energy. Within this approach, each building will have to have its own energy performance target, having its own contribution / roadmap to meet the district target. As an example, the 2030 Districts approach is to seek a percentage rise in efficiency for existing buildings – these will be benchmarked from a certain standard or building code that would provide a building type and age (a reference building). The reference building will be used as the basis for each building meeting the target.

Based on the overall achievable building reduction target, it will be possible to calculate the type and cost-effectiveness of the contribution of renewable energy needed for each building and the whole community. It was noted that there are challenges to this approach; the most critical is the definition of the systems boundary and ensuring buildings are not double-counted. As aforementioned, another challenge is the differentiation in efficiency of each building within the district, the developers would need to ensure building owners do not breach the minimum energy requirements for their building typology.

A district can be a mixture of existing and new buildings; some that are kept as they are, some that undergo targeted upgrades, some that undergo major renovations, and some zero or positive energy new buildings As per the EPBD, new buildings and major renovations would have to comply with applicable performance requirements, as these are in essence cost-optimal and mandatory. However, when discussing the cost optimality methods, it was mentioned that a key benefit of a transactional analysis PED / ZED would be to allow for some individual buildings within the community to undergo minor renovations or be left untouched and hence individually, they will not necessarily meet the districts' energy performance requirements but overall the district can still be zero or positive energy. For example, some buildings are far too complicated and not cost-effective to renovate (e.g. heritage buildings), whereas others are easily renovated to a high level of efficiency or positive energy at low cost.

4.1.5 Positive energy district

The general consensus of the interviewees was that the overall district target should not be zero energy or carbon, as that would be excessively complicated to calculate accurately, but in fact be positive energy or carbon. Most believed that a positive energy district would be more progressive, easier to calculate and implement, and more in line with the Paris Agreement and the SDGs. Positive energy districts should be districts that produce more energy than they use, therefore would not need to ensure a zero-energy balance, that is difficult to maintain. A positive district would also reduce the need to be linked to the grid. The positive energy district would act as a power station through positive energy buildings, deep renovation of a percentage of buildings, smart grids and renewable energy, thus ensuring the total target of the district is higher than the overall demand.

Building codes still need to guide and sustain, following the Energy Efficiency First principle. In line with the other solutions discussed in this paper, the view was that, within a positive energy district, the individual requirements would still stand for each building, additionally, a second requirement for the district would be the minimum RE requirement. Assuming the community's energy efficiency has been met and optimized through the building code, it would then, in order to become a positive district, combine this higher level of EE with onsite or nearby RES. This means the small amount of energy needed, and a bit more, will be provided by renewable energy. Cost-optimisation therefore only needs to concern the level above the building minimum level, not the whole calculation.

The renovations within the district should all be to a deep level, shallow renovations are not relevant for a PED and many interviewees would rather renovate a percentage of the buildings deeply rather than a shallow renovation of all buildings. In order for the district's inhabitants to reap multiple benefits of a ZED, building codes need to sustain and renovations need to be deep.

If all buildings met the minimum energy requirements, the district's renewable energy would be in surplus and could be used for other innovative systems (into chargers for electric cars and trains, a small service companies, something to bring the district's community together or provide them with extra income) rather than on the needed heating and cooling of the buildings.

4.1.6 Multiple benefits coupled with cost-optimality calculations

With regards to the cost-optimality calculations, one of the overarching issues with it is that, currently, it only calculates savings against investments. However, as many co-benefit studies show, the multiple benefits could in fact result in very large savings linked to health, social, economic and environmental costs. Were these to be taken into account, PEDs / ZEDs might prove to be a very cost-optimal solution. When looking towards PEDs, it is self-evident that a clean and healthy community would have a positive impact on the district's environment, citizens health and the economy and these monetary impacts could be accounted for as a whole community and not per individual building.

A precondition for using cost-optimality as a means to develop positive / zero energy targets is the inclusion of multiple benefits, as only using energy benefits will mean cost-efficiency will be hard to achieve and won't allow for the full potential of the benefits to the local and wider society to be understood.

Many interviewees mentioned the cost-optimality methodology of the EPBD being used to determine a district performance value by aggregating the values of individual buildings as a way to include the multiple benefits of a ZED into the performance calculations. Therefore, the developers can optimize the whole community as a unit, whilst ensuring the benefits for the inhabitants and municipality are included within the calculations whilst allowing the developer to know which option is cheaper and emits less carbon. This would use a cost-optimality balance in order to know what is best to invest in at a community level, for example:

- Reduction in kWh (renovations)
- Production of kWh (RES)

  Not only will including multiple benefits into the cost-optimality calculations get around the cost-optimal renovation problem, it would also provide the community with a deeper understanding of the benefits and perks of an energy district. Multiple benefits can be translated into a community level via:

- Individual cost-optimality calculations that include MB and Life-Cycle Costs
- Community cost-optimality calculations with larger energy systems included

4.1.7 Life cycle approach to a carbon neutral district

As one moves towards a positive or net-zero target, life-cycle approaches (LCA) can be relevant. Although some interviewees pointed out the LCA may be a more complex route to take to get to positive, and hence could be seen as a barrier rather than a solution. However, essentially, the development of these districts will come down to the cost of each measure against each other. While investors and developers often think of a project in terms of the long or short-term economic values, as the climate emergency becomes all the more apparent, where possible, developers should think of longer-term net-zero goals and what the trade-offs might be from an embedded carbon perspective. Therefore, when undertaking the cost-optimality assessment, the interviewees generally agreed that the embedded carbon for each measure needs to be taken into account.

Within this scope, one relevant initiative is the IEA's Annex 75 looking into understanding what the cost-effective combinations are between renewable energy measures and energy efficiency measures to achieve far-reaching reductions in carbon, greenhouse gas emissions and primary energy use in urban districts or group of buildings, depending on national contexts. Annex 75's methodology is composed around the concepts of cost-effectiveness and targets of ZEB and ZEB levels that are calculated using a life-cycle approach, in terms of primary energy (kWh/m^2/year) and GHG emissions according to national contexts and regulations.

The carbon footprint of the individual building will not just consider the energy balance in terms of electricity and heating, but also with an understanding of the embedded carbon levels.

4.2 Interviews: Insights into Developing P/ZED Targets

Overall, the interviewees all agreed that in order to develop a performance target for an energy district, the individual buildings within the district must follow the EPBD's methodology and have an individual minimum performance target. From this, the developers of the district can undertake an aggregation exercise in order to develop the overall district performance target. The general consensus was that the minimum performance targets for the individual buildings are to be obtained either using measured data or using reference buildings or archetypes of the building typologies within the specific district.

Using the EPBD methodology, the experts suggested the individual building targets be developed based on a minimum performance level from cost-optimality calculations, these may already be translated into the local context in local building codes. The interviewees generally agreed that in order for the targets to be realistic and investable, the cost-optimality calculation should include both a life-cycle analysis of the efficiency and renewable interventions (e.g. looking at the costs and reductions of carbon emissions of the measures) as well as the multiple benefits to the community, economy and environment. Although this is not yet current practice, the interviewees commonly stressed that multiple benefits in cost-optimality calculations for the district are a big driver for community involvement, and they should be considered.

The interviewees agreed that, although it is important to ensure renewable energy systems are included within the cost-optimality calculations, the project developers / municipalities must ensure the Energy Efficiency First principle is used to guide the district's target. An important overall rule of thumb the interviewees stressed was that the district should not be nearly or net zero, but positive energy and carbon neutral, supported by smart grids and technology. This is not only due to the fact that it is difficult to reach an exact "zero" target of energy from an energy system but also this positive target will help to achieve carbon neutrality within the shortest timeframe possible.

5. A ZED DISTRICT TARGET: Approach

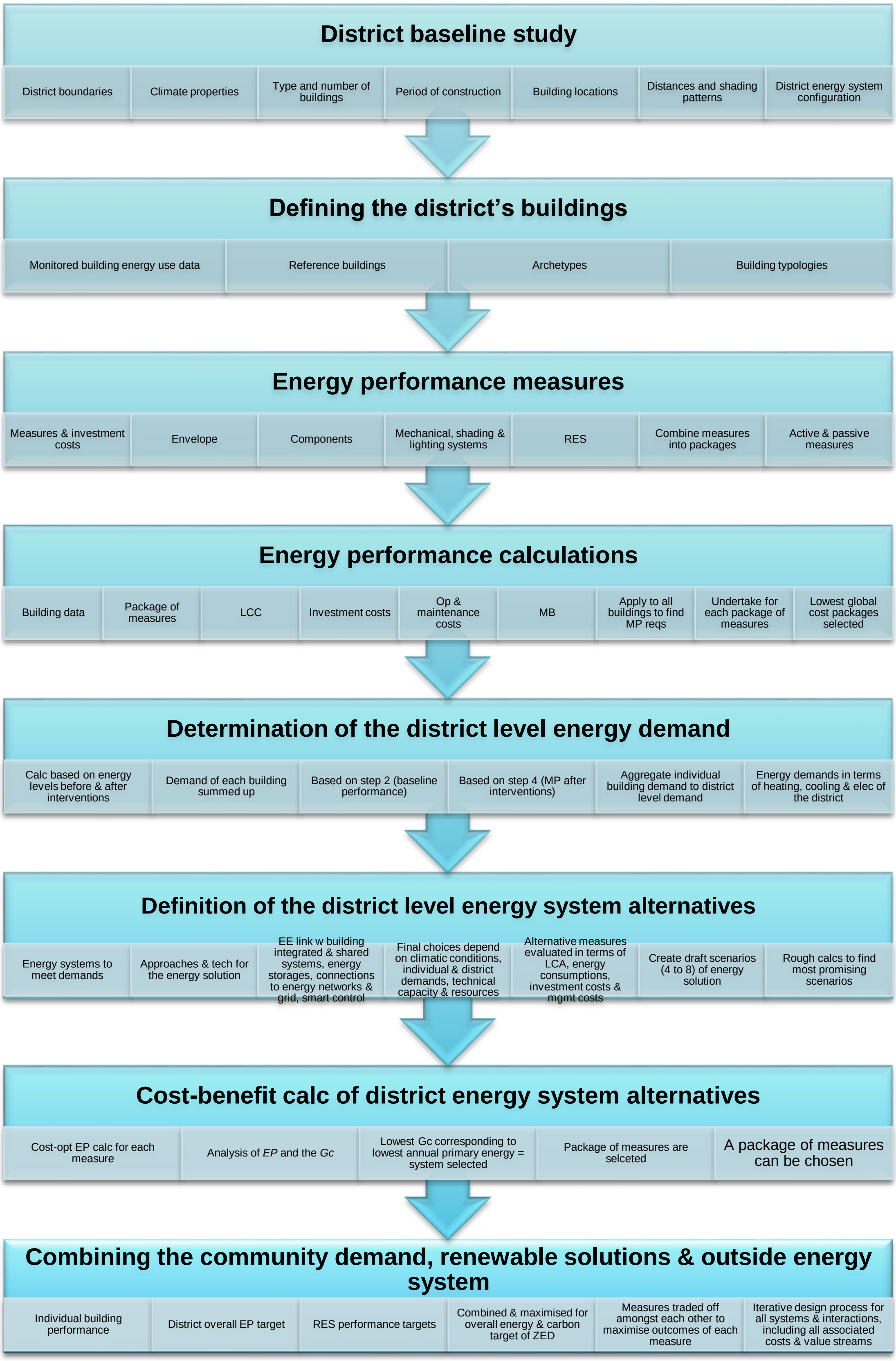
A district is a community of buildings, as it is possible to develop targets for individual buildings, it is possible to aggregate the individual building targets into an individual district target in kWh/m2/year. As per the suggestions from the interviews and the literature review, an approach to defining a district energy performance target has been developed as part of this research. This methodology outlines the broad steps to help developers and policy makers implement a cost-optimum positive or zero energy district. The approach allows for developers to find the least costly aka the "cost-optimal" route and interventions to meet the target of a zero or positive energy district, based on the energy efficiency first principle. Therefore the area on the curve would be chosen based on the lowest cost for a positive or zero energy solution. It is to be noted, that the "lowest point" of cost curve is unlikely to achieve a zero or positive district, hence the need to have a dedicated group of people, wanting to achieve the positive / zero goal for the ambition of a zero or positive energy district to be met. In order to meet the targets of the EU Green Deal and the Paris Agreement the following steps 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

Both the interviews and the literature review provided input into how an individual district target could be defined and can be undertaken in as much or little detail as the developer wishes to pursue. For example, as simply as adding all individual buildings in the district together and then dividing them by the floor area to give a whole district building target. Each building should adhere to the local building code's minimum energy requirements, thus meeting the EPBD's requirements. The developer would then have an understanding of the district's demand before and after the energy efficiency interventions and meet this by supplying the remaining demand with RE (onsite or nearby). The district will therefore have an "optimal" targeted performance and related renovation measures / packages rather than a "minimum" energy performance.

This methodology can help MS, municipalities and communities in developing carbon neutral districts, including multiple benefits and carbon emission life-cycle analyses. The overview of key steps identified are listed below and described in the following sections.

Figure 3. Steps to Developing a ZED Target & Strategy



Source: Authors' elaboration

Points 1-3 will be based on building EPCs and other available data on the district. Essentially a district's energy performance target should follow the same approach as the EPBD outlines and hence follow the rules in the local building code. Therefore, the individual buildings will follow the national or local building codes and in order for the district to understand the performance of them a "lowest-cost" / "cost-optimum" energy performance can be calculated and aggregated in order to find the kWh/m² for the whole group of different buildings. As per the current cost-optimality calculations, renewable energy should be included. Defining the district level energy system alternatives will potentially be complex due to the quantity of permutations 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.).

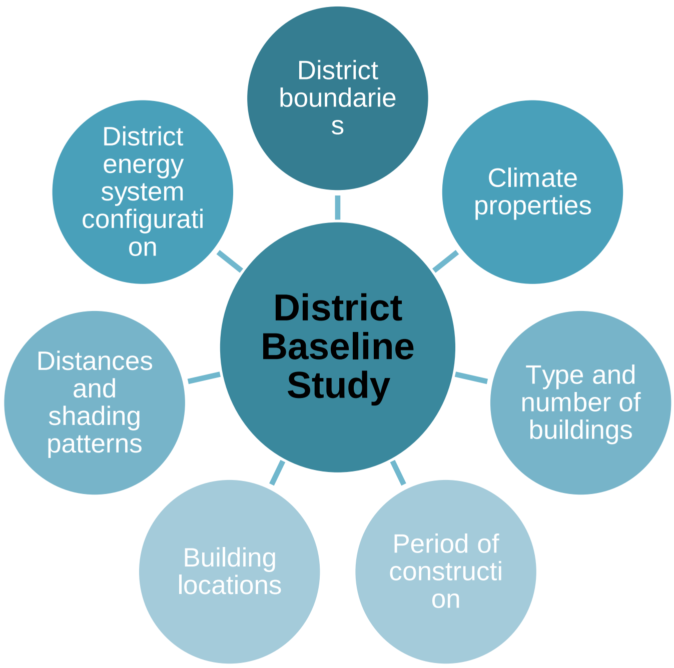
Some important points to note regarding this novel methodology are:

- The macroeconomic cost-optimality calculations are important for determining a district target linked to an EE and RE strategy and determine the benefits of the projects for society, however the private sector / project developer are likely to be less interested in the "optimal-performance" for society and more interested in the private return on investments. Therefore, it is important to think about a way to link the importance of macroeconomic aspects into the world of the private sector.
- The approach may be deemed as being complex; mainly because of potential amount of combinations of technologies on a district level is high.
- The data for these calculations are likely to exist but are probably scattered (Geissler, 2019).
- This 8-step process is developed for policy makers, yet before this can be turned into national and local legislation, it is important to collaborate with the real estate sector, in order to ensure that the process can be implemented by the people on the ground.

Therefore, it would be useful to conduct case studies in different countries to explore the feasibility of the methodology described below, this will allow for a fine tuning of the approach based on the approaches taken by the countries.

5.1 District Baseline Study

Figure 4. Stages within Step 1: District Baseline Study



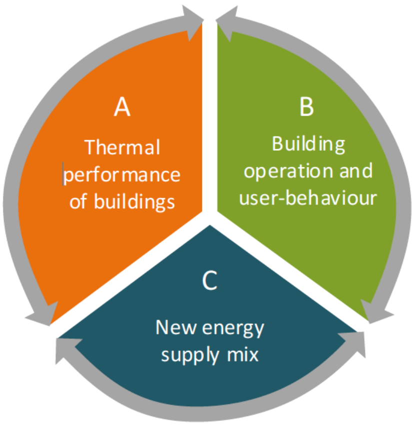
Source : Authors' elaboration based on Sartori, Napolitano et al. (2012), Polly et al. (2016). Koutra, Becue, Ioakimidis, (2016), Mathiesen et al. (2016).

In order to understand the role and interplay of the district's characteristics, the building stock needs to be first understood and a baseline benchmarking study undertaken. An overall assessment of the district should take the following list of parameters into account:

- 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
- District energy system configuration

The detail as to how developers can adjust the design parameters will depend largely on whether the district is a newly developed area with only new builds or an urban regeneration area with all old or some old and some new builds. Developing an existing district will not allow for much 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, the building stock will depend on three broad perspectives: the thermal performance of buildings, changing the operation of the buildings and user behaviour and enabling new energy supply technologies and infrastructures.

Figure 5. Key building perspectives for cost-effective ZED systems.



Source: Mathiesen et al. (2016).

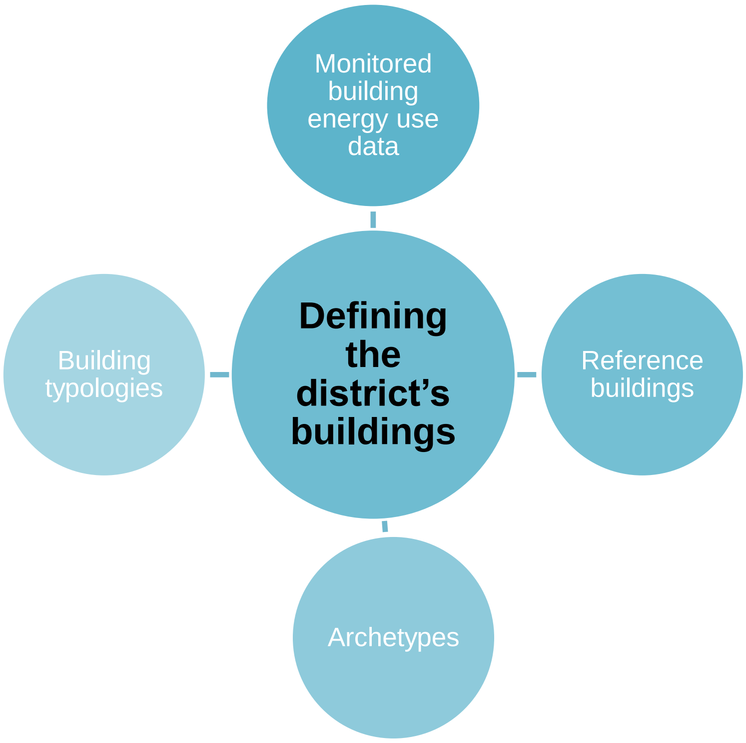
These perspectives and roles are interconnected and are key to ensuring cost-effective zero-energy system solutions. In order to determine the district's profile, the urban characteristics of the neighbourhood must be understood by the developer. Determining the boundary of the district ensures that data collected is accurate and will allow for building system energy flows to be estimated. The level of data needed for the baseline assessment is linked to ensuring a "smart" location and "smart" morphology.

The location should take climate and weather conditions, natural resource potentials and locations, land uses, meteorological data and the functional autonomy of the district into account. With regards to the district's morphology, the developers should consider the density (both residential and population), orientation and the spatial urban design and the compactness of the district.

This step should include a rough calculation of the energy consumption of the baseline case, i.e. if the district was initially built / renovated using a conventional approach with no ambitious energy goals (otherwise it will be hard to say how successful the ZED approach is).

5.2 Map the existing buildings in the district

Figure 6. Stages within Step 2: Defining the district's buildings



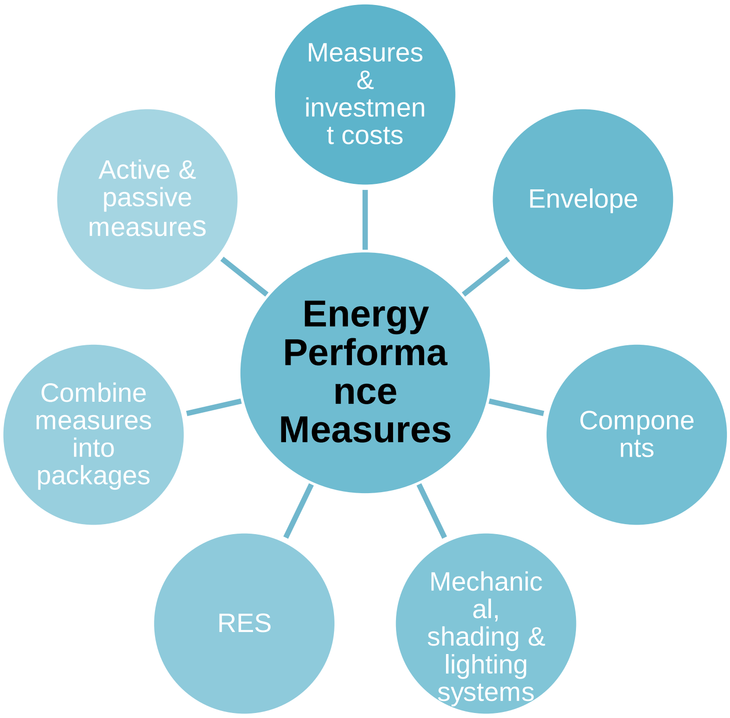
Source: Authors' elaboration based on Aguacila, (2017), Coyle (2019), Amaral (2018).

As a district will form a type of community, there will likely be a range of building typologies, ages and sizes within the building stock. The analysis of the building stock of the district can be undertaken in several ways in order to compare the energy performance improvements needed, including: monitored building energy use data, reference buildings (corresponding to real building examples), and building typologies (corresponding to common buildings).

If monitored data exists or is able to be collected, it is advised (as per the interviews) that this data be used to define the reference point of the energy consumption of each building in the district. Reference buildings can represent each building type and the geometry of the real buildings in the district and can be used and designed according to minimum requirements of the standards related to the building envelope and electrical and mechanical systems. The building typologies can be found using statistical data that extracts a set of parameters from buildings with the same makeup, including construction period, floor area, construction characteristics and energy usage.

5.3 Defining energy performance related measures

Figure 7. Stages within Step 3: Energy Performance Measures



Source: Authors' elaboration based on A2PBEER (2014), Polly et al. (2016), Aguacila (2017).

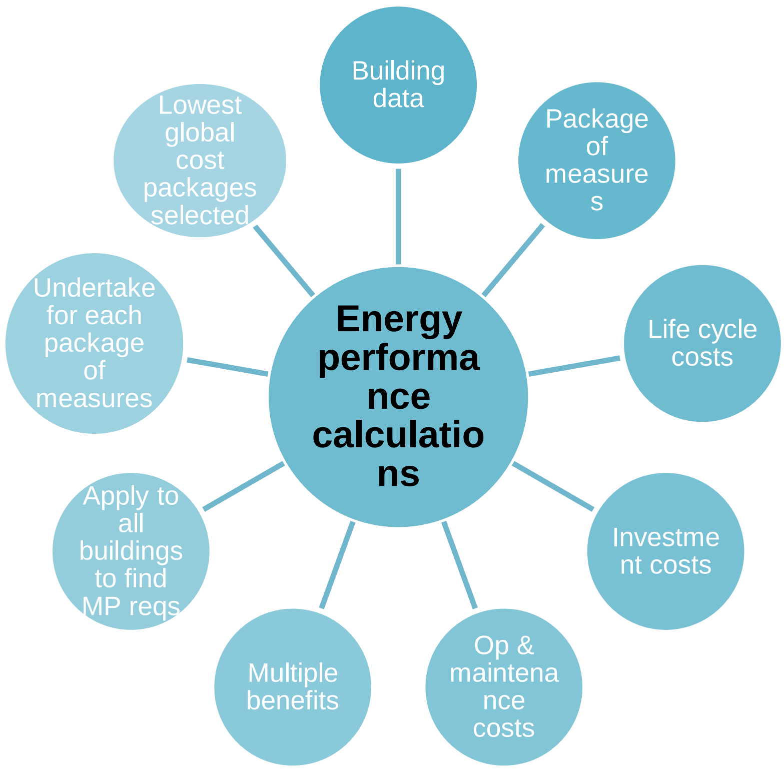
Part 3 entails recognising the existing energy-efficiency measures that can be undertaken in the district. After defining the original performance level for each building, a list of measures to increase this performance can be defined with their investment costs, considering the building types. Parameters such as envelope, components, mechanical system, shading, lighting systems and renewable energy systems should be considered in the assessment. These measures can be combined into packages that complement each other to reach carbon neutrality.

As per the EPBD and presently, most MS building codes, new buildings should meet NZEB requirements. The renovations in the district should follow a similar methodology and follow the national or local building codes, as the district is to be energy conscious and likely to be a front runner or demonstration project aiming at zero or positive energy or carbon, it is advised that, the renovation go beyond the building codes and, when possible, be deep energy renovations.

The intervention measures considered can be both active and passive as it is likely that the lifetime of each measure and component will differ, additionally it is important from a cost-optimal perspective that the high-value long-term energy savings are achieved first. Acting on the building envelope is essential in reducing the demand; active systems can then be installed / adapted to the new building demand. Before applying the cost-optimal methodology, the developers need to ensure each strategy is technically feasible, according to the characteristics of the building.

5.4 Energy performance calculations

Figure 8. Stages within Step 4: Energy performance cost-opt calculations



Source: Authors' elaboration based on Aguacila (2017), Barthelmes et al. (2016), Hamdya et al. (2017), Kalaycıoglu and YılmazIstanbul (2017), Shnapp (2020).

Using the buildings' baseline, the measures and packages of measures, the EPBD's cost-optimality calculations can be applied to the buildings in the district in order to find their minimum performance values. At this point the buildings that cannot achieve NZE should be identified as they can be compensated by other buildings that can do more. This would be an input for step 8. A minimum performance calculation will be undertaken for each identified package of measures applied to the buildings, input data will include energy performance as annual primary energy consumptions 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.

As per the cost-optimal calculations, the package of measures for each building and aggregated buildings with the lowest global cost that will support a positive or zero energy solution will be chosen as "cost-optimal solution". This methodology allows for the comparison of scenarios integrating different energy-efficient and renewable measures. 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 application of this calculation methodology is suggested by the EU for the calculation of the optimal levels as a function of the costs for the minimum energy performance requirements, so called cost-optimal methodology (EU 244/2012). 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. Both individual buildings and districts will reap many benefits including, but not limited to:

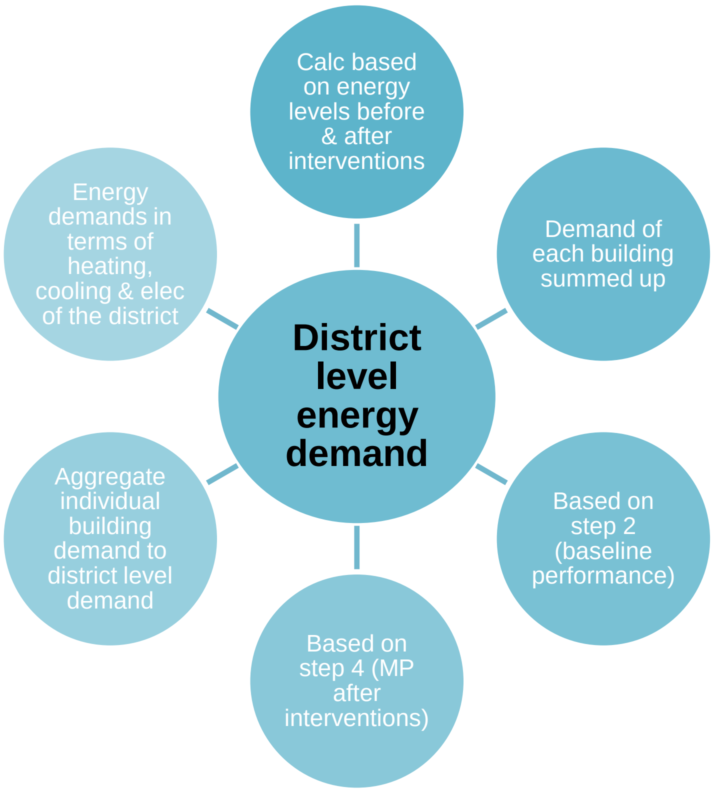
- Economic
- Energy and social security
- Health and wellbeing
- Environmental and biodiversity

These can and should be included into the cost-optimal calculations and can be added to the global cost calculations.

In addition, where relevant, a life-cycle analysis of all components, measures and environmental considerations that are included within the cost-optimality analysis can be undertaken in order for the amount and cost of carbon to be understood and included from a cradle to grave perspective. The most established approaches / standards that are advised to be used are the LCA and the LCC (ISO 15686, 2008).

5.5 Determination of the district level energy demand

Figure 9. Stages within Step 5: Determination of the district level energy demand

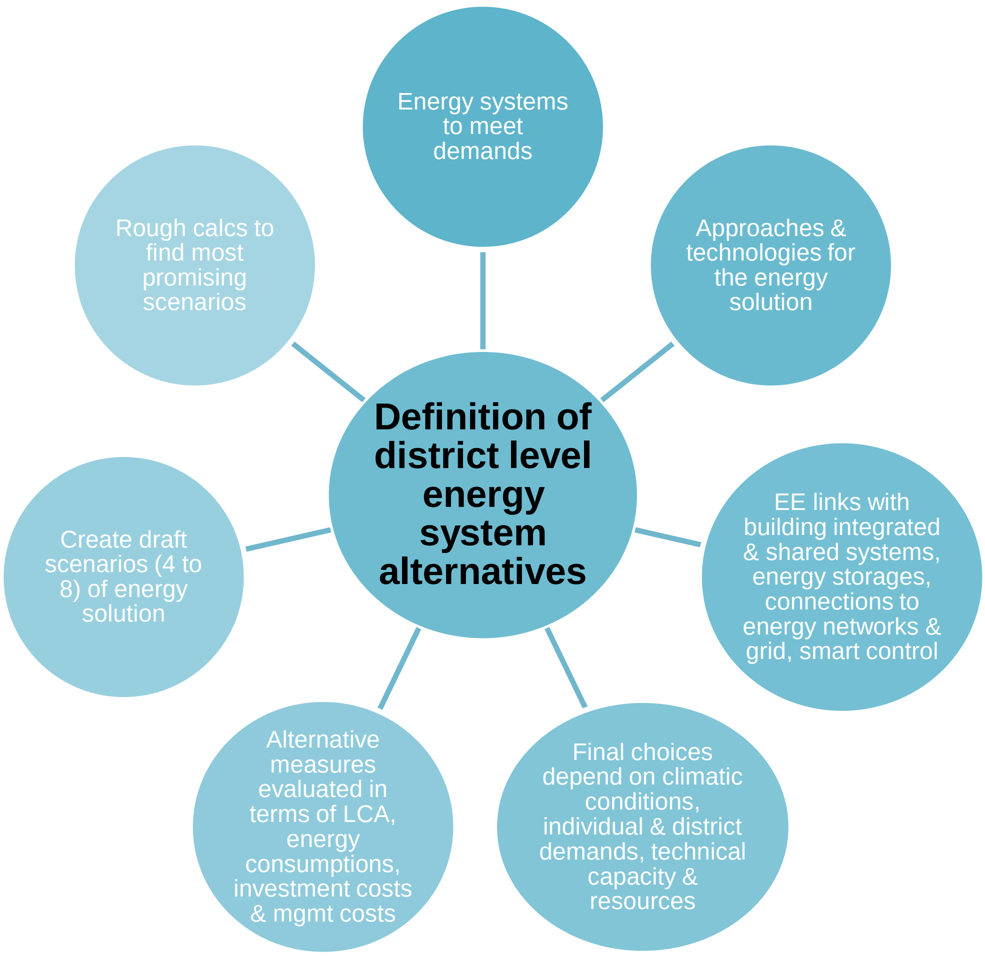


Source: Authors' elaboration based on Aguacila (2017).

The district energy demand, which will reveal the energy saving potential of the district, will be calculated based on the energy levels of the buildings before and after the proposed energy interventions. The energy demand of each building within the district will be calculated and then aggregated to reach the total district energy demand. Based on either the monitored or reference buildings being used as the building baseline and the minimum energy performance requirements of each building in the district being used as the final required demand of each building. The results of each scenario will allow for the developers to know the energy demand per building and can hence be aggregated to a district level demand.

5.6 Definition of the district level energy system alternatives

Figure 10. Stages within Step 6: Definition of the district level energy system alternatives



Source: Authors' elaboration based on Polly et al. (2016), Aguacila (2017).

As the district energy demand is established from the outcomes of the cost-optimal calculations, the developers are able to understand the energy demands in terms of heating, cooling and electricity of the district and hence employ energy systems that can meet and go beyond these demands. This part reviews the approaches and technologies that can conceivably be part of the district's energy solution (combining the energy efficiency levels with building integrated systems, shared systems, energy storages, connections to energy networks and grid, smart control, etc.) There are many options available to the developer and their final choices will depend on the climatic conditions, individual and district-wide demands, technical capacity, and natural resources within the district. A range of alternative measures should be evaluated in terms of life-cycle assessment, energy consumptions, investment costs and long-term management costs.

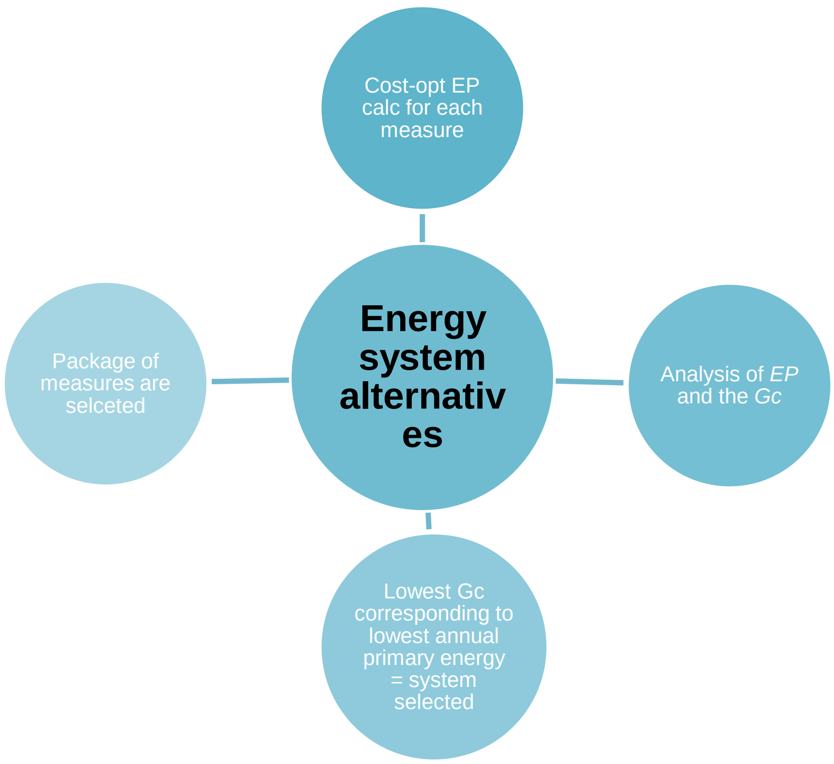
In terms of thermal district systems for heating and cooling, a wide variety of options and technical systems already exist, therefore the measures evaluated by the developers will depend on site-specific opportunities and limitations.

A wide range of renewable energy technologies exist in Europe and each MS, some of which can be used together to complement each other, the developers should look into the possibilities for:

- 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.

5.7 Cost-benefit calculations of the district's energy system alternatives

Figure 11. Stages within Step 7: District energy system alternatives



Source: *Authors' elaboration*

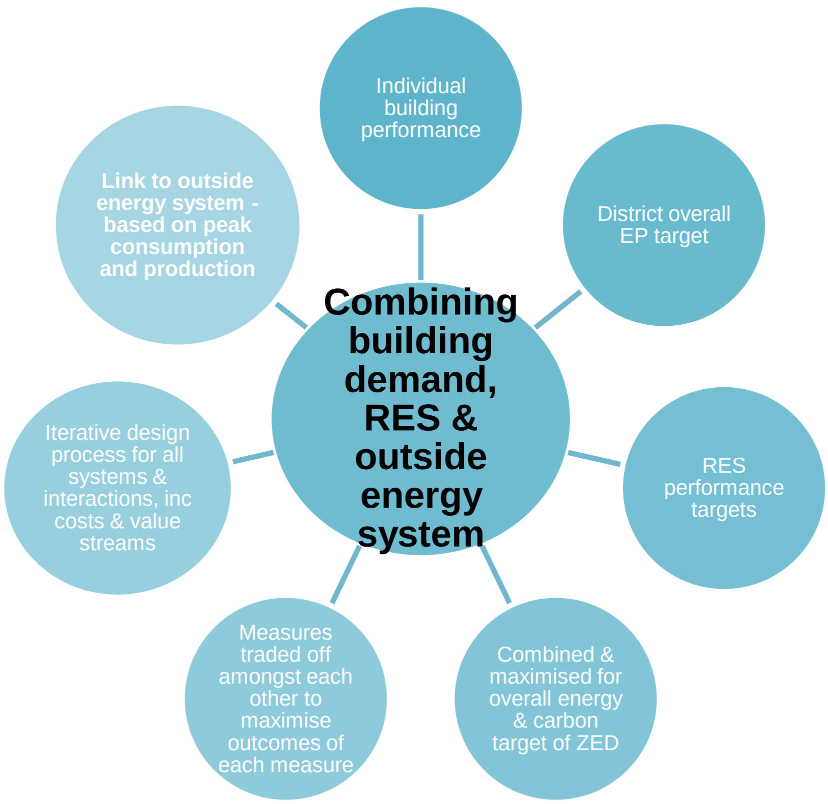
For each of the measures defined by the developers for the district energy system, a cost-optimal energy performance calculation can be made, as undertaken for each of the individual buildings in the district. The cost-benefit analysis of these systems will look at the *energy performance* (as annual primary energy use) and the *global costs* (including the investment costs together with long term operating and maintenance costs). The option with the lowest global costs that can meet or go beyond the community's energy demand for the district will be selected.

A package of measures may be chosen. The package could consist of individual building renewable energy systems, an on-site or nearby renewable energy farm and some form of renewable heating and or cooling system, e.g. district heating and cooling, micro networks, etc. In this step the district should create a few (e.g. 4 to 8) draft scenarios of what the energy solution could be like and then make rough preliminary calculations based to find out the most promising scenarios (e.g. 2 or 3 scenarios). The district can also combine parts of different scenarios to a new synthesis.

It is to be noted that the catchment area of a district may not be sufficiently large enough for the RES to supply the energy demand required by the community. In this case, it may be useful to consider the community's interaction with broader regional territories. ZEDs and PEDs should therefore not exclude a wider regional approach; in the case that this would be the best system boundary for optimisation.

5.8 Combining the building solutions, RES solutions and outside energy system

Figure 12. Stages within Step 8: Combining the building solutions, RES solutions and connection to grid



Source: Authors' elaboration.

Together, the individual building performance, the district overall energy performance target and the renewable energy systems performance targets are to be combined and maximised to give an overall energy and carbon target of zero or positive energy for the district. As an example, step 4 assesses the buildings that are not capable of achieving a nearly zero energy target, similarly it highlights the buildings that can be energy producers. These measures can be traded off amongst each other to maximise the outcomes of each measure. Therefore, an iterative design process is needed that accounts for all systems and their interactions, including all associated costs and value streams, minimising the carbon emissions of the district.

This part will provide district scenarios. An analysis of the selected scenarios that enable the communities to be positive or zero energy can be undertaken by the developers in order to find the optimum energy performance at the lowest cost.

The relationship the community will have with the outside energy system will depend on the consumption and production peaks of the district. ZEDs or PEDs should not necessarily be isolated energy islands but rather integrated and useful parts of the greater energy system. Since they will have more or less intense overproduction (e.g. solar energy during a spring day) and consumption peaks (e.g. a very cold and dark winter evening), the developers will have to take these into account when planning the district. Essentially, the district being connected to the grid can be seen as a backup for peak demand, ensuring the community has a security of supply or as a means to export surplus energy.

5.9 Conclusions of a ZED district target

This 8-step approach is a first attempt to develop a methodology for the development of district targets and optimisation techniques that can be adopted and adapted to any policy or implementation level. As the EPBD already sets out a formula and framework of cost-optimality, the approach taken uses this as a framework for a district approach.

As the literature suggests, it is important to find the baseline of the district before targets can be set, this is location and climate dependent. Hence not all community targets will be the same; some regions / districts will have the technologies and climate to reduce the consumption in their buildings whereas others will have the natural resources to supply the energy demand to the district. What is clear is that a multi-mechanism approach must be taken by the districts in order to find the optimal best fit solution for the district, based on the Energy Efficiency First principle. The solution for each community can be obtained in a "lowest-cost" or cost-efficient manner using the defined cost-optimal mechanism of the EPBD.

6. CONCLUSIONS

The literature review and the interviews undertaken in this study came to a common conclusion: although there are still some applicability barriers - *it is possible to develop cost-optimal energy performance targets for a ZED.* The EPBD's cost-optimality calculation methodology, set up 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, ending in having a locally adapted energy performance target of zero or positive energy and an optimised zero or positive energy district solution. The processes will depend on the morphology and building typology of the district, for example there will be fewer steps to take (or less elements to consider) in 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 deeper understanding of how targets can be set by districts and how policy makers can provide an 8-step methodology guiding MS and developers on how to develop a zero or positive energy district. The general conclusions of the paper, in accordance with the views of the interviewees and literature review, are:

- By means of expert interviews and a literature review: **a methodology for defining a ZED / PED target was developed based on a general consensus** amongst the experts interviewed; this approach was also supported in a few of the reviewed literature reports.
- The **districts should be positive energy districts** (not nearly or net "ZEDs") supported by smart grids and renewable and efficient technology.
- Although it is imperative to ensure RES are included within the district's plans, the project developers / municipalities must ensure **the energy efficiency first principle is used to guide the district's target.**
- Overall, in order to develop a performance target for an energy 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 obtained either using measured data, reference buildings or archetypes** of the building typologies within the specific district.
- In order to ascertain the minimum performance in a cost-optimal manner, this paper finds 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), thus ensuring the carbon footprint of the district is accounted for and is neutral.

- Similarly, **the multiple benefits of a PED / ZED 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 / ZED, individually and as a community.

Before this 8-step process is used by project developers or written into local, national or European legislation it is to be noted that:

- In terms of the applicability of the methodology to real-world, existing or new PED / ZED cases, the **researchers suggest for this methodology to be put to practice** and further explored.
- Both the research and interviews **highlighted the need for data, monitoring methodologies and common definitions** that are currently scarce or missing in current ZED experience.

When moving forward with this 8-step methodology, it will be important to test the methodology out on real life ZED projects. This can be achieved by collaborating with municipalities and / or project developers who are undertaking a ZED project. It could also be tested on PEDs / ZEDs that have already been finalised or are in a development stage to see how the results compare to the final decisions made by the developers / municipalities. Providing baseline data for highlighted case study projects is available, this methodology can be applied, fine-tuned and further developed.

Although there are many considerations to take into account when designing a ZED, this report sheds light on an 8-step process endorsed by building experts that will allow for project developers not only to have a district target but, in when defining the community target, the developers will also be able to develop a district energy strategy. By following each step, the district will essentially have an energy efficiency and renewable energy roadmap – from developing a baseline study to having a cost-optimal approach to designing and developing a zero energy or positive energy district.

Zero energy districts represents an interesting area for research and policy which is expected to be further explored in the future, building on 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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List of abbreviations and definitions

BREEAM - Building research establishment's environmental assessment method
CHP - Combined Heat and Power
CO2 – Carbon Dioxide
CO2eq - Carbon Dioxide Equivalent
EC - European Commission
EE – Energy Efficiency
EED – Energy Efficiency Directive
EEO – Energy Efficiency Obligations
EPBD – Energy Performance of Buildings Directive
EU – European Union
EU28 – European Union 28 countries
GDP – Gross Domestic Product
GHG – Greenhouse Gas
H2020 – Horizon 2020
HVAC - Heating, Ventilation, and Air Conditioning
IEA – International Energy Agency
IPCC - Intergovernmental Panel for Climate Change
kt - kiloton
Ktoe - Kilotonne of Oil Equivalent
LCA - Life cycle assessment
LEED - Leadership in energy and environmental design
mn - minimum
MS – Member States
Mt - Megatonne
NEB - Non-Energy Benefits
NECP – National Energy and Climate Plan
NPV - Net Present Value
NZEB- Nearly Zero Energy Building
NZED - Nearly zero energy district
OCED - Organisation for Economic Co-operation and Development
PV - Photovoltaics
SE4All – Sustainable Energy for All
SETAC - Society of Environmental Toxicology and Chemistry
TWh - TeraWatt Hour(s)
U-ZED - Urban zero energy district (Tool)
UN – United Nations
UNEP - United Nations Environment Programme

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Annex 1 – List of Sustainability Criteria for ZEDs

Annex 1 provides a list of sustainability criteria to be considered by local actors in order to develop a holistic zero energy district. Although this report will not take all aspects into consideration, as it focuses on the building sector within a zero energy district, it is important that the other factors are considered when developing a ZED.

Table 2. List of criteria to be considered by municipalities or developers of zero energy districts

Theme	Target	Objective	Indicator
Energy-water-waste nexus	Triple net zero (energy/carbon, water and waste)	Net zero energy/carbon	-Energy consumption and greenhouse gas emissions of the community
		Net zero waste	-% of waste recycled on-site and nearby -Quantity of waste produced per activity and per inhabitant
		Net zero water	-% of water re-used on site -Water consumption per activity and per inhabitant
Governance	Empowering local actors and citizens	Engagement of local actors and citizens	-% of inhabitants involved in the projects of the neighbourhood -% of citizens trained on environmental behaviour -% of citizens, environmental-friendly
Social equity	Functional and social mixing	-Affordability of the neighbourhood	-% of social housing -% of middle-class housing -% of privately-owned houses -% of population with support from the municipality to access cultural and sport activities
		Neighbourhood diversity	-% of m^2 of offices, % of m^2 of shops, % of m^2 dedicated to SMEs, % of m^2 for social, cultural and sport activities
		-Inter generational diversity	-% of each housing type (1 bedroom, 2, 3…)
Economic efficiency	Cost-effectiveness of the project	Contribution of the project to the local economy	-% of the project financed by the municipal budget -% of the project contribution to the municipal budget -Number of sustainable jobs created locally and % of unskilled ones
Conservation	Resource preservation	Reducing urban sprawl	-Number of inhabitants per m^2
		Ensuring the continuity of existing biodiversity and promoting new ones	-Ratio of green space (built areas/green areas) -Number of green spots -Number of species preserved -Number of new species -Water surface per capita
		Efficient use of raw materials	-% of re-used (from demolition) construction material -% of recycled construction material -% of certified material for health and environmental purposes -Embedded energy of the construction material used (J/tonnes) -% of low-GHG emission construction material -Travelling distance of each group of construction material (km/construction material)
Quality of life	Environmental friendly quality of life	Reducing pollution	-% of main pollutants in the air
		Eco-friendly mobility	-Average distance from each building to the closest public transport stop (m) -No. of parking places per dwellings -No. of parking places per m^2 for tertiary buildings -No. of m^2 per dwellings and m^2 of tertiary buildings dedicated for bikes -No. of parking places dedicated to car-pooling -Bike lines, pedestrian areas, garages for bikes -No. of km travelled by each occupant/user of the neighbourhood by different transport types
		Winter and summer thermal comfort	-No. of hours per year where the inside temperature is higher (summer) or lower (winter) than set point temperatures
		Digitalisation	-No. of inhabitants with internet access - Public access to internet
		Eliminating insecurity	- No. of complaints per year for thefts and personal attacks
		Growing food locally	-m^2 of vegetable garden per dwelling
		Making public facilities accessible to all including handicapped and old people	-Average distance from each building to major public facilities -Easy access for handicapped and old people

Source: Saheb, et al. (2019)

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