Title: The Zero Energy concept: making the whole greater than the sum of the parts to meet the Paris Climate Agreement's objectives

Short Title: Zero Energy for cities: Strategies to meet the 1.5°C target

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Highlights

- Identification of projects implementing a zero energy concept at community level in Europe.
- Novel framework for analysing community scale energy targets within broader urban sustainability criteria.
- Analysis of four pioneer zero energy communities, identifying strategies that support and underpin successful delivery.
- A hierarchical approach (energy sufficiency, energy efficiency and supply with renewables), is found to help achieve a zero energy community.

Keywords:

Zero energy/carbon communities, sustainable communities, urban/local governance, citizen engagement, local energy planning, local energy transition

Summary

Urban areas, which are expected to host more than two-thirds of the world's population by 2050, provide unique opportunities for the implementation of the radical policies needed to meet the Paris Climate objectives. Pioneer municipalities in Europe are leading the transformation needed to achieve zero energy and/or zero carbon communities by integrating policies across different sectors (buildings, transport, waste, water and energy supply). Critical factors identified through the analysis of existing initiatives include first, having clearly defined long-term targets, community boundaries and values, second, linking targets to community priorities such as economic development and urban renewal, and third, transposing long-term goals into milestones and short-term objectives to avoid discouraging the community. Challenges identified include first, capacity building, second, citizen participation and third, adequate project documentation as well as monitoring of the achievements.

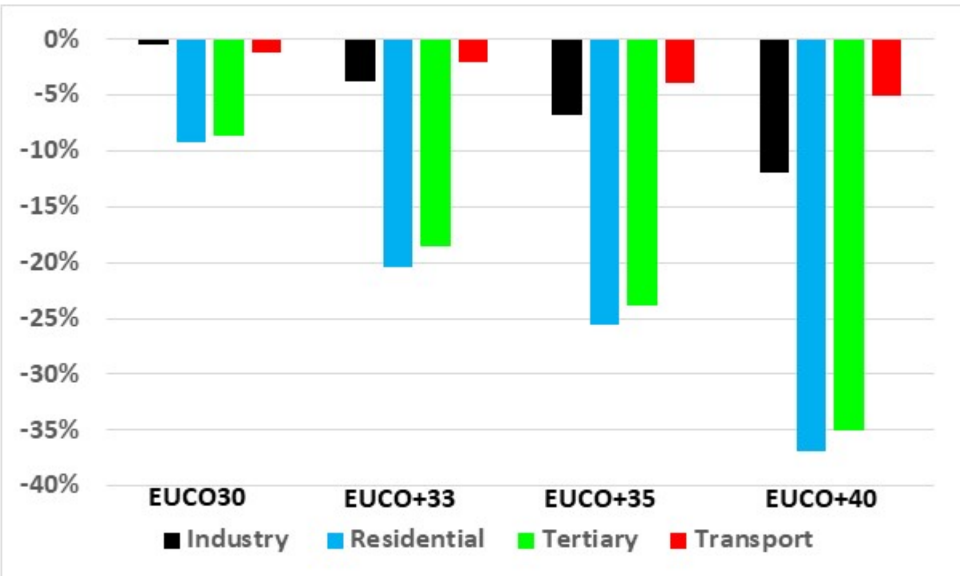
Introduction

In 2013, urban areas were occupied by 53% of the global population and were responsible for 64% of the global primary energy use and 70% of the global CO_2 emissions [1]. By 2050, urban areas are projected to host more than two-thirds of the global population [2] leading to an increase in cities' contribution to global warming and energy demand. The level of resilience of urban areas to climate change will, therefore, determine the global resilience as cities and metropolitan areas are considered to be the scale at which the battle for sustainability and against climate change will be won or lost [3].

The importance of cities and local authorities in making the planet sustainable came to prominence at the United Nations Earth Summit Conference in 1992 by introducing the concept of local Agenda 21 [4,5**,6]. European cities confirmed their commitment to sustainable development two years later in the Aalborg Charter [7] which constituted the European launch of the development of local Agenda 21 and consequently of sustainable com-munities by the signatories. In practice, Agenda 21 brought sustainable development goals to the urban scale. It initiated the implementation of locally contextualised solutions ranging from retrofitting existing infra-structures to building new sustainable ones and from focusing on ecological innovation to promoting socio-economic measures [8,9]. The implementation of Agenda 21 has also introduced new governance relation- ships between diverse actors such as local authorities, national governments, industry, experts, practitioners, non-governmental organisations and citizens [8,9]. The level of ambition of the local Agenda 21 implemented in European cities is variable and their ultimate impact is difficult to measure [10,11]. However, they are generally considered successful in raising awareness on sustainability at local level and in increasing the participation of local civil society [5**]. Agenda 21 has established mechanisms for city governments and urban communities to take action on climate change, and generated evidence on their outcomes.

Recent urban initiatives in Europe (such as Sustainable cities, Covenant of Mayors, Smart cities, C40) have worked on reducing energy consumption and green- house gas emissions at the local level with a special focus on the built environment given its estimated large energy savings potential (Figure 1). Energy measures implemented at local level are embedded within broader sustainability initiatives. The most ambitious ones aim at closing material and energy cycles by considering urban areas as ecosystems [12,13,15]. These initiatives link local systems of energy production and consumption, use local energy sources such as solar, geothermal, biomass and wind, and/or generate energy from waste and wastewater produced on site. The aim of these initiatives is to achieve zero energy and zero carbon or Z2 (zero energy and zero waste) or Z3 (zero energy, zero water and zero waste) communities by putting into practice the waste-energy nexus or the waste-water-energy nexus [12–16].

Figure 1: Projected savings potential in final energy consumption per sector in Europe by 2030



Source: PRIMES 2016 modelling results.
Note: Energy savings potential is calculated as a difference between the final energy consumption in the baseline scenario which aims at 27% energy efficiency target in 2030 and in the scenarios with more ambitious 2030 energy efficiency targets (30%, 33%, 35% and 40%).

This paper focuses on the zero energy target at a com-munity level, but some of the projects analysed aim at zero carbon and not necessarily at zero energy. The discussion on the differences between the zero energy and the zero carbon concepts is out of the scope of this paper. However, the authors distinguish between the two targets as emphasised by each project. The paper questions how successfully the target set (either zero energy or zero carbon) can be achieved within broader sustainability approaches. Analysis of pioneer projects shows that closing the energy loop at local level makes it possible to achieve zero energy communities.

The authors present findings from 62 pioneering communities, which are reducing their energy consumption and greenhouse gas emissions, with in depth discussion of the four projects which set either a zero energy or a zero carbon target. The implementation of the zero energy or the zero carbon concept is, in most of the identified initiatives, considered within broader local sustainable development agenda. Though the sustainability objectives do not apply equally across the initiatives, the authors demonstrate that the implementation of the zero energy or the zero carbon concept at local level requires a deep understanding of the interactions between the energy or carbon targets with other local sustainability priorities. These interactions explain the trade-offs decided by local actors as well as the revision of the ambition of the energy or the carbon target in some projects and the strategies developed to overcome barriers to higher energy and carbon savings ambition at local level [17**,18].

The authors have grouped in an analytical framework the sustainability criteria considered by local actors and the indicators used to assess progress towards each identified sustainability goal (Table 1). The proposed framework can be used for further analysis of mitigation pathways compatible with the 1.5°C target within the broader sustainability goals agreed, more recently, under the United Nations framework for the 2030 agenda for sustainable development [19]. This novel framework has been created to show areas of interaction between energy targets and broader sustainability goals that the community approach allows. The authors argue that this broader framework can support the implementation of zero energy or zero carbon communities because it can make it possible for communities to transcend the energy performance of an individual building to close the energy loop at a local level. The paper provides arguments that closing this loop, and working at a com-munity scale, rather than on the more typical individual building scale, offers a mitigation path towards the deep decarbonisation required to meet the Paris Climate Agreement target of 1.5°C [20]. The authors conclude by discussing options policy-makers could undertake to accelerate the scaling-up of existing community scale initiatives.

Table 1: Sustainability targets and indicators considered in the identified zero energy community projects

Theme	Target	Objective	Indicator	References	Project
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	[12- 15, 54-58]	BedZed, Hammarby, Apeldoorn EVA-Lanxmeer, Vaxjo, Hillerod, Haryberg
		Net zero waste	-% of waste recycled on-site and nearby -Quantity of waste produced per activity and per inhabitant	[12-15, 56-58]	BedZed, Hammarby,
		Net zero water	-% of water re-used on site -Water consumption per activity and per inhabitant	[12-15, 55-58]	BedZed, Hammarby, Bo01
Governance	Empowering	Engagement of	-% of inhabitants	[12-15, 54, 56-58]	BedZed,

	local actors and citizens	local actors and citizens	involved in the projects of the neighbourhood -% of citizens trained on environmental behaviour -% of citizens, environmental-friendly		Hammarby, Kronsberg, Bo01, Vesterbro, Hvar, Cernier
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	[15, 54,55, 57, 58]	BedZed, Hvar, Cernier, Concerto projects
		- Neighbourhood diversity	-% of m² of offices, % of m² of shops, % of m² dedicated to SMEs, % of m² 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	[12-15, 56-58]	Hammarby, BedZed
Conservation	Resource preservation	Reducing urban sprawl	-Number of inhabitants per m²	[15, 56, 58]	BedZed
		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	[12-14, 54, 55, 57]	Bo01, Hammarby, Arquata.
		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)	[15, 54,55,58]	BedZed, Bo01
Quality of life	Environmental friendly quality	Reducing pollution	-% of main pollutants in the air	[12- 15, 54-58]	All

	of life	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	[12-15, 54-58]	BedZed, Hammarby, Bo01, concerto projects for new developments
		Winter and summer thermal comfort	-No. of hours per year where the inside temperature is higher (summer) or lower (winter) than set point temperatures	[12-1, 54-58]	All
		Digitalisation	-No. of inhabitants with internet access - Public access to internet	[15,27, 54, 55, 58]	BedZed, Smart cities projects
		Eliminating insecurity	- No. of complaints per year for thefts and personal attacks	[15, 54, 55]	BedZed, Bo01, Vesterbro
		Growing food locally	-m2 of vegetable garden per dwelling	[15, 54, 55]	BedZed
		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	[12-15, 54-58]	All

Academic and policy frameworks for zero energy communities

The zero energy concept has been widely investigated over the recent years at the building scale. The focus has been on defining frameworks [21,22], assessing market opportunities and policies [23,24], or investigating issues related to energy generation with special attention paid to integrating solar photovoltaics and energy storage within the building itself or nearby [25]. The impact of user behaviour [26] and the risk of summertime overheating in zero energy buildings and associated health problems, have also been investigated [27]. This section presents a review of the different approaches targeting zero energy at the community level and synthesises the key factors considered for achieving the zero energy target.

From a policy perspective, United States' Energy Independence and Security Act was the first policy instrument to introduce the zero energy concept for individual buildings in 2007 [28]. This was followed by the European Union's Energy Performance of Buildings Directive, EPBD, in 2010 [29]. In Europe, all new buildings will be nearly zero energy by 2021 [29] while in the United States, buildings are required to be net zero energy by 2030 [28]. These two policy frameworks also call in both regions to explore pathways to renovate existing buildings to zero energy standards and to implement cost-effective solutions.

In practice, several zero energy buildings have been constructed in different climate zones demonstrating the feasibility of the zero energy concept for individual buildings. Most of these existing zero energy buildings are new residential buildings or office buildings. The zero energy tower in Dijon (France), for example, aimed at zero final energy consumption for a new high-rise office building [30]. More recently, the Netherlands pioneered zero final energy consumption for renovated residential buildings [24,31]. The concept is being promoted as "zero in the meter". Developers of the project have industrialised energy retrofits by factory producing zero energy renovation kits based on 3D scanning of occupied buildings. The industrialisation process has led to a reduction of the on-site intervention to one week and halved energy renovation costs. The target is to deliver zero energy renovated homes at €400/m² [24,31]. This would make the renovation work acceptable for the end-user and net zero energy renovation economically accessible for social housing and affordable for low-income families. The Dutch project focuses on post Second World War buildings, constructed before stringent building energy codes were implemented in the Netherlands. There is, however, little evidence on zero energy retrofits of older buildings at scale.

Making each individual building highly energy efficient and energy producer is the aim of the EPBD. However, when it comes to existing buildings, this objective is not always technically feasible and economically viable at individual building level. A core issue of the individual building approach is that different buildings require different interventions to achieve the same result. Another issue is that neighbouring buildings are not able to directly contribute to each other's carbon reduction target. A highly energy performing building generating decarbonised energy will typically export its surplus of energy through the grid without necessarily contributing to directly reducing carbon emissions of the poorly per- forming neighbouring building. The system benefits and environmental gains from local consumption of low car-bon energy are currently being researched [32] to address the needs of cities to balance the electricity system locally. Moreover, the increased development of more decentralised, small scale renewable generation systems is leading to more clustering of buildings to share renew-able electricity [33]. The opportunities for more local consumption of renewables also rises through for example innovative peer-to-peer trading schemes which allow local communities to optimise their use of local energy [34,35]. These issues have seen the concept of zero energy communities gaining prominence in both research and policy-making circles. The French law on self-energy consumption is a good illustration of policies aiming at putting this idea into practice [36].

The zero energy community concept appears in academic research on decentralised scenarios for energy systems transition modelling [34], peer-to-peer energy trading analysis, or case-study analysis of city's Climate Action Plans [35]. However, few papers exist on how to design and/or implement the zero energy concept at a community scale level. Studies on achieving zero energy at the community level have investigated single issues only. In fact, the focus has been either on urban form and its impact in reaching zero energy consumption [37,38] or on optimising the use of solar energy solutions, both active and passive ones [39–41]; or on the potential and the increasing future role for energy storage to facilitate the use of intermittent renewables [42]. Similarly, the impact of transport in achieving a zero energy community has been investigated but only from the transport sector's perspective rather than as an integrated part of the services used within the community [38,43].

From a policy perspective, the concept of a zero energy community has proven to be hard to implement and evaluate. The United States' army is pioneering a net zero energy community programme for selected camps based on the requirements to make all military camps net zero energy by 2058 [44]. The implemented concept is based on the water-waste-energy nexus and requires meeting the triple net zero target [45]. In France, the 'Grenelle' law (2009) requires new neighbourhood developments to be sustainable [46]. Sustainability criteria go beyond energy issues, but the law does not specify the level to be met by each criterion [47]. As a result, none of the sustainable neighbourhood projects developed since the law's promulgation, aims at zero energy consumption.

There is, therefore, a need for a multi-sector investigation about how the zero energy concept at a community level can be achieved in practice within the broader local sustainability agenda. The aim is to gain a better understanding of the trade-offs and the synergies between climate mitigation actions and the sustainability goals. This paper performs this investigation by analysing the implementation of zero energy communities, appraising the additional sustainability priorities that drive the community developments, and discussing how these priorities can support or undermine the achievement of ambitious energy targets at local level.

Local energy governance and citizen engagement to achieve zero energy communities

The role of local actors and citizens is another key parameter considered in the community scale approach to achieving zero energy and zero carbon cities. Multi-level governance and empowerment of local actors has been a pillar of sustainability since its introduction by the United Nations Earth Summit Conference [4,48] through the Agenda 21. The aim is to activate the dynamic potential of each level of governance to achieve a global mobilisation of all actors [5**]. Current climate negotiations provide evidence that the top-down era is ending, and local climate governance is gaining importance [49]. The agreement achieved at COP21 has partly resulted from the worldwide emergence of multi-level governance and the direct or indirect inclusion of various actors in the negotiations. The recent call by municipalities and cities in the United States to continue the implementation of the Paris Climate Agreement within their boundaries, despite the withdrawal of the country from the Paris accord, shows the increasing role of transnational municipal networks in governing climate change [50]. Academic research has matched this trend by putting resource and interest into understanding energy consumers, behaviour and the opportunities of demand side response to generate system level impacts.

In the European Union, institutions such as the Committee of Regions and the Directorate General for Regional Cohesion have encouraged and extended the implementation of multi-level governance to the neighbourhood level by emphasising the parallel processes of decentralisation and Europeanisation [51]. The EU Committee of the Regions has established the concept of multi-level governance as a guiding vision for the European regional policy including energy policies. The aim is to make European actions more effective by establishing a new culture of inter-institutional and political cooperation [52]. The 62 projects analysed in this paper were all partly financed with European funds and many of them included a component related to the active participation of local actors in the societal changes needed to make Europe sustainable [53]. This paper is the first systematic review of such projects which focuses on understanding how the shift to local governance enables zero energy targets to be achieved at a neighbourhood scale.

Methodology

The research has been carried out in stages. The first stage was a literature review of peer-reviewed papers available on Science Direct and Google Scholar and grey reports, covering publications from 1992 to 2017. The keywords were zero energy/zero carbon community, sustainable communities, urban/local energy governance, citizen engagement, local energy planning, local energy production and local energy transition. In parallel, relevant European projects databases (Intelligent Energy Europe, CONCERTO, FP7, Covenant of Mayors) were used to identify case studies. In total, 62 initiatives aiming to reduce energy consumption and greenhouse gas emissions at a local level were identified (Appendix A). At this stage of research, a balance was kept between different geographical areas within Europe and projects analysed have a range of energy objectives. Targets ranged from 10% energy savings target and 5% of local production of energy from renewable sources to more ambitious ones such as self-energy sufficiency, Z^2 (zero energy, zero waste) or Z^3 (zero energy, zero water, zero waste) in the most ambitious initiatives (Appendix A). Projects were screened for clarity on energy achievements and the availability of monitored energy data at least for one year. Moreover, the literature review allowed the identification of additional sustainability criteria used by local decision-makers and highlighted the trade-offs considered between energy targets and other local sustainability priorities.

The second stage of research was to group the sustain- ability targets according to the themes and indicators used to assess progress towards each target. The resulting analytical framework (Table 1) was used to select projects for deeper analysis. The selection criteria included first, ambition to close the energy loop at a local level, second, availability of monitored energy data validated by third independent party or taken directly from the developer's monitored and remote planning systems; third, availability of information about the interactions between energy targets and other sustainability priorities; and fourth, availability of information about the trade-offs decided locally. Access to local actors involved in the project was also taken into account in order to supplement the in-depth analysis through interviews and/or feedback from local actors on the assessment of the identified projects. The availability of monitored data by third independent parties as well as the access to local actors to deepen the analysis of the results are the two criteria considered by the authors for the final selection of the projects to analyse deeply. One important feature, highlighted by the literature review and considered in the selection of projects, is the use of the three-pronged approach covering deep reduction of energy needs through the implementation of sufficiency measures, the reduction of energy demand through the use of the most efficient technologies and the target to achieve 100% of energy production from local renewable sources. Two out of the four projects selected for deeper analysis, pushed this reasoning further by considering also the use of wastewater and/or waste in producing energy locally.

Implementing and evaluating zero energy communities

The identified zero energy initiatives were driven either by urban renewal, the transformation of industrial and/or brown field areas into residential/mixed districts or the development of new settlements with strong sustainability outcomes for all residents. Reducing energy consumption and greenhouse gas emissions are not the only drivers of existing zero energy communities as illustrated by the variety of objectives and indicators considered by local actors to assess progress towards the agreed targets in the 62 projects initially identified (Table 1).

The sustainability criteria, summarised in Table 1, are not equally targeted and/or assessed in all the selected projects. However, their interactions with energy and green-house gas targets have been instrumental in the trade-offs decided by local authorities in achieving initial energy or carbon targets. Identifying sustainability criteria considered in the design of zero energy or zero carbon communities and analysing synergies and trade-offs considered by local actors in the selection of the solutions to implement goes beyond the analyses of energy and climate targets available in the literature. The framework developed by the authors and the indicators identified contribute to framing climate mitigation pathways within the broader sustainability targets which are today grouped under the United Nations framework for the 2030 agenda for sustainable development [19].

Factors that have worked in the communities analysed include first, having clearly defined long-term targets, community boundaries and values to support citizen engagement; second, linking targets to community priori- ties such as economic development, urban renewal, energy poverty, energy security (especially for isolated communities); and third, transposing long-term goals into milestones and short-term objectives to avoid discouraging the community. These factors are analysed in more detail through the review of four zero energy communities selected for deeper analysis (Table 2). The four pioneer initiatives have documented their steps towards closing the energy loop locally and have published data on their progress towards achieving their energy targets (Table 3).

Table 2: Zero energy projects considered for deep analysis

Project	Location	Programme	Size	Targets	References
BedZed	Former industrial site in South of London (United Kingdom)	- 82 New housing units for 244 inhabitants - New office buildings for 50 employees	1.7 ha	Z^2 (zero carbon and zero waste)	[15, 56, 58]
Hammarby	Former industrial site in Harbour area South of Stockholm (Sweden)	-10 000 New housing units for 25 000 inhabitants - New office buildings for 5 000 employees	250 ha	Z^3 (zero energy, zero water and zero waste)	[12-14, 57]
Cernier	Cernie, canton of Neuchâtel, (Switzerland)	-4 New multi-family flats -Renovation of 13 000 m² floor area of public and private buildings	910 ha	Energy independence by using 70% of renewable energy for heating and 90% for electricity	[54,55,59]
Hvar	Hvar Island is part of Split-Dalmatia County (Croatia)	-4 New eco buildings -11 refurbished buildings	29.7 ha	Zero energy, energetic self-sufficiency up to a quota of 20% by 2020.	[54,55,60]

Table 3: Measured energy consumption and production in the selected projects

Project	Energy consumption (monitored for buildings only)	Solutions for local energy production	Distance to targets	References
BedZed	-Electricity: 35KWh/m². yr -Heat: 48 KWh/m². yr	Cogeneration, photovoltaic, solar thermal, heat recovery, district heating	The zero carbon target is met by purchasing green electricity on the grid because the CHP implemented never worked properly.	[15, 56, 58]
Hammarby	-Total final energy consumption: 82 KWh/m². yr	Photovoltaic, solar thermal, heat recovery, district heating and wind power	The zero energy target as defined in the development phase was met within the identified boundaries of the community which go beyond Hammarby site.	[12-14, 57]
Cernier	-Heat consumption in new buildings: 27 KWh/m². yr -Average final energy consumption in renovated buildings: 86 KWh/m². yr	Photovoltaic, solar thermal, wind, geothermal energy and wood burners.	In 2014, Cernier reached 22% level of self-sufficiency in electrical production.	[54-55,59]
Hvar	-Total final energy consumption in new buildings: 76 KWh/m². yr -Average final energy consumption in refurbished buildings: 121 KWh/m². yr	-9 Photovoltaic systems with an energy production of 45 MWh/year - 39 solar thermal systems with an energy production of 150 MWh_{th}/year -1 bio gas plant with an energy production of 200 MWh_{th}/year and 150 MWh_{el}/year	The island's 47 GWh energy demand can be met by local energy by 2030. Hvar was accepted as one of the four Concerto Solution communities to demonstrate the feasibility of the concept of self-sufficiency, aiming to make its energy supply 20% self-sufficient by 2020.	[54-55,60]

Achieving zero energy and/or carbon targets in pioneer community developments

The review of the four identified pioneer projects (Table 2) demonstrates four key factors that can be used to analyse projects aiming to close the energy loop locally. First, there needs to be measurable targets and a clear implementation timeline. Second, there needs to be transparency about progress towards these targets and any revisions or trade-offs made during project implementation. Third, the supply and demand of urban services (energy, waste, water and transport) needs to achieve some integration at a local level. Fourth, the local residents and community need to be meaningfully engaged.

Criteria 1: Targets

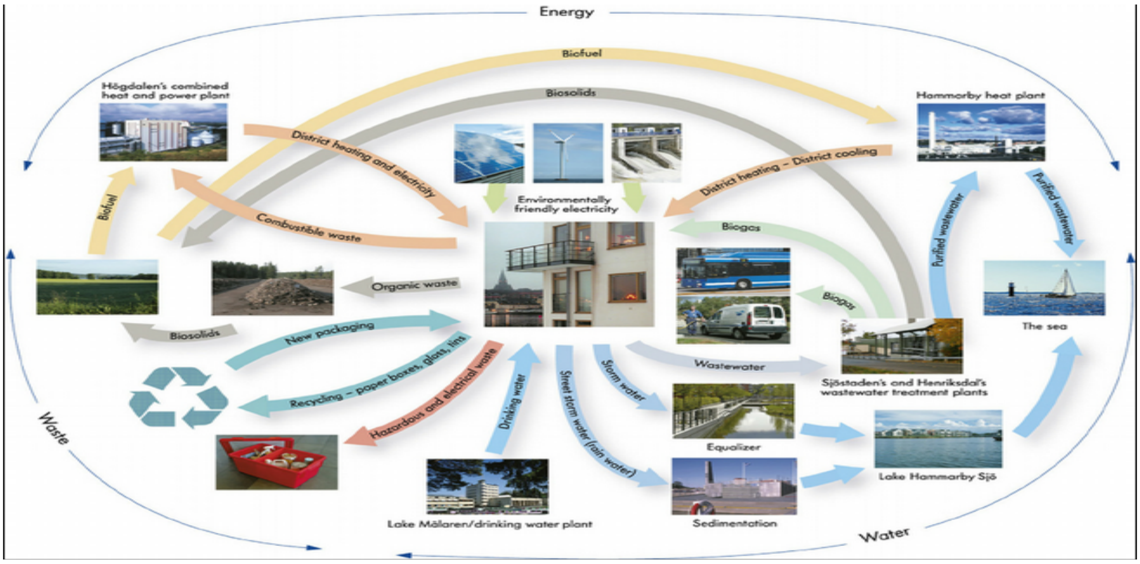
The review shows a lack of agreement on how to define a zero energy community, which urban services to include and where to put the boundaries, especially when it comes to communities that include existing buildings and infrastructures. A zero-energy community can be defined as a zero carbon or low carbon or a carbon neutral urban development by proposing hierarchical emissions categories [61]. The energy balance considered in the identified projects is generally expressed in primary energy and includes only the energy consumption of buildings in the use phase. However, monitored data available (Table 3) are expressed in terms of final energy consumption. Embodied energy is rarely included in the energy balance and the location of energy generation sources (within the community or nearby) determine the hierarchical emissions categories [57]. The four pioneer pro-jects had all clear, but not directly comparable targets. Cernier and HVAR aim at partial self-sufficiency by 2020 while BedZed's objective was to be Z2 (zero carbon and zero-waste) and Hammarby was based on Z3 (zero energy, zero waste and zero water) when all buildings are fully occupied.

Criteria 2: Approaches

The four projects have taken related but different pathways. They all adopted a three-pronged energy approach based on; first, implementing energy sufficiency measures to reduce energy needs; second, using the best available technologies to reduce the energy demand; and third, using renewable energies, preferably produced locally or nearby. Literature on the hierarchical approach argues that this enables the smooth implementation of the zero energy concept at the community level [61,62]. However, review of the four projects also shows the challenges confronted during the implementation of this approach.

Hammarby used the eco-cycle principles, a hierarchical approach to all urban services (sufficiency, efficiency, use/ reuse of local resources) (Figure 2). The implementation of this approach required an early involvement of local utilities in the project to optimise waste and wastewater treatment [12–14,57,58]. However, the implementation of the approach has also led to changes in the initial design. The intention had been to close the energy loop within the boundaries of the project, but the location of the project in the middle of the Nordic electricity net- work meant local solar and wind solutions were rejected in favour of the renewable electricity already available in the Nordic electricity network [12–14,58]. Waste produced in Hammarby is used to produce biogas for transport, but this outcome was initially contested and contingent. First, the local biogas production was rejected by the municipal energy company involved in the project to avoid competition with other energy sources used for public transport and sold by the local energy company. However, the increased share of private cars using biogas in Stockholm has led the municipality to implement the waste treatment plant in Hammarby. The aim was to make biogas available for Stockholm's residents owning private cars fuelled with biofuel [12–14,57]. Closing the energy loop in Hammarby has therefore resulted from citizen's engagement in sustainability beyond the boundaries of the zero energy community project, and in the ability of decision-makers to recognise and respond to this low carbon opportunity. Literature analysing these changes in Hammarby's energy supply [13] concludes that Hammarby did not meet its energy target within its boundaries. However, the initial target stipulates that 'energy should be derived from renewable sources and as far as possible from local sources' [53] without specifying the boundaries for the use of the energy produced locally. The hierarchical approach enabled a flexible design response at the development stage to meet the initial target.

Figure 2: Hammarby eco-cycle



Source: Hammarby

BedZed used a hierarchical approach for waste, water and energy including embodied energy for construction materials and food. The resulting ecological footprint is almost half the national average [15,56,58], however, the size of the project and the use of unproven technologies for water treatment and heat production meant the initial target of a zero carbon community was not met within the predefined boundaries of the community [15,56,57]. Again, the hierarchical approach led to design changes, BedZed, was initially designed to be a residential district. However, given the constraints at a master plan level, a few square meters were allocated for offices. This ensured all residential buildings had access to daylight and natural heating through glazed areas. This design change had an impact on the economic effectiveness of the project given that the income from the sale/rent of office buildings are higher than the ones from residential buildings, especially from those dedicated to low-income households [15,56]. The changes in the design have also allowed the architect to give all homes direct access to gardens, increasing resident well-being [15,56,57] while the changes in the boundaries of the initial project allowed closing the loop by purchasing green energy from the existing local networks.

Cernier and Hvar Island projects adopted a step-by-step approach, rather than taking a clear hierarchical approach and included the renovation of existing buildings and infrastructures in the boundaries of both projects [59,60]. While Hammarby and BedZed do not include renovation of existing buildings. The main goal of the Cernier project was to demonstrate that municipalities are able to approach energy independence by reducing energy demand of existing infrastructures through the implementation of energy efficiency measures and supplying the municipality with energy produced from local renew-able sources. The mix of measures selected for achieving the energy target included the already existing energy projects within Cernier territory such as the district heating network and the cogeneration plant. During the implementation phase, project's developers had to adapt these measures to ensure the size of the community was accounted for, and hence included the development of an on-site wind farm [59]. The Hvar island project aimed at reaching, in the initial phase, 20% self-sufficiency using the local renewable energy sources, such as: photovoltaic panels, solar thermal and energetic use of biomass. The main objective of the Hvar project was to increase the security of supply by reducing energy demand of existing residential and public buildings and powering the island with electricity produced from local renewables [60].

Criteria 3: local integration of supply and demand of urban services

The third factor to evaluate the use of a community scale to achieve a zero energy target is the integration of supply and demand of urban services (energy, waste, water and transport). The literature reviewed identified a number of benefits this integration could create such as optimised, cost-effective and environmental friendly service management solutions with a single point for all maintenance [63]; the ability for transport and building energy consumption to be linked [64]; opportunities for seasonal storage, smart grids for power sharing between housing units, peak electricity production timing and utility peak demand reduction [41,65**,66] as well as design flexibility including increased surface areas for renewable energy solutions. However, the four projects demonstrate that on-site energy generation can be limited, especially in densely populated areas, which leads to extending the boundaries of the community from the neighbourhood to the district level and from the district to the city level. Existing zero energy communities are all connected to the regional electricity and heat networks to address the seasonal production of energy with renewable sources.

Criteria 4: governance and citizen engagement

Different forms of cooperation, networking and mutual learning are recognised in the literature as driving forces in the battle against climate change [67,68] and in triggering the innovation needed to deeply decarbonise energy systems. The four pioneers zero energy communities have all been initiated by local actors: municipalities in collaboration with local utilities in the case of Hammarby, Cernier and Hvar and a non-governmental organisation in collaboration with an architect motivated by environmental concern and innovation in the case of BedZed.

Hammarby pioneered an integrated planning process to enable the successful delivery of the eco-cycle system [69–71]. It engaged multiple stakeholders (the municipality, construction industry and other services providers) to participate in the visioning, design and development process. The process was iterative, dynamic and inclusive, bringing key stakeholders together to create integrated and holistic urban systems. It stimulated both co-production and learning processes amongst key stake-holders in the development regime [70,71]. Similarly, the originality of BedZed comes from the involvement of an architect and a non-profit organisation aiming at sustain- able development [71]. These two actors have been instrumental in halving the ecological footprint of the project compared to the one of London's residents.

Likewise, Hvar and Cernier involved local actors, especially in the renovation of existing buildings [59,60]. The project in Hvar was developed and planned as a show case for energy renovation and then became a stepping-stone for energy renovation initiatives including setting guide- lines for the energy performance of existing buildings [60]. Similarly, the project in Cernier acted upon renovation projects that were already planned in the area. Thus, ensuring buildings undertook deeper renovations linked to energy saving technologies and plans [59]. However, the fact that the town was too small to have a local authority capable of running a local energy service has been identified as an impediment to the project's progress. This implies more could have been achieved, if the local municipality would have been able to take on this role [59]. The project demonstrates that municipal administrative and technical capacity will play a key role in implementing zero energy communities and making them deliver on their energy targets successfully.

The levels of actual citizen engagement are hard to assess based on the identified projects. The current monitoring of citizen engagement in zero energy communities is limited to reporting the number of organised meetings, number of attendees as well as platforms developed, and channels used to inform current and/or future users about the project. The picture presented, in the four cases, is of more passive than active citizen engagement as the metrics only capture attendance at meetings organised by the more structured actors such as utilities and developers. One explanation could be the lack of capacity and understanding of technical aspects by citizens [72]. The case studies reviewed have, therefore, highlighted a need for improved citizen engagement mechanisms and monitoring to support the more radical changes that zero energy and zero carbon communities promise.

Conclusions

Pioneer municipalities and actors have demonstrated the benefits and the feasibility of the zero-energy concept at local levels. Existing projects are built within the broader context of local sustainability objectives. The paper has reviewed existing literature and initiatives related to zero energy communities in order to identify how the broader drive for sustainability goals can help achieve a zero energy target at a local level. The review allowed synthetizing, from a detailed list of the much broader sustain- ability criteria used, an analytical framework to assess existing projects aiming to achieve the zero energy or the zero carbon target. The framework has been used to analyse the relative successes and challenges experienced in four pioneer projects.

The review identified four key factors that can be used to compare and draw lessons from zero energy projects implemented at a neighbourhood scale. First, there is a need for clear and comparable targets. The review highlighted the lack of consistent terminology and targets used when implementing 'zero energy communities'. This makes it hard for academics and policymakers to carry out independent assessment.

Second, the review identified the use of a hierarchical approach to meeting targets in the analysed cases. The approach aims at reducing the waste of natural resources, followed by an efficient use of the resources and the use and/or reuse of resources available within the boundaries of the community or nearby. The use of this approach allowed decision makers to be pragmatic and to adapt to the local context specific challenges and opportunities. The aim has been to keep the zero energy target set while changing the path and the scale by which this can be achieved.

Third, the review showed how existing projects have benefitted from cross-sectoral planning which goes beyond energy issues to include waste and water optimisation. This has enabled the integration and the optimisation of supply and demand across urban services (waste-energy-water). In some cases, the integrated approach created additional benefits, such as the provision of biofuel used for transport by other local communities.

Fourth, the review showed that existing projects recognise the value of citizen engagement and have benefitted from some strong local actors pursuing low carbon visions for their communities. Despite this initial engagement, the four projects do not provide evidence for a sustained and meaningful engagement of local residents. This suggests that more research and innovation is needed to better understand the role of citizens in making zero energy communities successful in the use phase.

Finally, the review has shown some difficulties in implementing the zero energy concept at the community scale. This starts with the difficulty of agreeing targets and definitions, and of maintaining these in the face of competing sustainability objectives and local needs. Furthermore, taking zero energy initiatives to a community level places a burden on municipal administrative and technical resources, which are limited in some local authorities, and therefore fail to deliver the full potential of the community approach. The paper highlighted these issues to show the additional research and policy support needed.

Despite the challenges identified, the achievements of the pioneer projects demonstrate the potential for the zero energy approach at local level to help cities meet the 1.5°C target. The challenge is to scale-up such initiatives and to make them business as usual, especially when it comes to retrofitting existing buildings and infrastructures. The Paris Climate Agreement offers a clear time frame and clear target. Its implementation represents an opportunity to accelerate this scaling-up and to achieve the radical transformation of energy systems attempted by the reviewed initiatives.

The review has also indicated strategies that could further support the energy transition at the community level. The identified strategies include capacity building and training of municipalities and citizens to enable their full and effective participation. It also includes careful documentation and monitoring of projects to provide a solid evidence base of what went well and more importantly to learn from what did not work well and mistakes. Such tangible strategies demonstrate how the vision of zero energy communities can be implemented. This in turn offers a pathway for cities to take more radical mitigation action and achieve the emissions reduction as required by the 1.5°C target and within the broader sustainability agenda.

Conflict of interest:

The authors declare no conflict of interest related to this work. The analyses were conducted as part of the work programme of each author.

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Appendix A. List of the 62 projects screened

Project	Programme	Targets	References
Ajaccio (France)	• Renovation of 419 apartments and one historical building. • PV on flat roof of residential buildings	20% energy savings target and a target of 15% of energy produced from renewables	[54,55]
Alessandria - AL Piano (Italy)	• Construction of a 104 dwellings (eco-village) fuelled by poly-generation and solar energy, featuring sheltered housing for the elderly, a health centre and kindergarten • Refurbishment of 300 social housing units	35 to 50% energy savings target	[54,55]
Almere (The Netherlands)	• Construction of 1,710 eco-homes, commercial and public buildings • Construction of 589 “Solar Homes”, constructed from wood, with low energy demand, an optimized use of daylight and solar powered energy supply from solar panels • Planning of around 100 passive houses • District heating supplies heat to all new dwellings	48% energy savings target and a target of 22% of energy to be produced from renewables	[54,55]
Apeldoorn - Zuidbroek (The Netherlands)	• Construction of 31,000 new housing units to highest energy standard • Renovation of 20 houses to ‘energy neutral” level	Carbon neutral by 2020	[54,55]

Arquata district (Italy)	• Thermal insulation (mainly under the roof) and highly-efficient glazing 46% • Erection of photovoltaic modules on the roofs of social housing buildings • Erection of PV modules on façades of an office building • Refurbishment of council buildings • Realisation of green areas • Creation of common spaces dedicated to social activities • Social and occupational development • Improvement of mobility • Creation of small commercial spaces	46% energy savings target and 5% of energy supplied by renewables	[54,55]
Bagenals town Community Better Energy Project (Ireland)	Renovation of 20 dwellings, 3 schools, an office building, a day care centre and a council office building	30% savings in electricity demand and 55% savings in thermal demand.	[54,55]
BedZed (United Kingdom)	• 82 new housing units for 244 inhabitants and new offices for 50 employees • On-site facilities incorporating innovative approaches to energy conservation and sustainability. • Building construction using thermally massive materials that store heat during warm conditions and release heat at cooler times	Z² (zero carbon and zero waste)	[15, 56, 58]
Birštonas (Lithuania)	Renovation of 360 buildings equivalent to 25,500 m²	70% energy savings target and 90% of energy supplied by renewables	[54,55]
Bo01 / Ekostaden Augustenborg (Sweden)	• 35% energy consumption reduction compared to the Swedish 1996 building regulation • Urban regeneration according to sustainable principles • Reinvention of the district as a 'climate'/ 'solar' / 'eco' city	100% of energy supplied by renewables by 2030	[55]
Cerdanyola del Vallès (Spain)	• Low energy construction measures • Natural ventilation solutions • Building envelope optimisation	55% energy savings target and a target of 33% supply from renewables	[50,51]
Cernier, Val-de-Ruz (Switzerland)	• Renovation of buildings • Development of a large district-heating network based on wood and biomass waste • Production of renewable energy in buildings (heat pump, photovoltaic electricity, etc.) • Reducing the energy consumption using information and tools (behavioural and technical measures) • Wind Power Generation • Sanitation of the water system with power generation by micro-turbines • Optimisation of street lighting	Reducing demand by improving the existing infrastructure (energy savings) Producing supply from renewable sources	[54,55,59]
Confluence (France)	New buildings with energy performance higher than the French 2005 building energy code	Energy savings target of 77% and a target of 80% of heat supplied by renewables	[54]

ZAC De Bonne (France)	900 low energy buildings (50 kWhep/m2/y) apartments and France's first positive energy office building.	CO_2 emissions reduced by 14% by 2014 (compared to 2005) and 14% of all energy consumed is supplied by renewables.	[54]
Dundalk (Ireland)	• Retrofitting of over 300 homes to meet energy efficiency requirements • Planning a biomass district heating system for residential and tertiary buildings	targets of 20% renewable heat, 20% renewable electricity and 40% improvement in energy efficiency of selected buildings by 2020	[54,55]
Eco-Viikki (Finland)	• New buildings • Construction of a large residential area adjacent to the Science Park • Conservation of the local environment and culture	A reduction of 20% in CO_2 emissions compared to conventional constructions. of water saving technologies (target 40-50 liters / person / day). a reduction of 20% of waste compared to the usual standard (max 160 kg / person / year).	[54,55]
Eco-village Jizni Chlum (Czech Republic)	New builds based on passive house standard.	60 - 90% of the heat is provided from renewables.	[54,55]
El Picarral (Spain)	• 8,000 households & refurbishment with bioclimatic criteria of 196 social housings • 616 new-build homes	Energy saving target of 70% and 40% of energy supplied by renewables	[54]
EVA-Lanxmeer (The Netherlands)	• Additional insulation • Heat recovery units (ventilation) • Solar water heaters • Solar tubes • District heating system	Zero energy balance	[54,55]
Falkenberg (Sweden)	Renovation of existing buildings from the 1950ties	No specific target nor timeline identified	[55]
Galanta (Slovak Republic)	Renovation of 8-storey residential buildings with 32 dwellings and a school	Geothermal energy from thermal streams for district heating	[55]
Gothenburg (Sweden)	• Construction of 116 apartments based on passive house standard • Energy efficient refurbishment of 16 apartments in Backa-Röd in 2009 (reduction in annual energy consumption from 180 kWh/m^2 to 60 kWh/m^2)	Local environmental objective of reducing carbon footprint to a sustainable level by 2050, with CO_2 emissions reduced to 2t/capita. An interim target is that, by 2020, CO_2 emissions are reduced by 40% in comparison with 1990 emissions level.	[54,55]
Gotland - Lindas (Sweden)	Passive house buildings	100% supply with renewables	[54,55]
Hammarby - Sjöstad (Sweden)	• Unified infrastructure of energy, water and waste • Urban-scaled density • Access to multiple transport modes • Preservation/restoration of existing natural systems • Progressive construction and housing policies	Z^3 (zero energy, zero waste and zero water) based on "closed-looped urban metabolism" with the aim of achieving a sustainable neighbourhood.	[12, 13, 14, 57]
Hartberg (Austria)	• Renovation of existing buildings • Construction of new commercial buildings to passive house standard as exemplary pilot projects • Decentralised district heating systems and polygeneration • Large-scale implementation of	33% energy savings target consumed, a target of 44% supply with renewables and 40 % CO_2 emissions reduction on short term & be carbon neutral on long-run.	[58]

	small/medium renewable applications • Symbiotic integration of novel electricity storage units • Improvements in the framework for potential private investors • Promotion of the innovative integration aspects of renewables		
Hedebygade (part of Vesterbro) (Denmark)	• Urban renewal • Renovation of existing buildings • Integration of photovoltaic to existing buildings	58% reduction in electricity consumption against the Danish average and around a third less CO_2 emissions, again against the national average.	[54]
Heerlen (The Netherlands)	• Construction of new buildings and renovations in two demonstration sites	Savings target of 116 MWh/y in electricity and 7,118 MWh/y in heating. A target of supply with renewables of 3,399 MWh/y for electricity and 13,885 MWh/y for heating	[54]
Helsingør (Helsingborg) (Sweden/ Denmark)	• 584 dwellings (64,380 m²) have been eco-rehabilitated stepwise towards high energy-efficiency • including 33,923 m² of office, school and cultural institutions	Energy saving target of 25-35% and a target of 60% renewables share.	[54,55]
Hillerød (Denmark)	• Construction of over 78,000m² eco-housing that will exceed current energy efficiency standards by a minimum of 25% • Approximately 50 Energy Class 1 dwellings • Approximately 670 Eco dwellings • Fully integrated energy supply structure • Combining different renewable energy sources for energy provision • A variety of additional techniques complementing renewable sources, including wind energy, photovoltaic capacity, heat pumps and low-energy district lighting	Zero CO_2 community	[54,55]
Hoje Taastrup - ECO-life (Denmark)	• 10-15 refurbished single family, 4 finished more ongoing (total 8-9) • 10,800 m2 refurbished semi-detached and concrete block social dwellings, in design phase	Energy savings target of 50% compared to current Danish standard and a target of 100% supply with renewables.	[59]
Høje-Taastrup (Denmark)	• Renovation of 150 public buildings • Construction of 40 dwellings based on passive house standard and 70 energy class A+ dwellings	50% energy savings target and a 100% renewable energy target.	[59]
Hvar (Croatia)	• 11 refurbished buildings • 4 new eco-buildings • 9 PV systems with an energy production of 45 MWh/yr • 39 solar thermal systems with an energy production of 150 MWh_{th}/year • 1 bio gas plant with an energy production of 200 MWh_{th}/year and 150 MWh_{el}/year	• Decrease greenhouse gas emissions by 20% compared to 1990 level. • Increase the share of renewable energy by 20% in annual gross energy consumption of the country • Cover 10% of energy consumption in the transport sector by	[55,60]

		renewables • Decrease final energy consumption by 9% by 2016	
Kortrijk (Belgium)	• Renovation of single family homes • Installation of low temperature district heating network, supplied by 1 MW woodchip boiler, connected to all buildings • Installation of 10 kW biofuel cogeneration unit producing auxiliary electricity for the system (pumps, control and monitoring equipment) • Heat from cogeneration unit is fed into the district heating network	Energy savings target of 85%	[54,55]
Kronsberg (Germany)	• Passivhaus building level • Sustainable transport • Solar storage	60-80% energy reductions Environmental and biodiversity agenda	[58]
Lambeth (United Kingdom)	• Renovation of blocks of flats • Installation of solar thermal and solar photovoltaic technologies on schools • Training and development of professionals in the sustainable buildings sector • Creation of a suite of learning resources for local residents • Energy audits and advice for local businesses	80% reduction of energy demand	[58]
Lapua (Finland)	• Local district heating provided by biogas polygeneration and boilers • Heat pumps • Wind power • Effective energy management • Remote control systems • Improved consumer behaviour	Energy savings target of 35% and a target of 75% supply with renewables	[59]
Lehen, Stadtwerk (Austria)	• New buildings and renovation of existing ones • Low-energy standard for new buildings and as economically as possible for renovations • High rate of renewable energy supply for the whole area (new buildings and renovations) • Energy-efficient components in the public electrical applications (especially pumps and lighting)	45% energy savings target	[58]
Linero (Sweden)	• 16 new buildings with 79 dwellings • 40,400 m2 conditioned area	A target of 31% reduction in energy consumption and a target of 80% supply with renewables	[54,55]
Milton Keynes (United Kingdom)	• Construction of 3 office buildings and 445 residential units to raised sustainability levels • CHP plant serving commercial and residential buildings	30% energy savings target and 25% renewable energy target	[54,55]

Mödling (Austria)	• Renovation of social housing and kindergarten • Connection to district heating • Construction of police department eco-building • Construction of commercial building 'Sol 4" to passive standard • Sewage treatment plant, • Renovation of municipal swimming pool and two administration buildings	50% reduction of greenhouse gas emissions compared to 1990 level.	[54,55]
Montieri (Italy)	• Retrofitting of selected dwellings by using integrated approaches and techniques • Connection of 425 dwellings to the district heating system. • Retrofitting of 20% of the total dwellings in Montieri	No measurable energy savings target identified	[58]
Mórahalom (Hungary)	Retrofitting of public buildings – a cultural centre, school, gymnasium and kindergarten/day-care complex.	No measurable target	[59]
North Tipperary - Cloughjordan (Ireland)	• Renovation of existing buildings and construction of new ones. • Making the North Tipperary region a leader in implementing sustainable energy actions • Reduce the energy consumption in 400 existing buildings • Develop an eco-village with 132 houses in Cloughjordan • Increase the use of renewable energy technologies by supporting the installation of renewable energy heating systems and demonstrating the use of electricity from micro-wind turbine sites • Utilise technical and socio-economic expertise from European Partners to monitor performance and impacts in the region and to disseminate the results widely • Provide training and information within the region to stimulate further action in the field of sustainable energy	An eco-village with a target of 40% reduction in energy use, a supply with renewables by increasing the use of biomass.	[58]
ONE Brighton (United Kingdom)	Renovation of residential buildings	Low carbon targets	[60]
Ostra Sala backe (Sweden)	• Aiming for "innovative integration of energy technology" • Monitoring and analysis • Energy planning towards net-zero energy district targets	No measurable energy target identfiied	[54,55]
Poptahof (The Netherlands)	• New and existing buildings • To emit 15% less CO_2 by 2012 • To raise the share of renewable energy to 5% of total consumption in comparison with 1990 • To use 15% less energy through renovations	15% reduction of CO_2 emissions, 5% increase of the share of renewables and 15% energy demand reduction.	[59]

Rieselfeld (Germany)	• New development project in the state of Baden-Württemberg. • District heating network powered by a combined heat and power plant • Storm water management	50% of electricity supplied by a cogeneration plant	[59]
Stenlose (Denmark)	Construction of over 400 homes, a kindergarten and an activity centre for the elderly	No measurable energy target identified.	[59]
Scharnhauser Park (Germany)	• Mainly low energy new buildings • Ecological model community providing integrated transport and low energy consumption in a well-being environment	38% energy savings target and standards and 80% of the total energy demand supplied by renewables.	[54,55]
Solanova (Hunagry)	Retrofit of residential buildings	Reduction in annual space heat consumption (from 220 kWh/m^2/yr to 200 kWh/m^2/yr in 2006	[59]
Szentendre (Hungary)	Retrofit of residential buildings	No measurable energy target identified	[59]
Trondheim (Norway)	• Installation of 750kW biomass fuelled boilers • Installation of solar collectors (265m2) • Implementation of polygeneration, 6MW$_{th}$ energy conversion central, with 3 MW absorption cooling and district heating from waste	A target of 20% CO_2 emissions reduction.	[59]
Tudela (Spain)	• Retro-fitting of existing buildings • Construction of a new neighbourhood • Use of sustainable building materials • Implementation of advanced monitoring and demand-supply system in new buildings • Installation of renewable energy	A target of 60% energy demand reduction and a target of 100% supply with renewables	[54,55]
Valby (Denmark)	• Improved energy performance • Increased use of renewable energy • Reduction of greenhouse gases and pollution emissions • Enhancement of the competitiveness of the European industry • Reduction of the environmental impacts of associated products and services • Improvement in the quality of life • Implementation of solar solutions	81% renewables to match building demands	[59]
Valdespartera (Spain)	New Social housing	Energy saving target of 70% and over 40% of energy supplied by renewables.	[59]
Vauban (Germany)	• 100 Passive houses • Minimum energy consumption of 65 kWh/m$_2$/yr in other homes. • Construction of 6 student settlements with wall and roof insulation • High engagement of local actors	90% energy savings target	[59]

Växjö - Biskopshagen (Sweden)	• Biomass + smart metering houses. • Construction of new eco-buildings with 31% energy savings • Construction of around 400 energy efficient apartments • Introduction of absorption cooling, based on biomass	Fossil fuel free by 2030	[59]
Vesterbro - Østerbro (Denmark)	Solar heating for domestic hot water, solar walls, facade insulation, low energy windows and individual HRV systems. individual monitoring screens on each house	14% CO_2 emissions reduction	[59]
Viladecans (Spain)	• Five public buildings will be built or largely refurbished • 60 new social housing dwelling will be built with high energy efficiency requirements.	Energy saving target of 51% and 51% of supply with renewables.	[54,55]
Vitoria-Gasteiz (Spain)	• Solar technology • Retrofit of existing buildings • Encouraging community participation in the improvement of quality of life and reduction of environmental impact	40% energy savings target and a target of 50% supply with renewables.	[59]
Weilerbach (Germany)	• 100 fully retrofitted buildings • 200 partly retrofitted houses • 80 energy efficient houses built • 50 biomass boilers installed (in total 826 kW) • 124 solar thermal systems (in total 890 kW) installed.	Energy savings target of 10% and 100% target for renewables supply.	[59]
Zaragoza (Spain)	Promote the adoption of high performing bioclimatic buildings as standard practice and to research and develop mechanisms for this that are attractive to public authorities, public and private investors	Reduction of energy demand in building up to 70% compared to the current Spanish standard	[59]
Zlin (Czech Republic)	• Increasing renewable energy supply, mainly through solar energy and biomass • Refurbishment of buildings • Construction of new low-energy housing • Reconstruction of district heating system • Information and education campaigns	No measurable energy target identified	[59]

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