

Defining and Operationalising the Concept of an Energy Positive Neighbourhood

Mia Ala-Juusela*

VTT TECHNICAL RESEARCH CENTRE OF FINLAND, Espoo, Finland

e-mail: mia.ala-juusela@vtt.fi

Dr Tracey Crosbie

Technology Futures Institute

Teesside University, Middlesbrough, UK

e-mail: T.Crosbie@tees.ac.uk

Mari Hukkalainen

VTT TECHNICAL RESEARCH CENTRE OF FINLAND, Espoo, Finland

e-mail: mari.hukkalainen@vtt.fi

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.

* Corresponding author

1 1. INTRODUCTION

2 The realisation of CO₂ emissions reduction targets for the built environment, along with wider
3 sustainability targets, requires an integrated approach. Municipal decision making plays a key
4 role in reducing emissions [1] and improving overall energy efficiency through urban
5 planning and land use policies [2] along with the development of sustainable energy and
6 transport systems [3]. It is widely recognised that urban and energy system planning should
7 be linked early in the planning process [4] to achieve efficient low carbon urban
8 developments. However, currently there is a lack of well-defined concepts [5], metrics [6] and
9 robust decision support tools [7] to enable the formulation and comparison of potential
10 sustainable energy solutions. The research presented in this paper presents a contribution to
11 the development of such concepts, metrics and decision support tools: In doing so it moves
12 beyond previous work in the field by defining and operationalising the concept of an Energy
13 Positive Neighbourhood (EPN).

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

20 In line with changes in energy systems, research into the energy performance of the built
21 environment is broadening its scope from the building scale towards neighbourhood and
22 district scales. For example, recent research explores the concept of net-positive energy by
23 considering the role of a building in adding value to the setting and systems in which it is
24 situated [10]. Thus, moving beyond the notion that single buildings are the most effective unit

25 to make meaningful energy gains [11]. This research highlights the significance of increasing
26 the boundaries of energy analysis from the building scale. It also highlights the requirement
27 for new methods and metrics to gauge the success of sustainable urban development
28 initiatives and the need for a shift from annual timeframes to a lifecycle approach in energy
29 analysis [10].

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

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

45 The research presented was conducted as part of a recently concluded project called “IDEAS -
46 Intelligent Neighbourhood Energy Allocation and Supervision”. The main goal of the IDEAS
47 project was to develop and validate the technologies and business models required for the cost
48 effective and incremental implementation of EPNs. The project was part of a cluster of smart

49 city projects¹. These projects are indicative of the notion that within Europe the concept of
50 net energy positive design beyond the building scale is coalescing around the concept of an
51 EPN.

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

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

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

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.

71 an understanding of the long-term impacts of these different solutions [18, 19]. The
72 development of the tool is based on the key requirements of the intended users [20] and the
73 findings of a review of existing tools². The AtLas tool seeks to overcome the following
74 problems associated with existing tools: Their complexity, the detailed energy and building
75 related knowledge required as data input, their fixed geographical scale, a lack of clarity in the
76 data and calculation methods they employ and the lack of time and cost analysis functionality.

77 The AtLas tool is used to evaluate the potential future scenarios for two pilot sites: a Finnish
78 residential neighbourhood in Porvoo and part of a French university campus in Bordeaux. The
79 Finnish demonstration site was selected because it is representative of 75% of European
80 building stock which is residential [23]. In addition, as is common practice in Northern and
81 Eastern Europe, the buildings at the Finnish site are heated by a CHP plant [24]. The second
82 demonstration site at a French university was selected because it is representative of some
83 17 % of non-residential European buildings which are schools colleges and universities [23].
84 The second demonstration site is also similar to hospitals, which constitute 7 % of the
85 European building stock [23]. The demonstration sites are described in section 7 of this paper,
86 along with the main results of the results from AtLas simulations.

87 **2. DEFINITION OF ENERGY POSITIVE NEIGHBOURHOODS**

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

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

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

99 The Thematic Working Group on ICT for energy efficiency [25] stated that:” *Energy-positive*
100 *buildings and neighbourhoods are those that generate more power than their needs. They*
101 *include the management of local energy sources (mainly renewable, e.g. solar, fuel cells,*
102 *micro-turbines) and the connection to the power grid in order to sell energy if there is excess*
103 *or, conversely, to buy energy when their own is not sufficient”*. In the COOPERaTE project³
104 [26], an EPN is defined as “*a neighborhood which can maximize usage of local and*
105 *renewable energy resources whilst positively contributing to the optimization and security of*
106 *the wider electricity grid”*.

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

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 transport¹. 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.”

115

116 *Figure 1 Energy positive neighbourhood definition*

117 **3. KPIS FOR AESSING THE QUALITY OF AN EPN**

118 **3.1. KPIs for measuring the balance between local energy supply and demand**

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

123 The foremost KPI is the one used to measure the balance between energy demand and
124 renewable energy supply from all energy sources in a neighbourhood. This **On-site Energy**
125 **Ratio (OER)** aims to express the relation between the annual energy supply from local
126 renewable sources and the annual energy demand. However, in addition to considering the

127 total annual energy balance, it is essential that the balance between supply and demand for
128 different types of energy is assessed, as well as how the supply and demand of these different
129 types of energy matches in terms of timing. The latter is necessary to avoid the problems
130 created by peak energy demand especially with regard to electricity. Therefore, in addition to
131 the OER, the following indicators are suggested (calculated individually for each energy type:
132 x = either heating, cooling or electricity):

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

143 **3.2 Additional indicators for EPN**

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

- 150 • **Level of energy demand:** measured by comparing the energy demand of the area to
151 that of similar areas or using the energy classification of the buildings (if they represent
152 the largest part of the demand).
- 153 • **Environmental impact:** CO₂ equivalent emissions may be used here and in some cases
154 the amount of radioactive waste may also be relevant. The emissions can also be
155 compared to those of similar areas, or e.g. calculate the emissions avoided by using the
156 renewable supply in the area compared to the case of using external supply.
- 157 • **The distance biofuels are transported:** this is mentioned in the definition as a
158 condition and as such needs to part of the evaluation of an EPN.

159 **4. ENERGY POSITIVITY LABEL**

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

168 To create the desired effect, the energy positivity label has to be clear and easy to recognise.
169 The label proposed is similar in style to that used for white goods⁴, with plus signs to provide
170 an intuitive indication of energy positivity (see Figure 2). The challenge, as with all labelling
171 schemas developed to express complex phenomena, is that many details have to be excluded

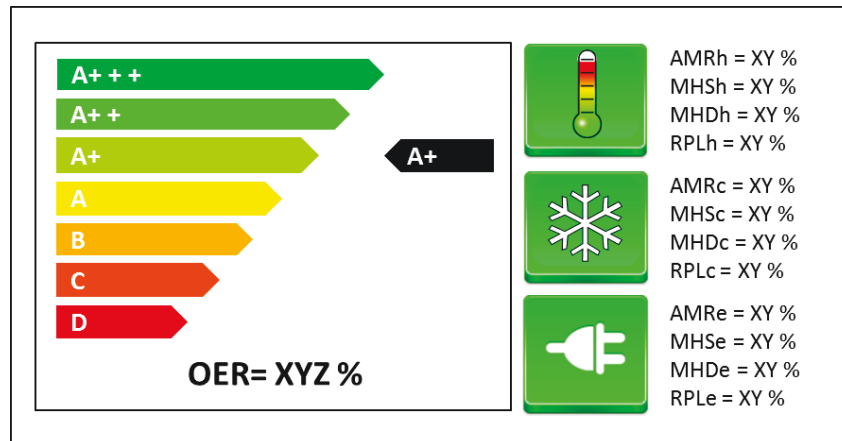
⁴ Household electrical goods that are traditionally white in colour such as refrigerators and washing machines.

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

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

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

- 189 • A+++ represents an energy positive neighbourhood with very high OER, > 150 %
- 190 • A++ represents an energy positive neighbourhood with high OER, > 125 %
- 191 • A+ represents an energy positive neighbourhood, OER > 100 %
- 192 • A represents a zero energy neighbourhood, OER = 100 %
- 193 • B represents a neighbourhood with 50 % < OER < 100 %
- 194 • C represents a neighbourhood with 10 % < OER < 50 %
- 195 • D represents a neighbourhood with OER < 10 %



196

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

199 **5. CALCULATING OF THE KEY PERFORMANCE INDICATORS**

200 The mathematical formulation for OER and AMR (as suggested in [24]) are presented below.

201 Due to space constraints only the concept is presented in the case of the other mismatch
 202 indicators. These are presented in detail in [24], similarly to the additional, more traditional
 203 indicators.

204 **5.1 On-site Energy Ratio**

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

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

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

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:

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

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

238 on-site supply includes the stored energy. This hourly data provides a reasonable resolution
 239 for the mismatch.

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

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

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

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

254 $G_x(t)$ is the on-site energy generation rate for heating, cooling or electricity, $L_x(t)$ is the load
 255 for that energy type and $S_x(t)$ is the rate for loading or discharging the storage, $dt = 1$ hour. To
 256 enable the calculation of HMRx for each time step, it is important to know the state of the
 257 storage at end of the previous time step. The loss factor for the storage must also be known.

258 AMRx obtains values between 0 and 1: it is 0 when local supply supported with the storage
 259 for a particular energy type meets the demand for a particular hour, and 1 when all energy

260 needs to be imported to the area. The smaller AMR_x, the nearer local renewable energy
261 supply is to meeting the demand at the correct time.

262 **5.3 Other mismatch indicators**

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

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

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

283 **6. DECISION SUPPORT TOOL FOR URBAN PLANNING**

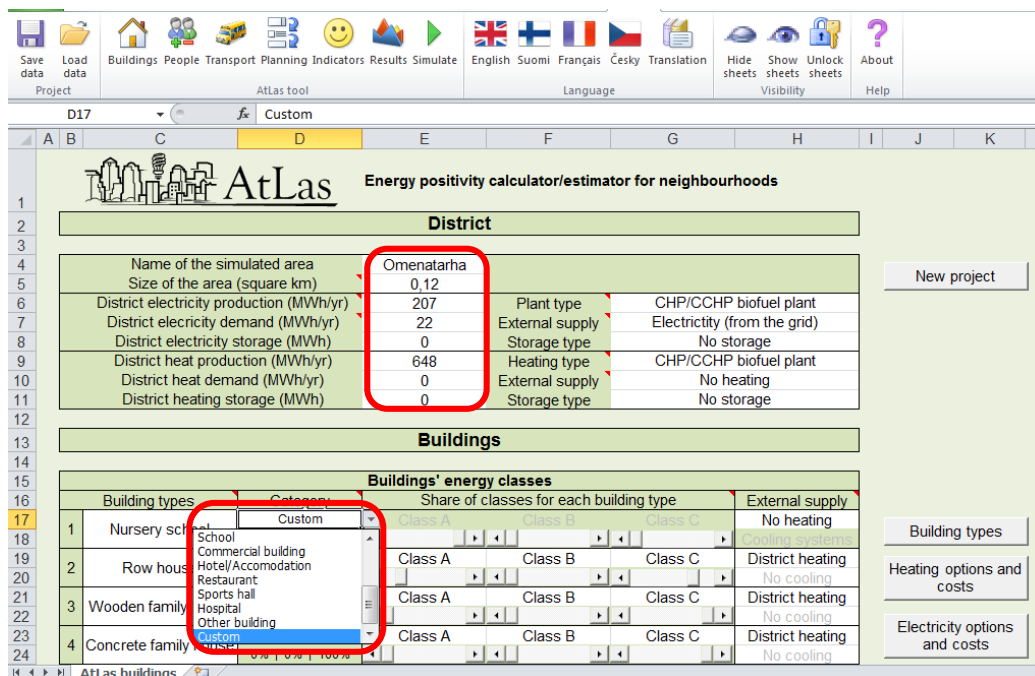
284 A decision support tool called AtLas was designed and piloted to inform the long-term planning
285 of neighbourhood energy solutions towards energy positivity [19]. The following key
286 requirements for the AtLas tool development [20] were expressed by the envisaged users:
287 Simplicity of use,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

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

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

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

309 Due to the large number of possible input variables, the Excel spreadsheets are formatted to
 310 guide the user to understand the meaning of the input data and its possible impacts on the
 311 simulation results. The data input, such as the name or size of the area, required for the
 312 spreadsheets is either inserted by the user or it is provided by selecting from drop down menus.
 313 These are populated by the information stored in the Advanced sheet (e.g. the building types or
 314 the energy production options) (see Figure 3). The data input for the Advanced sheet requires
 315 expert knowledge but normally needs to be input to the tool once for each country and updated
 316 only when shares of energy types, CO₂ emissions, energy costs or building codes change. If
 317 available, site specific data can also be input into the Advanced spreadsheet (e.g. energy
 318 sources).



319
 320 *Figure 3. On the Buildings spreadsheet the user inserts information about the area in the white*
 321 *cells by hand or chooses the options from drop-down menus.*

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

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

335 AtLas tool presents the results in formats that will help the user to present the relevant
336 information to other decision makers and stakeholders. The outputs can be presented as energy
337 positivity indicators and as particular impacts in the form of 1) purchased energy, 2) costs
338 including investments required or 3) CO₂ emissions, each normalized to different bases (e.g.
339 floor area, population or area of the district). The values can also be presented separately by each
340 energy type or in total, and as time-related or cumulative values. This makes the software very
341 versatile, and thereby it can support the decisions of facility managers, city planners or energy
342 companies in the planning of energy distribution networks.

343 **7. DEMONSTRATION SITES IN FINLAND AND FRANCE**

344 The first demonstration site is a Finnish residential neighbourhood “Omenatarha” in Skaftkärr
345 area in Porvoo [23]. The Skaftkärr area is being redeveloped with the goal of offering

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

355 The second demonstration site is the University Institute of Technology (IUT), which is part
356 of the university campus in Bordeaux, France [24]. IUT has teaching and office facilities to
357 cater for two thousand students and five hundred staff in a total of twenty two buildings. The
358 site is 80 000 m² with 40 000 m² of buildings. The buildings are mostly teaching and office
359 facilities. A gas boiler and local heat network provide a large proportion of the heating. This
360 heating system is managed by the IUT's energy management/maintenance staff. A couple
361 photovoltaic (PV) panels are fitted to one of the buildings, but they are mainly used for
362 teaching purposes and are not connected to the national electricity network. The key
363 stakeholders at the French demonstration site are the Chief Executive Director (in charge of
364 overall site management) and his site management team, and the university staff and students.

365 Neither of the demonstration areas currently reaches energy positivity (as their OER < 1). The
366 Finnish site is close to energy positivity, as already 98% of the energy demand is produced
367 from renewable sources in the area. It still only reaches level B on the suggested scale for
368 energy positivity. To reach energy neutrality (A level), it would be necessary to produce
369 8 MWh of more renewable energy annually. This means e.g. 53 m² solar panels or 25 m² solar

370 collectors. The French site currently represents C-level on the energy positivity scale.
371 Currently there is no local renewable energy production on the area, except the few PV
372 panels. To reach energy neutrality (A level), and cover the current energy demand, the French
373 site would need to produce 4700 MWh of more renewable energy annually. This would mean
374 e.g. a bio based CHP (producing all the heat and 70 % of electricity) and 3 000 m² of solar
375 panels. Local energy storages could also be introduced to both sites to better match the timing
376 of production and demand.

377 Selections of scenarios for both sites were studied with the AtLas tool. Which of the different
378 scenarios tested is the best case scenario for scaling up each of the demonstration sites
379 depends on the priorities of the stakeholders involved. For example, the driving factor could
380 be costs, CO₂ reduction or reaching energy positivity.

381 In the Finnish case, the city planners used the tool for comparing different scenarios for three
382 different planning areas in Porvoo (including the demonstration site), while the energy
383 provider and Posintra Oy (as the development coordinator) participated in formulating the
384 scenarios. The comparisons will be presented in different occasions to the other stakeholders,
385 like the local government officials, construction companies or the residents of the areas. The
386 comparisons of the future scenarios for the Finnish site showed that among the tested
387 scenarios, the one where energy efficiency of the houses was improved (from C-class to A-
388 class), while keeping the sizing of the CHP for the less energy efficient buildings, would be
389 the one with shortest payback period and best energy positivity level (A++). The one
390 producing least CO₂ emissions would be a scenario where the energy production in the area
391 was increased with solar thermal to achieve 100 % local renewable heating and PV
392 production to achieve 100 % local renewable electricity.

393 In the French case, the Chief Executive Director (in charge of overall site management) and
394 his site management team defined seven different scenarios, which were compared to the
395 baseline for the IUT site. The information was presented to the other stakeholders - the
396 university staff and students – through information screens as part of the demonstration. In the
397 case of the French demonstration site, the scenario with the shortest payback period (10 to 13
398 years, depending on the cost evolution model) was the scenario where district PV generation
399 was introduced on the site according to the real specifications of IUT site. This was also the
400 scenario with the highest energy positivity level (B). This scenario almost reached A-class in
401 energy positivity. The lowest CO₂ emissions (15 ton CO₂ ekv/year) were reached with the
402 scenario where a bio-CHP plant was built on the area.

403 **8. FUTURE WORK**

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

411 The target values for AMR and MHS need to be further considered. This is not a
412 straightforward issue. This is because surplus energy production in an EPN is only
413 advantageous when there is a demand for that energy outside of the EPN or it can be stored in
414 the EPN until there is a local or national demand for it. For instance, if the energy production
415 at an EPN is greater than the local demand at times of the day when national electricity
416 demand is high then this is advantageous, as the surplus energy can be used to help meet the

417 national energy demand. On the other hand, if surplus electricity production occurs when
418 national energy demand is low and it cannot be stored locally until there is a national or local
419 demand for that energy. This is problematic, because this may contribute to overload
420 problems on national distribution and transmission networks. National energy demand also
421 affects the economics of the EPN, as explained in business related work of the project group
422 [30]: *“When national electricity demand is low, supply comes from relatively inexpensive*
423 *base load generation. When demand is high and base load generation is exhausted, supply*
424 *comes from relatively expensive peaking generators. This creates rapidly fluctuating energy*
425 *costs throughout the day in all EU energy markets.”*

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

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

437 **9. CONCLUSIONS**

438 The research presented in this paper is the first work, which explicitly defines the concept of
439 an Energy Positive Neighbourhood and the metrics and tools to measure the energy positivity
440 level of an area. In addition, it presents an energy positivity label to enable the visualisation of

441 the progress of an area towards becoming energy positive. In doing so it extends the systems
442 limits of current approaches to energy analysis for urban sustainability. The energy positivity
443 level of an area is estimated with calculating energy matching indicators: on-site energy ratio,
444 annual mismatch ratio and other mismatch indicators.

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

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

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465 **NOMENCLATURE**

| | | |
|-----|-----|---|
| 466 | CHP | Combined heat and power production |
| 467 | EPN | Energy Positive Neighbourhood |
| 468 | KPI | Key Performance Indicator |
| 469 | OER | On-site Energy Ratio |
| 470 | AMR | Annual Mismatch Ratio |
| 471 | MHS | Maximum Hourly Surplus |
| 472 | MHD | Maximum Hourly Deficit |
| 473 | RPL | Monthly Ratio of Peak hourly demand to Lowest hourly demand |
| 474 | OEF | On-site Energy Fraction |
| 475 | HMR | Hourly Mismatch Ratio |

476 **REFERENCES**

- 477 1. Neves A.R. and Leal V. (2010) Energy sustainability indicators for local energy planning:
478 Review of current practices and derivation of a new framework, Renewable and Sustainable
479 Energy Reviews, Volume 14, Issue 9, December 2010, Pages 2723-2735.
480 [doi:10.1016/j.rser.2010.07.067](https://doi.org/10.1016/j.rser.2010.07.067)
- 481 2. Yamagata Y. and Seya H. (2013) Simulating a future smart city: An integrated land use-
482 energy model, Applied Energy, Volume 112, December 2013, Pages 1466-1474, ISSN
483 0306-2619, <http://dx.doi.org/10.1016/j.apenergy.2013.01.061>
- 484 3. Kumar P. and Geneletti D. (2015) How are climate change concerns addressed by spatial
485 plans? An evaluation framework, and an application to Indian cities, Land Use Policy,
486 Volume 42, January 2015, Pages 210-226, ISSN 0264-8377,
487 <http://dx.doi.org/10.1016/j.landusepol.2014.07.016>

- 488 4. Zaron, B. and Verones, S. (2012) Climate change, urban energy and planning practises:
489 Italian experiences of innovation in land management tools. *Land Use Policy* Volume 32,
490 May 2013, Pages 343–355. doi:10.1016/j.landusepol.2012.11.009
- 491 5. Marique A.-F. and Reiter S. (2014) A simplified framework to assess the feasibility of zero-
492 energy at the neighbourhood/community scale, *Energy and Buildings*, Volume 82, October
493 2014, Pages 114-122, ISSN 0378-7788, <http://dx.doi.org/10.1016/j.enbuild.2014.07.006>
- 494 6. Sampaio H. C; Dias R.A. and Perrella Balestieri J.A. (2013) Sustainable urban energy
495 planning: The case study of a tropical city, *Applied Energy*, Volume 104, April 2013, Pages
496 924-935, ISSN 0306-2619, <http://dx.doi.org/10.1016/j.apenergy.2012.12.022>
- 497 7. Eicker U.; Monien D.; Duminil É. and Nouvel R. (2015) Energy performance assessment in
498 urban planning competitions, *Applied Energy*, Volume 155, 1 October 2015, Pages 323-
499 333, ISSN 0306-2619, <http://dx.doi.org/10.1016/j.apenergy.2015.05.094>
- 500
- 501 8. EC (2010) 2010/31; Directive 2010/31/EU of the European Parliament and of the Council of
502 19 May 2010 on the energy performance of buildings. Available: [http://eur-](http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32010L0031)
503 [lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32010L0031](http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32010L0031) [accessed 22.9.2014]
- 504 9. Manfren M., Caputo P. and Costa G. (2011) Paradigm shift in urban energy systems through
505 distributed generation: Methods and models. *Applied Energy*, Volume 88, Issue 4, April
506 2011, Pages 1032-1048, <http://dx.doi.org/10.1016/j.apenergy.2010.10.018>
- 507 10. Cole, R.J. and Fedoruk, L. (2015) Shifting from net-zero to net-positive energy buildings
508 [Building Research & Information](#) Vol. 43, Iss. 1, 2015.
- 509 11. Cole, R.J. (2015) Net-zero and net-positive design: a question of value *Building Research &*
510 *Information* Vol. 43, Iss. 1, 2015.

- 511 12. Bhatt, V.; Friley, P. and Lee, J. (2010) Integrated energy and environmental systems
512 analysis methodology for achieving low carbon cities. Journal of Renewable and
513 Sustainable Energy vol. 2 (3) p. 031012. <http://dx.doi.org/10.1063/1.3456367>
- 514 13. Mirakyan A. and De Guio R. (2013) Integrated energy planning in cities and territories: A
515 review of methods and tools, Renewable and Sustainable Energy Reviews, Volume 22, June
516 2013, Pages 289-297, ISSN 1364-0321, <http://dx.doi.org/10.1016/j.rser.2013.01.033>
- 517 14. Sperling K., Hvelplund F. and Mathiesen B. V. (2011) Centralisation and decentralisation in
518 strategic municipal energy planning in Denmark. Energy Policy, Volume 39, Issue 3, March
519 2011, Pages 1338–1351. [doi:10.1016/j.enpol.2010.12.006](http://dx.doi.org/10.1016/j.enpol.2010.12.006)
- 520 15. Thellufsen, J. Z. and Lund, H. (2015) Energy saving synergies in national energy systems,
521 Energy Conversion and Management, Volume 103, October 2015, Pages 259-265, ISSN
522 0196-8904, <http://dx.doi.org/10.1016/j.enconman.2015.06.052>
- 523 16. Kılıkış Ş. (2014) Energy system analysis of a pilot net-zero exergy district, Energy
524 Conversion and Management, Volume 87, November 2014, Pages 1077-1092, ISSN 0196-
525 8904, <http://dx.doi.org/10.1016/j.enconman.2014.05.014>
- 526 17. Mohareb E. A. and Kennedy C. A. (2014) Scenarios of technology adoption towards low-
527 carbon cities, Energy Policy, Volume 66, March 2014, Pages 685-693, ISSN 0301-4215,
528 <http://dx.doi.org/10.1016/j.enpol.2013.10.070>
- 529 18. Ala-Juusela, M.; Hradil, P.; Jantunen, J.; Kontio, M.-R.; Ståhlberg, M.; Rosqvist, J.;
530 Rouhiainen, J. and Brassier, P. (2014) Specifications for the urban planning decision support
531 tool. Deliverable 3.4 of IDEAS project.
- 532 19. Hradil, P. and Ala-Juusela, M. (2014) Prototype of the urban planning decision support tool.
533 Deliverable 4.2 of IDEAS project. Synopsis available:
534 [http://www.ideasproject.eu/IDEAS_wordpress/wp-content/uploads/2014/11/IDEAS_D4-](http://www.ideasproject.eu/IDEAS_wordpress/wp-content/uploads/2014/11/IDEAS_D4-2_Synopsis.pdf)
535 [2_Synopsis.pdf](http://www.ideasproject.eu/IDEAS_wordpress/wp-content/uploads/2014/11/IDEAS_D4-2_Synopsis.pdf)

- 536 20. Huovila, A.; Jantunen, J.; Ala-Juusela, M.; Sepponen, M.; Tuominen, T.; Thibault, E.;
537 Decorme, R.; Brassier, P.; Rouhiainen, J.; Tuomi, L.; Varis, A.; Ståhlberg, M.; Gras, D.
538 (2013) Business & community requirements analysis. Deliverable D2.1 of IDEAS project.
539 Available: [http://www.ideasproject.eu/IDEAS_wordpress/wp-](http://www.ideasproject.eu/IDEAS_wordpress/wp-content/uploads/2013/08/IDEAS_D2-1_Business-and-Community-Requirements-Analysis.pdf)
540 [content/uploads/2013/08/IDEAS_D2-1_Business-and-Community-Requirements-](http://www.ideasproject.eu/IDEAS_wordpress/wp-content/uploads/2013/08/IDEAS_D2-1_Business-and-Community-Requirements-Analysis.pdf)
541 [Analysis.pdf](http://www.ideasproject.eu/IDEAS_wordpress/wp-content/uploads/2013/08/IDEAS_D2-1_Business-and-Community-Requirements-Analysis.pdf)
- 542 21. Säynäjoki, E.; Heinonen, J.; Rantsi, J.; Ristimäki, M.; Nissinen, A.; Seppälä, J.; Lahti, P and
543 Haapio, A. (2012) Kaupunkien ja kuntien aluetasoiset ekolaskurit: Katsaus tarjolla oleviin
544 ekolaskureihin. KEKO. In Finnish. English summary table: KEKO study: Cities district
545 level eco efficient analysis: existing tools.
- 546 22. Crosbie, T.; Crilly, M.; Oliveras, J.; Gamboa, G.; Niwaz, N. and Lynch, D. (2013)
547 Stakeholder requirements analysis. Deliverable D6.1 of SEMANCO (Semantic Tools for
548 Carbon Reduction in Urban Planning) project.
- 549 23. Economidou, M. (ed.). (2011) Europe's buildings under the microscope A country-by-
550 country review of the energy performance of buildings. BPIE. ISBN: 9789491143014.
- 551 24. Ala-Juusela, M.; Antila, A.; Brassier, P.; Bäckström, K.; Crosbie, T; Dawood, M.; Gras, D.,;
552 Rouhiainen, J.; Rosqvist, J.; Short, M.; Ståhlberg, M.; Tuomi, L. and Varis, A. (2014) D3.1
553 Case Study Scoping. Deliverable D3.1 of IDEAS project, available:
554 [http://www.ideasproject.eu/IDEAS_wordpress/wp-content/uploads/2013/08/IDEAS_D3-](http://www.ideasproject.eu/IDEAS_wordpress/wp-content/uploads/2013/08/IDEAS_D3-1_Case-Study-Scoping.pdf)
555 [1_Case-Study-Scoping.pdf](http://www.ideasproject.eu/IDEAS_wordpress/wp-content/uploads/2013/08/IDEAS_D3-1_Case-Study-Scoping.pdf)
- 556 25. Davis, K. (2009) Towards an ICT Infrastructure for Energy Positive Neighbourhoods.
557 Report from ELSA Thematic Working Group on ICT for energy efficiency (Available at:
558 [http://ec.europa.eu/information_society/activities/sustainable_growth/docs/elsa/elsa_1/ELSA](http://ec.europa.eu/information_society/activities/sustainable_growth/docs/elsa/elsa_1/ELSA-EnergyPositive-Report1.pdf)
559 [A-EnergyPositive-Report1.pdf](http://ec.europa.eu/information_society/activities/sustainable_growth/docs/elsa/elsa_1/ELSA-EnergyPositive-Report1.pdf)

- 560 26. Pesch, D.; Ellis, K.; Kouramas, K. and Assef, J. (2013) Deliverable D1.1 of the
561 COOPERaTE Project: Report on Requirements and Use Cases Specification
562 [http://www.cooperate-
563 fp7.eu/files/cooperate/downloads/COOPERATE_D11.pdf#page=1&zoom=auto,-47,165](http://www.cooperate-
563 fp7.eu/files/cooperate/downloads/COOPERATE_D11.pdf#page=1&zoom=auto,-47,165)
- 564 27. Perez-Lombard, L.; Ortiz, J.; Gonzalez, R. and Maestre, I.R. (2009) A review of
565 benchmarking, rating and labelling concepts within the framework of building energy
566 certification schemes Energy and Buildings Vol 41 pp. 272–278
- 567 28. Lampputieto. (2015) Näin valitset lampun (How to choose a lamp). A brochure by
568 PremiumLight IEE/EU-project. In Finnish. [Cited on 13.4.2015. Available at:
569 <http://www.lampputieto.fi/lampunvalintakone/>
- 570 29. Cao, S.; Hasan, A. and Sirén, K. (2013). On-Site Energy Matching Indices for Buildings
571 with Energy Conversion, Storage and Hybrid Grid Connections. Energy and Buildings, Vol.
572 64, pp. 423-438, 2013.
- 573 30. Crosbie, T.; Ye, J.; Short, M.; Thibault, E.; Rosqvist, J.; Brassier, P. and Huovila, A. (2014)
574 Specific business models for demo cases. Deliverable 2.2 of IDEAS project, Available:
575 [http://www.ideasproject.eu/IDEAS_wordpress/wp-content/uploads/2013/08/IDEAS_D2-
576 2_Specific-Business-Models-for-Demo-Cases.pdf](http://www.ideasproject.eu/IDEAS_wordpress/wp-content/uploads/2013/08/IDEAS_D2-
576 2_Specific-Business-Models-for-Demo-Cases.pdf)