Defining and Operationalising the Concept of an Energy Positive Neighbourhood

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ABSTRACT

The increase in distributed renewable energy supply offers new opportunities to improve the performance of local energy systems. In line with this, research and development has begun to broaden its scope from the building scale towards the neighbourhood and district scales. The formulation and comparison of potential energy solutions in different contexts at different scales of analysis demands well-defined concepts and robust decision support tools. This paper studies the concept of Energy Positive Neighbourhoods, which it defines as areas "*in which the annual energy demand is lower than annual energy supply from local renewable energy sources. .... The aim is to support the integration of distributed renewable energy generation into wider energy networks and provide a functional, healthy, user friendly environment with as low energy demand and little environmental impact as possible.*" Key Performance Indicators for energy positive neighbourhoods are proposed along with an 'energy positivity label'. A decision support tool, called AtLas, designed to inform the long term planning of neighbourhood energy solutions is described and used to evaluate the energy positivity level of a Finnish residential neighbourhood and part of a French university campus.

HIGHLIGHTS

- A definition for Energy Positive Neighbourhoods is proposed.
- Key Performance Indicators for Energy Positive Neighbourhoods are proposed.
- The AtLas urban planning decision support tool is described.
- The use of the tool in two pilot studies is presented.

KEYWORDS

Energy Positive Neighbourhood (EPNs), Key Performance Indicators (KPIs), energy positivity label, urban planning decision support tool, neighbourhood.

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1. INTRODUCTION

The realisation of CO_2 emissions reduction targets for the built environment, along with wider sustainability targets, requires an integrated approach. Municipal decision making plays a key role in reducing emissions [1] and improving overall energy efficiency through urban planning and land use policies [2] along with the development of sustainable energy and transport systems [3]. It is widely recognised that urban and energy system planning should be linked early in the planning process [4] to achieve efficient low carbon urban developments. However, currently there is a lack of well-defined concepts [5], metrics [6] and robust decision support tools [7] to enable the formulation and comparison of potential sustainable energy solutions. The research presented in this paper presents a contribution to the development of such concepts, metrics and decision support tools: In doing so it moves beyond previous work in the field by defining and operationalising the concept of an Energy Positive Neighbourhood (EPN).

Recent nearly zero energy building policies set by the European Commission [8] are driving an increase in local renewable energy production in buildings and neighbourhoods. These developments are leading to a paradigm shift in energy systems: from national systems with centralised energy supply and one-way energy distribution towards local energy systems that utilise hybrid energy sources with significantly increased share of distributed renewable energy supply from buildings and districts [9].

In line with changes in energy systems, research into the energy performance of the built environment is broadening its scope from the building scale towards neighbourhood and district scales. For example, recent research explores the concept of net-positive energy by considering the role of a building in adding value to the setting and systems in which it is situated [10]. Thus, moving beyond the notion that single buildings are the most effective unit to make meaningful energy gains [11]. This research highlights the significance of increasing the boundaries of energy analysis from the building scale. It also highlights the requirement for new methods and metrics to gauge the success of sustainable urban development initiatives and the need for a shift from annual timeframes to a lifecycle approach in energy analysis [10].

The importance of long term integrated urban energy planning is widely recognised [12]. In line with this integrated energy planning has become increasingly important and popular in cities and territories [13] and there is a consensus that municipalities are to play a more pronounced role during the implementation of the future energy systems [14]. This makes logical sense as strategic planning at the level of the municipality offers the opportunity to connect buildings and energy systems enabling consideration of ‘urban energy systems’ as a whole [14] by acknowledging the interactions and interdependencies between their different components [12]. When analysing ‘urban energy systems’, different synergies and benefits can be recognised for optimal energy efficiency and energy performance [15]. It must also be noted that ‘urban energy systems’ analysis requires consideration of the whole energy supply chain: that is energy production, distribution, storage and end use [16].

There is no clear or simple strategy that can be applied to achieve low-carbon urban development. Rather, those involved in urban planning, construction and renovation need to identify suitable strategies within their particular geographical context and operational environment [17].

The research presented was conducted as part of a recently concluded project called “IDEAS - Intelligent NeighbourhooD Energy Allocation and Supervision”. The main goal of the IDEAS project was to develop and validate the technologies and business models required for the cost effective and incremental implementation of EPNs. The project was part of a cluster of smart city projects[1]. These projects are indicative of the notion that within Europe the concept of net energy positive design beyond the building scale is coalescing around the concept of an EPN.

The phrase EPN is widely used, however it is not clearly defined in earlier work. What is meant by the phrase EPN is frequently vaguely expressed or taken for granted. If the concept of an EPN is to offer a meaningful contribution to achieving net energy positive design and development in the built environment it must be clearly defined, operationalised and easily communicated to the relevant academic, government and community stakeholders.

A definition of an EPN is proposed in section 2 in this paper. To operationalise the proposed definition, a number of Key Performance Indicators (KPIs) is developed (section 3) to enable the assessment of how adequately a neighbourhood is satisfying the definition of EPN, that is to say the neighbourhood ‘energy positivity level’. Furthermore, for the concept of an EPN to provide an impetus towards net energy positive design in the built environment, it is necessary to have a method for clearly communicating the ‘energy positivity level’ of a neighbourhood. To enable this, an ‘energy positivity label’ is proposed in section 4. This label provides a clear and easily understood method of visualising the energy performance of a neighbourhood. The calculation of the KPIs for the energy positivity label are presented in section 5.

As part of the work conducted in the IDEAS project into defining an EPN and developing relevant KPIs, a decision support tool called AtLas was developed to support energy efficient urban planning and site renovation, as described in section 6. AtLas enables the comparison of different sustainable energy solutions, for both new and existing urban developments, and

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[1] The IDEAS sister project and other EU projects in this field include: COOPERATE, ODYSSEUS, EPIC-HUB, NRG4Cast, ORIGIN, SMARTKYE, E+, URB-Grade and EEPOS.

an understanding of the long-term impacts of these different solutions [18, 19]. The development of the tool is based on the key requirements of the intended users [20] and the findings of a review of existing tools[2]. The AtLas tool seeks to overcome the following problems associated with existing tools: Their complexity, the detailed energy and building related knowledge required as data input, their fixed geographical scale, a lack of clarity in the data and calculation methods they employ and the lack of time and cost analysis functionality.

The AtLas tool is used to evaluate the potential future scenarios for two pilot sites: a Finnish residential neighbourhood in Porvoo and part of a French university campus in Bordeaux. The Finnish demonstration site was selected because it is representative of 75% of European building stock which is residential [23]. In addition, as is common practice in Northern and Eastern Europe, the buildings at the Finnish site are heated by a CHP plant [24]. The second demonstration site at a French university was selected because it is representative of some 17 % of non-residential European buildings which are schools colleges and universities [23]. The second demonstration site is also similar to hospitals, which constitute 7 % of the European building stock [23]. The demonstration sites are described in section 7 of this paper, along with the main results of the results from AtLas simulations.

2. DEFINITION OF ENERGY POSITIVE NEIGHBOURHOODS

According to Cole [8], "*Net-positive approaches…. emphasize how buildings work collectively within networks. A key issue, therefore, is how new buildings fit into and work with the existing building stock*". As such, the concept of net-positive energy demands that the function of buildings is reconceptualised to see them as adding value to the setting and infrastructures of the area in which they are situated [7]. This in turn demands that debate is moved from defining energy positive buildings to defining energy positive building contexts

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[2] This was based on expert knowledge and in-depth analysis of existing tools and earlier analyses [21, 22].

and their energy infrastructures. In line with this approach, the definition of an EPN was developed [24], and updated according to discussions with the researchers developing ICTs to support EPNs in the following projects co-financed by the European Commission: COOPERATE, EPIC-HUB, URB-Grade, EEPOS, ODYSSEUS, NRG4Cast ORIGIN and SMARTKYE, E+.

The Thematic Working Group on ICT for energy efficiency [25] stated that:" *Energy-positive buildings and neighbourhoods are those that generate more power than their needs. They include the management of local energy sources (mainly renewable, e.g. solar, fuel cells, micro-turbines) and the connection to the power grid in order to sell energy if there is excess or, conversely, to buy energy when their own is not sufficient*". In the COOPERaTE project[3] [26], an EPN is defined as *"a neighborhood which can maximize usage of local and renewable energy resources whilst positively contributing to the optimization and security of the wider electricity grid*".

Both the above definitions were compatible with the original definition of an EPN developed in the IDEAS project. However, the notion that local energy demand is met by locally produced renewable energy, which is central to the IDEAS definition, is lost in the COOPERaTE definition, and both the above definitions of EPNs lack the level of clarity in the more extensive IDEAS definition of an EPN. However, their core ideas were later also incorporated into the definition of an EPN by adding the notion of contributing to the efficient operation and security of the wider energy networks. The final proposed definition for EPN is presented in figure 1.

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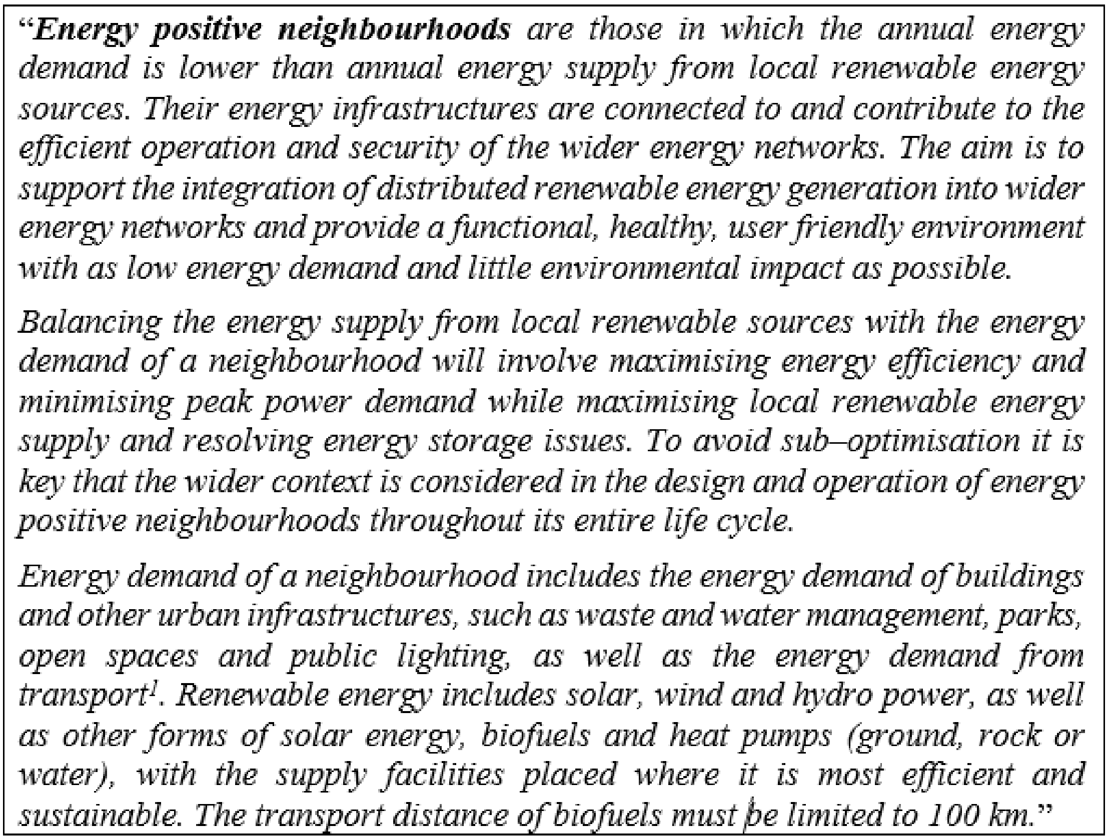
[3] http://www.cooperate-fp7.eu/



"***Energy positive neighbourhoods*** *are those in which the annual energy demand is lower than annual energy supply from local renewable energy sources. Their energy infrastructures are connected to and contribute to the efficient operation and security of the wider energy networks. The aim is to support the integration of distributed renewable energy generation into wider energy networks and provide a functional, healthy, user friendly environment with as low energy demand and little environmental impact as possible.*

Balancing the energy supply from local renewable sources with the energy demand of a neighbourhood will involve maximising energy efficiency and minimising peak power demand while maximising local renewable energy supply and resolving energy storage issues. To avoid sub–optimisation it is key that the wider context is considered in the design and operation of energy positive neighbourhoods throughout its entire life cycle.

Energy demand of a neighbourhood includes the energy demand of buildings and other urban infrastructures, such as waste and water management, parks, open spaces and public lighting, as well as the energy demand from transport[1]*. Renewable energy includes solar, wind and hydro power, as well as other forms of solar energy, biofuels and heat pumps (ground, rock or water), with the supply facilities placed where it is most efficient and sustainable. The transport distance of biofuels must be limited to 100 km.*"

Figure 1 Energy positive neighbourhood definition

3. KPIS FOR ASESSING THE QUALITY OF AN EPN

3.1. KPIs for measuring the balance between local energy supply and demand

A set of KPIs was designed to measure the balance between local energy supply and demand in a neighbourhood [24]. These KPIs operationalise the concept of an EPN by enabling the assessment of how good a neighbourhood is in terms of meeting the definition of EPN by measuring the energy positivity level of the area.

The foremost KPI is the one used to measure the balance between energy demand and renewable energy supply from all energy sources in a neighbourhood. This **On-site Energy Ratio (OER)** aims to express the relation between the annual energy supply from local renewable sources and the annual energy demand. However, in addition to considering the total annual energy balance, it is essential that the balance between supply and demand for different types of energy is assessed, as well as how the supply and demand of these different types of energy matches in terms of timing. The latter is necessary to avoid the problems created by peak energy demand especially with regard to electricity. Therefore, in addition to the OER, the following indicators are suggested (calculated individually for each energy type: x = either heating, cooling or electricity):

- **Annual Mismatch Ratio (AMRx)** to measure the amount of energy imported into the neighbourhood in the case of each energy type, per year.
- **Maximum Hourly Surplus (MHSx)** to measure what is the maximum value on how much bigger the hourly local renewable supply (for each energy type) is than the demand during that hour (per year).
- **Maximum Hourly Deficit (MHDx)** to measure the maximum value of how much bigger the hourly local demand is compared to the local renewable supply during that hour (per year).
- **Monthly Ratio of Peak hourly demand to Lowest hourly demand (RPLx)** to measure how big is the peak power demand.

3.2 Additional indicators for EPN

The ultimate goal of an EPN is not merely to reach energy positivity. As indicated in the definition, the idea is that energy positivity also "*contributes to providing a functional, healthy, user friendly environment with as low energy demand and little environmental impact as possible*" [23]. As the indicators discussed earlier are not designed to measure the energy efficiency or the social sustainability of a neighbourhood etc., additional indicators are required to address these factors. These include the following:

- **Level of energy demand**: measured by comparing the energy demand of the area to that of similar areas or using the energy classification of the buildings (if they represent the largest part of the demand).
- **Environmental impact**: CO_2 equivalent emissions may be used here and in some cases the amount of radioactive waste may also be relevant. The emissions can also be compared to those of similar areas, or e.g. calculate the emissions avoided by using the renewable supply in the area compared to the case of using external supply.
- **The distance biofuels are transported**: this is mentioned in the definition as a condition and as such needs to part of the evaluation of an EPN.

4. ENERGY POSITIVITY LABEL

An Energy positivity label is also suggested for EPN (see figure 2). It uses the indicators presented above for annual energy demand, annual energy supply and short term imbalances. The fundamental difference between existing labels related to sustainable construction and the proposed energy positivity label is the scale of analysis. Existing labels are largely designed to indicate the sustainable construction of individual buildings, and on the whole, focus on new construction [8, 27]. The 'neighborhood energy positivity label' is designed to support the incremental development of sustainable neighbourhoods or districts, which include pre-existing buildings as well as new developments.

To create the desired effect, the energy positivity label has to be clear and easy to recognise. The label proposed is similar in style to that used for white goods[4], with plus signs to provide an intuitive indication of energy positivity (see Figure 2). The challenge, as with all labelling schemas developed to express complex phenomena, is that many details have to be excluded

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[4] Household electrical goods that are traditionally white in colour such as refrigerators and washing machines.

to provide a simplified presentation. To achieve the required simplicity of representation, the energy positivity class shown on the label is based on one basic indicator - the yearly on-site energy ratio (OER). This does not distinguish between different types of energy or the similar time profiles of the energy supply and demand. This is, however, well in line with the core of the definition of an EPN [24] as an area in which *"the annual energy demand is lower than annual energy supply from local renewable energy sources"*.

In energy labelling, it is also a common practice to present figures to give further details in the energy efficiency class image. For instance in the case of light bulbs, the energy consumption for 1000 hours and the lumen value is shown in the figures for the label, as well as the power demand and estimated product lifetime [28]. This approach is also used in the energy positivity label, so that the mismatch indicators (AMRx, MHSx, MHDx and RPLx) are presented to further qualify the information about the overall energy class (see Figure 2).

No definitive scale or threshold values for different classes of EPNs are available as it is part of ongoing research (see section 8). Currently a scale from A to D, indicating energy positivity with a plus sign (A+, A++ or A+++ for very good level of energy positivity) is proposed, with the following threshold values (based on the cumulated experience of the project group regarding the current status of energy efficient neighbourhoods):

- A+++ represents an energy positive neighbourhood with very high OER, > 150 %
- A++ represents an energy positive neighbourhood with high OER, > 125 %
- A+ represents an energy positive neighbourhood, OER > 100 %
- A represents a zero energy neighbourhood, OER = 100 %
- B represents a neighbourhood with 50 % < OER < 100 %
- C represents a neighbourhood with 10 % < OER < 50 %
- D represents a neighbourhood with OER < 10 %

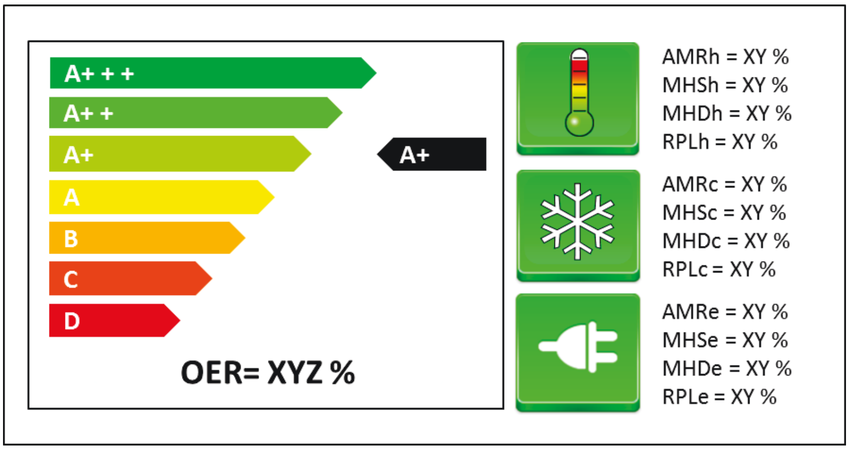


Figure 2. The energy positivity label for EPN. (As the energy 'positivity' level indicated here is A+, the OER would be greater than 100% in this case.)

5. CALCULATING OF THE KEY PERFORMANCE INDICATORS

The mathematical formulation for OER and AMR (as suggested in [24]) are presented below. Due to space constraints only the concept is presented in the case of the other mismatch indicators. These are presented in detail in [24], similarly to the additional, more traditional indicators.

5.1 On-site Energy Ratio

The OER is rooted in the idea of an on-site energy fraction (OEF) [29]. The OEF was designed to measure nearly zero-energy buildings, and as such it measures the proportion by which the demand is met by on-site energy supply. The OER, on the other hand, measures the ratio between on-site renewable supply and local demand as this is more important in case of EPNs.

Following the definition of an EPN, the local supply from renewable energy sources must be bigger than the annual energy demand in order to the neighbourhood to be considered as energy positive. Therefore, it is necessary to compare the local renewable supply to the local demand over one year. This is expressed by the OER [24]:

$$OER = \frac{\int_{t_1}^{t_2} G(t)dt}{\int_{t_1}^{t_2} L(t)dt} \qquad (1)$$

Where dt = 1 year, G(t) is the on-site energy generation power and L(t) is the load power of all energy types together (heating, cooling, electricity). Simplified expression can be articulated as follows:

$$\text{OER} = \text{Annual local supply in kWh/Annual demand in kWh} \qquad (2)$$

Following the IDEAS definition of an EPN, an energy positive neighbourhood has OER > 1. A net zero energy neighbourhood has OER=1, meaning that 100% of the energy demand is covered by local renewable energy supply. For other types of neighbourhoods OER is < 1. In the energy positivity label, OER is shown as a percentage, which is simpler for the general public to understand.

Following the IDEAS definition of an EPN, the different energy types are not taken into account separately, which means that OER > 1 is the only condition that must be met for the neighbourhood to be energy positive. However, it is also helpful to look at different energy types separately, along with the timing of the demand and supply. To do this it is necessary to calculate the energy mismatch indicators for each energy type individually. The OER does not consider issues such as primary energy factors.

5.2 Annual mismatch ratio

Annual Mismatch Ratio (AMR) indicates the average amount of energy imported into the neighbourhood for heating, cooling and electricity. The AMR is the average of the mismatch percentage for each hour of the year: presenting the difference between local renewable energy supply in comparison to the demand. Its' relevance is related to the periods when local demand is not met by local renewable supply. If energy is stored in the neighbourhood for certain hour and later used in the area, then there is no need to import energy. In this case, the on-site supply includes the stored energy. This hourly data provides a reasonable resolution for the mismatch.

The Annual Mismatch Ratio (AMRx) for heating, cooling and electricity considers the average of the hourly mismatch ratios [24]:

$$AMRx = \frac{\sum_{t=1}^{8760} HMRx\,(t)}{8760} \tag{3}$$

Hourly mismatch ratios are calculated depending on the status of the storage and the generation versus load situation in each hour of the year as follows. When the local renewable energy supply meets or exceeds the demand, the value for the hourly mismatch ratio HMRx(t) is 0. If the local storage is not full (and assuming that the storage capacity is able to totally meet the surplus generation), or if the stored energy with the local supply fully covers the need, then for these hours the storage rate S(t) gets values different from 0, (positive value when loading the storage, and negative value when discharging). If $\int_{t_1}^{t_2} G_x(t)dt < \int_{t_1}^{t_2} L_x(t)dt$ and the local storage is empty, then

$$HMRx(t) = \frac{\int_{t_1}^{t_2} [L_x(t) - G_x(t)]dt}{\int_{t_1}^{t_2} L_x(t)\,dt} \tag{4}$$

G_x(t) is the on-site energy generation rate for heating, cooling or electricity, L_x(t) is the load for that energy type and S_x(t) is the rate for loading or discharging the storage, dt = 1 hour. To enable the calculation of HMRx for each time step, it is important to know the state of the storage at end of the previous time step. The loss factor for the storage must also be known.

AMRx obtains values between 0 and 1: it is 0 when local supply supported with the storage for a particular energy type meets the demand for a particular hour, and 1 when all energy needs to be imported to the area. The smaller AMRx, the nearer local renewable energy supply is to meeting the demand at the correct time.

5.3 Other mismatch indicators

Maximum Hourly Surplus (MHSx) indicates the maximum value of how much bigger the hourly local renewable supply (for each energy type) is than the demand during that hour (per year). It is obtained by calculating the ratio for each hour of the year, for those hours when there is demand in the area, and taking the maximum of these values. The relative sizes of MHSx and OER will ultimately indicate how well the neighbourhood is able to balance the demand and supply in the short term: if the MHS is high, but OER is low, then the renewable supply of the area is not produced in optimal time. While if OER is high, then MHS will naturally be high, as the neighbourhood has more renewable supply than is needed to cover its own demand overall. This comparison is an element of the process of developing the energy positivity label and the thresholds for it.

Maximum Hourly Deficit (MHDx), indicates the maximum value of how much bigger the hourly local demand is compared to the local renewable supply during that hour (per year), taking also into account the energy retrieved from local storage to cover the load. It is calculated for each energy type separately, taking the biggest value of those ratios calculated for each hour of the year, for those hours when local renewable supply is smaller than the demand.

The monthly Ratio of Peak hourly demand to Lowest hourly demand (RPLx) is the ratio between the highest and lowest value for hourly demand over the month (by energy type).
The greatest value of these twelve monthly values is that considered for the energy positivity label. In a good energy positivity level, this will be as low as possible.

6. DECISION SUPPORT TOOL FOR URBAN PLANNING

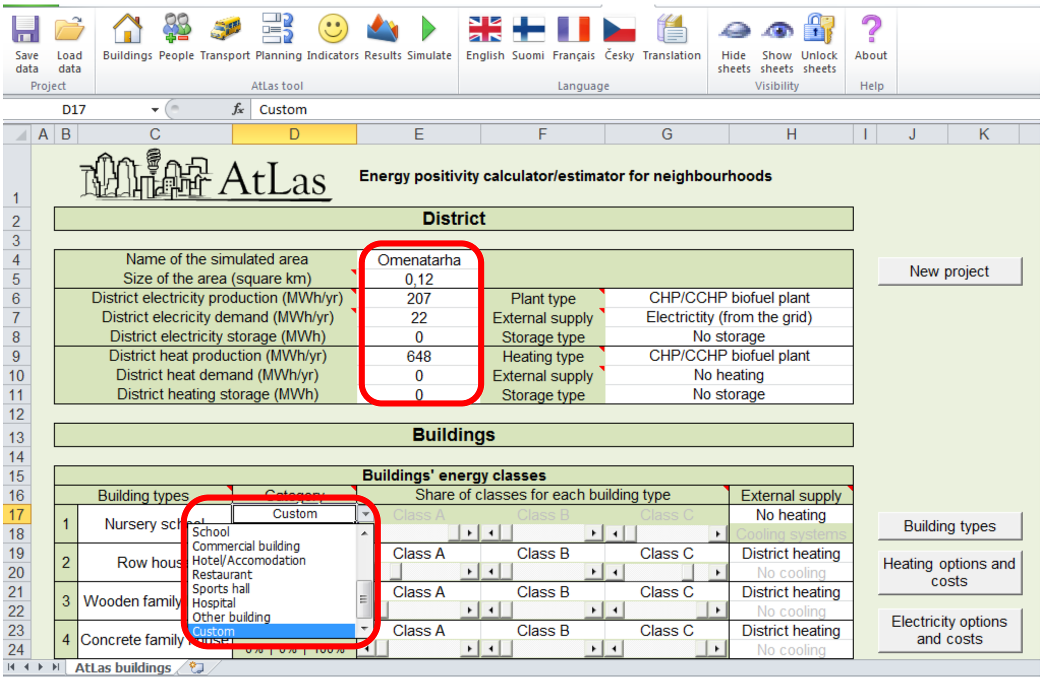
A decision support tool called AtLas was designed and piloted to inform the long-term planning of neighbourhood energy solutions towards energy positivity [19]. The following key requirements for the AtLas tool development [20] were expressed by the envisaged users: Simplicity of use, the capacity to operate with restricted data and conduct calculations to estimate the impact of different energy solutions over the short, medium and long term. The specifications of the tool were also influenced by a review of benefits and shortcomings of current tools used by city planners and facility managers to inform their decisions, and by test uses of the initial pilot versions of the Atlas tool with intended users [18].

The AtLas tool simulates the long-term impacts of the energy consumption and production in buildings and districts. It enables the assessment of multiple possible options for interventions in urban planning and energy supply and distribution. The calculations underpinning the tool combine, in a computationally efficient way, detailed hourly data of the energy demand and supply with long-term planning that usually spans several decades. If no hourly energy data is available, the tool also incorporates simplified methods for energy analysis calculation. For example, this includes simplified energy demand specifications based on the energy classes of buildings.

The AtLas tool is implemented using Excel. It contains: a ‘Buildings’ spreadsheet for defining a neighbourhood and its buildings; a ‘People’ spreadsheet for detailing the population of the area; a ‘Planning’ spreadsheet for detailing the simulated interventions and their comparison; an ‘Indicators’ spreadsheet to display the energy positivity level visualised with the help of the energy positivity label; and a ‘Results’ spreadsheet which displays the results calculated by the tool as tables. The AtLas ribbon with the navigation icons contains links to basic modules (the spreadsheets), simulation control and the language options (see Figure 3). The tool is available in

English, French and Finnish. Detailed user guides are available in Finnish and French, the languages of the intended users at the demo sites [19].

Due to the large number of possible input variables, the Excel spreadsheets are formatted to guide the user to understand the meaning of the input data and its possible impacts on the simulation results. The data input, such as the name or size of the area, required for the spreadsheets is either inserted by the user or it is provided by selecting from drop down menus. These are populated by the information stored in the Advanced sheet (e.g. the building types or the energy production options) (see Figure 3). The data input for the Advanced sheet requires expert knowledge but normally needs to be input to the tool once for each country and updated only when shares of energy types, CO_2 emissions, energy costs or building codes change. If available, site specific data can also be input into the Advanced spreadsheet (e.g. energy sources).



Energy positivity calculator/estimator for neighbourhoods

District

Name of the simulated area	Omenatarha		
Size of the area (square km)	0,12		
District electricity production (MWh/yr)	207	Plant type	CHP/CCHP biofuel plant
District elecricity demand (MWh/yr)	22	External supply	Electrictity (from the grid)
District electricity storage (MWh)	0	Storage type	No storage
District heat production (MWh/yr)	648	Heating type	CHP/CCHP biofuel plant
District heat demand (MWh/yr)	0	External supply	No heating
District heating storage (MWh)	0	Storage type	No storage

Buildings

Buildings' energy classes

	Building types	Category	Share of classes for each building type			External supply
1	Nursery sch	Custom	Class A	Class B	Class C	No heating Cooling systems
2	Row hous		Class A	Class B	Class C	District heating No cooling
3	Wooden family		Class A	Class B	Class C	District heating No cooling
4	Concrete family house		Class A	Class B	Class C	District heating No cooling

Figure 3. On the Buildings spreadsheet the user inserts information about the area in the white cells by hand or chooses the options from drop-down menus.

The Planning sheet is a key element of the user interface. On the Planning sheet, the user chooses the actions (= the combination of changes to the district and the buildings) that are to be taken on the area, from the drop-down menus, and inserts the new values that are realised after the action is completed. Also the values for the start date of the plan and its duration, as well as the action start and duration and related costs are inserted by the user. The original values are retrieved from the Building sheet.

The tool is designed to be very flexible. It facilitates the comparison of scenarios related to one building or a group of buildings in an area, with building integrated or centrally located energy production and storages in the area. Different scenarios can be simulated such as a change of district level energy consumption and production (e.g. installing a new wind farm), a change of buildings floor area (e.g. new construction or demolition), a change of buildings energy efficiency level (e.g. renovation) or a change of buildings energy production (e.g. new solar panels on the roof), to mention but a few.

AtLas tool presents the results in formats that will help the user to present the relevant information to other decision makers and stakeholders. The outputs can be presented as energy positivity indicators and as particular impacts in the form of 1) purchased energy, 2) costs including investments required or 3) CO_2 emissions, each normalized to different bases (e.g. floor area, population or area of the district). The values can also be presented separately by each energy type or in total, and as time-related or cumulative values. This makes the software very versatile, and thereby it can support the decisions of facility managers, city planners or energy companies in the planning of energy distribution networks.

7. DEMONSTRATION SITES IN FINLAND AND FRANCE

The first demonstration site is a Finnish residential neighbourhood “Omenatarha” in Skaftkärr area in Porvoo [23]. The Skaftkärr area is being redeveloped with the goal of offering different living alternatives in an energy efficient, safe, personal and cosy area. Omenatarha is the first stage in this redevelopment. It will have 500 residents and a Kindergarten for 120 young children situated in twelve hectares. The local energy supplier of the area is Porvoo Energy, which supplies both electricity and district heat from a predominantly bio-fuelled combined heat and power (CHP) plant. Porvoo Energy plans to augment the current district heating plant with solar collectors. The main stakeholders at the Finnish pilot site are the people living in the area, the Kindergarten children and employees, the energy provider, the local government officials and Posintra Oy (as the development coordinator) and the construction companies involved in building the new developments.

The second demonstration site is the University Institute of Technology (IUT), which is part of the university campus in Bordeaux, France [24]. IUT has teaching and office facilities to cater for two thousand students and five hundred staff in a total of twenty two buildings. The site is 80 000 m^2 with 40 000 m^2 of buildings. The buildings are mostly teaching and office facilities. A gas boiler and local heat network provide a large proportion of the heating. This heating system is managed by the IUT's energy management/maintenance staff. A couple photovoltaic (PV) panels are fitted to one of the buildings, but they are mainly used for teaching purposes and are not connected to the national electricity network. The key stakeholders at the French demonstration site are the Chief Executive Director (in charge of overall site management) and his site management team, and the university staff and students.

Neither of the demonstration areas currently reaches energy positivity (as their OER < 1). The Finnish site is close to energy positivity, as already 98% of the energy demand is produced from renewable sources in the area. It still only reaches level B on the suggested scale for energy positivity. To reach energy neutrality (A level), it would be necessary to produce 8 MWh of more renewable energy annually. This means e.g. 53 m^2 solar panels or 25 m^2 solar collectors. The French site currently represents C-level on the energy positivity scale. Currently there is no local renewable energy production on the area, except the few PV panels. To reach energy neutrality (A level), and cover the current energy demand, the French site would need to produce 4700 MWh of more renewable energy annually. This would mean e.g. a bio based CHP (producing all the heat and 70 % of electricity) and 3 000 m^2 of solar panels. Local energy storages could also be introduced to both sites to better match the timing of production and demand.

Selections of scenarios for both sites were studied with the AtLas tool. Which of the different scenarios tested is the best case scenario for scaling up each of the demonstration sites depends on the priorities of the stakeholders involved. For example, the driving factor could be costs, CO_2 reduction or reaching energy positivity.

In the Finnish case, the city planners used the tool for comparing different scenarios for three different planning areas in Porvoo (including the demonstration site), while the energy provider and Posintra Oy (as the development coordinator) participated in formulating the scenarios. The comparisons will be presented in different occasions to the other stakeholders, like the local government officials, construction companies or the residents of the areas. The comparisons of the future scenarios for the Finnish site showed that among the tested scenarios, the one where energy efficiency of the houses was improved (from C-class to A-class), while keeping the sizing of the CHP for the less energy efficient buildings, would be the one with shortest payback period and best energy positivity level (A++). The one producing least CO_2 emissions would be a scenario where the energy production in the area was increased with solar thermal to achieve 100 % local renewable heating and PV production to achieve 100 % local renewable electricity.

In the French case, the Chief Executive Director (in charge of overall site management) and his site management team defined seven different scenarios, which were compared to the baseline for the IUT site. The information was presented to the other stakeholders - the university staff and students – through information screens as part of the demonstration. In the case of the French demonstration site, the scenario with the shortest payback period (10 to 13 years, depending on the cost evolution model) was the scenario where district PV generation was introduced on the site according to the real specifications of IUT site. This was also the scenario with the highest energy positivity level (B). This scenario almost reached A-class in energy positivity. The lowest CO_2 emissions (15 ton CO_2 ekv/year) were reached with the scenario where a bio-CHP plant was built on the area.

8. FUTURE WORK

The indicators for measuring energy positivity need further work in relation to target and threshold values. It is likely that they will need to be adapted for different countries with different climates and energy sources. For example, it may be most effective to achieve low AMR values by adding local solar energy supply in a neighbourhood situated in a country in the south of Europe, where local energy demand is largely a result of electricity driven cooling and domestic hot water. On the other hand, in a country in the north of Europe, the timing of solar energy supply and energy demand is typically less synchronised.

The target values for AMR and MHS need to be further considered. This is not a straightforward issue. This is because surplus energy production in an EPN is only advantageous when there is a demand for that energy outside of the EPN or it can be stored in the EPN until there is a local or national demand for it. For instance, if the energy production at an EPN is greater than the local demand at times of the day when national electricity demand is high then this is advantageous, as the surplus energy can be used to help meet the national energy demand. On the other hand, if surplus electricity production occurs when national energy demand is low and it cannot be stored locally until there is a national or local demand for that energy. This is problematic, because this may contribute to overload problems on national distribution and transmission networks. National energy demand also affects the economics of the EPN, as explained in business related work of the project group [30]: "*When national electricity demand is low, supply comes from relatively inexpensive base load generation. When demand is high and base load generation is exhausted, supply comes from relatively expensive peaking generators. This creates rapidly fluctuating energy costs throughout the day in all EU energy markets.*"

During the design of the EPN indicators discussed in this paper, the authors focused on the near future potential for EPNs. In the short term, EPNs will probably be nearly zero-energy neighbourhoods with a modest surplus energy supply. In the longer term, as the cost of energy storage reduces, it should become financially viable to produce significantly more energy within an EPN than required to meet local energy demand as the surplus energy could be stored and sold when national energy demand is high and therefore the possible remuneration for that energy is at its peak. These more futuristic scenarios will require a re-appraisal of the indicators discussed here.

Currently in the AtLas tool, the costs for different actions are inserted by the user, but it is planned that in the future the tool could already give indications of typical costs related to typical actions e.g. in the comments provided inside the tool.

9. CONCLUSIONS

The research presented in this paper is the first work, which explicitly defines the concept of an Energy Positive Neighbourhood and the metrics and tools to measure the energy positivity level of an area. In addition, it presents an energy positivity label to enable the visualisation of the progress of an area towards becoming energy positive. In doing so it extends the systems limits of current approaches to energy analysis for urban sustainability. The energy positivity level of an area is estimated with calculating energy matching indicators: on-site energy ratio, annual mismatch ratio and other mismatch indicators.

In addition to the energy balance implications, understanding the costs and environmental impacts of different energy solutions over time is essential in urban planning related decision making for all involved actors, including local government officials, urban planners, facility managers and energy companies. The developed AtLas urban planning tool described provides this information, presented with the help of the newly developed indicators for energy positive neighbourhoods, in addition to more traditional indicators for costs and emissions. It has the advantage of enabling estimates of the cost and environmental impacts of different possible building types, building classifications and energy infrastructures already in early planning stages with using limited data. However, if more detailed energy demand and supply data is available, more precise estimates can be calculated with the tool.

The AtLas tool was piloted in two demonstration neighbourhoods to assess and compare different future development scenarios and their impacts to energy demand and supply and their environmental and economic impacts. The comparisons of the different future scenarios for the two demonstration sites confirm that the newly developed KPIs bring new insights to the decision making and provide a powerful tool to compare the effects of several very different actions combined impact.

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NOMENCLATURE

CHP	Combined heat and power production
EPN	Energy Positive Neighbourhood
KPI	Key Performance Indicator
OER	On-site Energy Ratio
AMR	Annual Mismatch Ratio
MHS	Maximum Hourly Surplus
MHD	Maximum Hourly Deficit
RPL	Monthly Ratio of Peak hourly demand to Lowest hourly demand
OEF	On-site Energy Fraction
HMR	Hourly Mismatch Ratio

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