Three dimensions on the road to feasible energy positive neighbourhoods: stakeholder, time frame, physical scale

Mia Ala-Juusela
Three dimensions on the road to feasible energy positive neighbourhoods: stakeholder, time frame, physical scale

Mia Ala-Juusela

A doctoral thesis completed for the degree of Doctor of Science (Technology) to be defended, with the permission of the Aalto University School of Engineering, at a public examination held at the lecture hall 326 (Otakaari 4) on 16th February 2023 at 12.

Aalto University
School of Engineering
Department of Built Environment
Real Estate Economics
Supervising professors
Professor Seppo Junnila,
Aalto University, Finland

Thesis advisors
Prof. Dr. Abdul Samad (Sami) Kazi,
VTT Technical Research Centre of Finland Ltd., Finland

Preliminary examiners
Associate Professor Şiir Kılış,
The Scientific and Technological Research Council of Türkiye - TUBITAK, Türkiye

Professor Maria Beatrice Andreucci,
Sapienza University of Rome, Italy

Opponents
Professor Minna Sunikka-Blank,
University of Cambridge, United Kingdom
Climate change is one of the greatest challenges faced by humankind today, and this calls for urgent action. Energy Positive Neighbourhoods (EPNs), offer a solution for reducing the effects of the built environment on climate change, by increasing the energy efficiency of buildings and integrating renewable energy facilities closer to the points where energy is needed. EPNs also support surrounding areas on their way toward climate neutrality. However, EPNs are not yet widely in use. The Dissertation identifies the means to promote EPNs.

An extensive literature review indicated that the roles and needs of different stakeholders are the key aspects to consider on the way to feasible EPNs. These aspects are highly related to the different life-cycle stages of the project, as well as the different physical scales. The literature review also revealed shortcomings in current tools and business models. Stakeholder interviews and workshops showed that to encourage the stakeholders to develop and make wider use of EPNs, they need more information on the concept and its benefits.

Based on these findings, a set of key performance indicators, calculation tools and a business model were developed, engaging the key stakeholders in the process. A clear definition of EPN was missing, and that was formulated first. The developed solutions were tested and validated in a second round of interviews and workshops, and with a web survey.

The feedback from the stakeholders confirmed several benefits of the solutions: The AtlAs tool developed for EPN planning will help city planners and energy companies in developing EPNs and explaining the benefits and positive impacts of EPNs to building owners, users and other stakeholders. The new method for thermal comfort evaluation is able to show the optimal conditions for thermal comfort also in the Northern climate. The easy-to-use tool for renovation planning fulfils the needs of small renovation companies for showing the energy and cost effects to their clients. An aggregator business model helps facilitate the complicated process of district-scale refurbishment.

It can be concluded that easily understandable information and easy-to-use tools are essential for promoting EPNs. It is important that all stakeholders share a common vision and understanding of what an EPN is and what the aims are, and therefore a definition is essential to facilitate efficient and fruitful cooperation. It is important to ensure that the EPN fulfils the needs of the building users and demonstrate that this is achieved with a minimal environmental and economic burden. Neighbourhood-level solutions require much more cooperation and coordination than building-level solutions. The tools and indicators developed in connection with this Dissertation will support this process.

**Keywords**  Energy positive neighbourhoods, stakeholders, definition, key performance indicators, thermal comfort, easy-to-use tools, business models, district-scale renovation
Acknowledgements

“It takes a village.” - Hillary Rodham Clinton 1996

Although originally referring to raising a child, this African proverb quoted by Hillary Rodham Clinton as the title of her book is also highly relevant to my Dissertation. Although I will get the credit, i.e. the Doctoral title, I must admit that it is true teamwork. Without the support that I got from the people around me, this would never have been possible. In addition to those listed below, these include e.g. my teammates and my extended family.

I’m extremely grateful to my supervising Professor Seppo Junnila for his support, his consistency with the format of the Dissertation and the English expressions. And his patience with my lack of time for the writing. This endeavour would also not have been possible without my supervisor Sami Kazi: his encouragement during the process and his perseverance for not letting me stop. Professor Masanori Shukuya had a double role as a co-author, but also as an important guide to the world of human body exergy analyses. Heartfelt thanks for the opportunity to work in his laboratory on two occasions, and for the numerous interesting discussions related to energy, exergy, nature and Japanese culture. I also want to express my sincere gratitude to the pre-examiners for their thorough analysis of and positive feedback on my work.

My co-authors played an important role in deepening my understanding of the research subject through numerous discussions, and getting the results published as scientific articles. Tracey Crosbie, my sister abroad, thank you for being my friend and co-worker for so many years. It has been about 15 years of discussions, projects and project preparation, and items from heaven to earth – mostly on earth as we are concerned. Thank you Mari Hukkalainen for being a close colleague and friend. It is amazing how quickly you adopted the learnings and proceeded to the Doctoral status well before me, so that we have not had many occasions to work in the same projects, as you had to adopt a leading role, in parallel with me. I am also grateful to Tarja Häkkinen for showing me the true meaning of teamwork. In all of your projects, I really felt that I was contributing as one of the team members and that together we could accomplish much more than alone. Special thanks to Jari Shemeikka for being there for me as team leader and also as co-author in one of the articles. We often wander to the big questions in life when we start by discussing the work. Thank you Nusrat Jung for underlining our responsibility for high quality scientific work, and by encouraging me to continue with the PhD work, on the times when it seemed to
not progress at all. I am also grateful to Tarja Mäkeläinen for bringing an out-of-the-box view to the discussions, often giving new insights by asking the right questions.

In addition to the working community, my family deserves special thanks for their patience and support. I am grateful to my mother for supporting me, not only financially during the high-school and university studies, but also by travelling to Japan to take care of my sons during the days while I was working at Tokyo City University. Many thanks to my sister Rauni for her persistent trust in my wit and my ability to get through this. And standing by me in good and bad times. Together we can handle anything. I want to express my deep gratitude to my sons Akseli and Onni for bearing my absent-minded appearance every now and then, when I was deep in my thoughts. I felt that I simply had to finalise this work because I dragged you to Japan twice in the beginning of the process. Akseli also managed to enlighten me with the very grown-up discussions and eye-opening views on humanity. Sincere thanks to Onni for the entertainment - you know what I mean. And finally, thank you, my dearest Juhaveikko. Your support has been essential for achieving this goal. The truly visible equality that you express in our daily life is a fundamental ingredient in managing to finalise this work. It also helps that still after 30 years I can enjoy your company and the intelligent, and sometimes funny discussions with you.

Espoo, 4th January 2023

Mia Ala-Juusela
Contents

Acknowledgements ................................................................................................. 1
List of Abbreviations and Symbols ......................................................................... 7
List of Publications .................................................................................................. 9
Author’s Contribution .............................................................................................. 10

1. Introduction ........................................................................................................... 13
   1.1 The need for energy positive neighbourhoods (EPNs) ............................. 14
       1.1.1 Climate change calls for immediate action ...................................... 14
       1.1.2 Role of the built environment in climate change mitigation ....... 14
       1.1.3 Benefits of neighbourhood scale view ....................................... 15
   1.2 Problem: Slow application of EPNs ......................................................... 16
   1.3 Structure of the dissertation ....................................................................... 16

2. Conceptual framework and problem identification ............................................. 18
   2.1 Conceptual framework .............................................................................. 18
       2.1.1 Energy positive neighbourhood: history and definition .......... 18
       2.1.2 Key concepts in EPNs ................................................................... 22
       2.1.3 Energy demand ............................................................................... 23
       2.1.4 Local renewable energy sources .................................................. 26
       2.1.5 Connection to and co-operation with wider energy networks .... 26
       2.1.6 A functional, user friendly environment ..................................... 28
       2.1.7 Environmental impacts ............................................................... 28
       2.1.8 Life-cycle aspects ......................................................................... 29
       2.1.9 Key stakeholders for EPNs ........................................................... 30
       2.1.10 Sustainability goals for EPNs ....................................................... 32
   2.2 Central viewpoints based on the key concepts .......................................... 32
       2.2.1 Stakeholder .................................................................................... 33
       2.2.2 Time frame .................................................................................... 35
       2.2.3 Physical scale ............................................................................... 35
   2.3 Problem identification ............................................................................... 36
2.3.1 Energy positive neighbourhood: focus on the concept and benefits
37
2.3.2 Interior space - room view: focus on thermal comfort........... 39
2.3.3 Building scale view: focus on renovation.......................... 39
2.3.4 District scale view: focus on refurbishment...................... 40
2.4 Gaps and needs ................................................................. 44
2.5 Research questions .......................................................... 45
2.5.1 The perspectives in the Publications ............................... 46
3. Methodology ........................................................................ 47
3.1 Detailed analyses of the current information and solutions... 52
3.2 Interviews with the stakeholders........................................ 53
3.3 Definition of typical and extreme weather conditions in Finland
55
3.4 Human Body Exergy Consumption rate calculations in Finnish
conditions .............................................................................. 56
3.5 Survey on the usability of the E-PASS tool ......................... 57
3.6 New indicators, tools and business models .......................... 57
3.6.1 EPN definition, KPIs, label and assessment tool............... 58
3.6.2 Easy-to-use tool for SMEs to choose renovation methods ... 59
3.6.3 Activator business model for district-scale renovation....... 59
4. Results: Evidence of the role of the three integrated dimensions in
promoting EPNs........................................................................ 60
4.1 Knowledge needs of key stakeholders for the promotion of EPNs
60
4.1.1 Definition of Energy Positive Neighbourhoods ............... 61
4.1.2 KPIs for EPNs ............................................................... 63
4.1.3 Energy Positive Neighbourhood Label ......................... 65
4.1.4 Decision support tool AtLas ............................................ 66
4.2 Ensuring service level with minimised energy demand....... 69
4.2.1 Solution: New method to evaluate thermal comfort ........ 70
4.3 Energy and cost efficient renovation actions for a building ... 72
4.3.1 Energy performance assessment tools for refurbishment.... 72
4.3.2 Solution: Easy-to-use tool E-PASS ................................. 73
4.4 Promoting district scale renovation ....................................... 75
4.4.1 Drivers and barriers for district-scale refurbishment approaches
76
4.4.2 Solution: New business model for district-scale refurbishment
76
5. Discussion ........................................................................... 78
5.1 The solutions in relation to stakeholder, time frame and physical scale 80
5.1.1 Stakeholder roles and interests ......................................................... 80
5.1.2 Time frame: short or long term .......................................................... 83
5.1.3 Physical scale: building or neighbourhood ........................................ 85
5.2 Points in need for further attention ..................................................... 85

6. Conclusions and recommendations ....................................................... 89
6.1.1 Main findings and conclusions ......................................................... 90
6.1.2 Recommendations ........................................................................... 91
6.1.3 Potential impacts ............................................................................. 93

References .................................................................................................. 95

Publications 1 to 4 ................................................................................... 109
# List of Abbreviations and Symbols

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AEC</td>
<td>Architecture and Engineering Company</td>
</tr>
<tr>
<td>AMRx</td>
<td>Annual Mismatch Ratio (by energy type)</td>
</tr>
<tr>
<td>BESS</td>
<td>Battery Energy Storage System</td>
</tr>
<tr>
<td>BEST</td>
<td>Building Energy Simulation Tools</td>
</tr>
<tr>
<td>BIPV</td>
<td>Building Integrated PhotoVoltaics</td>
</tr>
<tr>
<td>CHP</td>
<td>Combined Heat and Power generation</td>
</tr>
<tr>
<td>CO₂</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>D-SER</td>
<td>District-Scale Energy Refurbishment</td>
</tr>
<tr>
<td>DSO</td>
<td>Distribution System Operator</td>
</tr>
<tr>
<td>EPN</td>
<td>Energy Positive Neighbourhood</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>GDP</td>
<td>Gross Domestic Product</td>
</tr>
<tr>
<td>GHG</td>
<td>GreenHouse Gas</td>
</tr>
<tr>
<td>HBEC tool</td>
<td>Human Body Exergy Consumption rate calculation tool</td>
</tr>
<tr>
<td>IBPSA</td>
<td>International Building Performance Simulation Association</td>
</tr>
<tr>
<td>ICT</td>
<td>Information and Communication Technology</td>
</tr>
<tr>
<td>IDEAS</td>
<td>Intelligent neighbourhooD Energy Allocation &amp; Supervision</td>
</tr>
<tr>
<td>IEA</td>
<td>International Energy Agency</td>
</tr>
<tr>
<td>IEQ</td>
<td>Indoor Environment Quality</td>
</tr>
<tr>
<td>IES</td>
<td>Innovative Energy Systems</td>
</tr>
<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>KPI</td>
<td>Key Performance Indicator</td>
</tr>
<tr>
<td>LCA</td>
<td>Life Cycle Assessment</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Full Form</td>
</tr>
<tr>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>MHDx</td>
<td>Maximum Hourly Deficit (by energy type)</td>
</tr>
<tr>
<td>MHSx</td>
<td>Maximum Hourly Surplus (by energy type)</td>
</tr>
<tr>
<td>NZEB</td>
<td>Nearly Zero Energy Building</td>
</tr>
<tr>
<td>OEF</td>
<td>On-site Energy Fraction</td>
</tr>
<tr>
<td>OER</td>
<td>On-site Energy Ratio</td>
</tr>
<tr>
<td>PED</td>
<td>Positive Energy District</td>
</tr>
<tr>
<td>PMV</td>
<td>Predicted Mean Vote</td>
</tr>
<tr>
<td>PPP</td>
<td>Public-Private Partnership</td>
</tr>
<tr>
<td>PV</td>
<td>Photovoltaic</td>
</tr>
<tr>
<td>PVT</td>
<td>Photovoltaic thermal</td>
</tr>
<tr>
<td>RED II</td>
<td>Renewable Energy – Recast to 2030</td>
</tr>
<tr>
<td>RES</td>
<td>Renewable Energy Source(s)</td>
</tr>
<tr>
<td>ROI</td>
<td>Return On Investment</td>
</tr>
<tr>
<td>RPLx</td>
<td>Monthly Ratio of Peak hourly demand to Lowest hourly demand (by energy type)</td>
</tr>
<tr>
<td>SCC</td>
<td>Smart Cities and Communities</td>
</tr>
<tr>
<td>SME</td>
<td>Small and Medium-sized Enterprise</td>
</tr>
<tr>
<td>TRL</td>
<td>Technology Readiness Level</td>
</tr>
<tr>
<td>TRY</td>
<td>Test Reference Year</td>
</tr>
<tr>
<td>WGBC</td>
<td>World Green Building Council</td>
</tr>
</tbody>
</table>
List of Publications

This doctoral dissertation consists of a summary, and of the following publications which are referred to in the text by their numerals


Author’s Contribution

Publication 1: Defining and operationalising the definition of Energy Positive Neighbourhoods

Mia Ala-Juusela was the main author of the publication, leading the work for the definition and Key Performance Indicators (KPIs) for Energy Positive Neighbourhoods. Co-author Tracey Crosbie was the Coordinator of the IDEAS project, in which the work towards the definition, KPIs and tools was carried out, contributing to the formulations of the definition. Co-author Mari Hukkalainen participated in the definition work.

Publication 2: Human body exergy consumption and thermal comfort of an office worker in typical and extreme weather conditions in Finland

Mia Ala-Juusela was the main author of the publication, carrying out the literature review and data collection, as well as the calculations and writing the conclusions. Co-author Masanori Shukuya was the main developer of the Human Body Exergy rate calculation method, developed by himself and his students at Tokyo City University. He also gave comments on the choice of the cases and the article in general.

Publication 3: Usability of energy performance assessment tools for different use purposes with the focus on refurbishment projects

In this publication, Mia Ala-Juusela carried out the main part of the literature review and the analysis of the different types of energy performance assessment tools, their benefits and limitations for different purposes. She also participated in defining the interview questions on the barriers for SMEs in refurbishment projects and carried out part of the interviews. She contributed to the analysis of the interviews. Based on this background work, she participated in defining the survey questions regarding the current use of tools and the usability of the new tool, as well as the analysis of the survey results. Tarja Häkkinen was the main author and led the process, participating in most parts of the work. Jari Shemeikka was the main developer of the E-PASS tool, participating also in the interviews and surveys.

Publication 4: Drivers and Benefits for District-Scale Energy Refurbishment

This publication is based on very tight collaboration between the authors, and all of them made an important contribution to all parts of the work. Therefore,
Mia Ala-Juusela participated in the literature review, defining the interview questions, carrying out part of the interviews, the analysis of the interviews and the development of the activator business model. For the interviews, Mia concentrated especially on energy companies due to her study background in new energy technologies.
1. Introduction

According to the Author’s understanding and vision, the aim of the built environment is to support human activities while minimising the harmful effects to the natural environment and humans themselves. This is supported by the international views on human rights (United Nations 1948) and sustainable development (World Commission on Environment and Development 1987).

In our strive towards a development that “meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development 1987), we need to look for ways to achieve carbon neutrality by 2050 (IPCC 2021). One essential step is the transfer to a fully renewable energy system (IEA 2020). Energy efficiency will increase the chances of reaching this goal earlier (IEA 2021, IPCC 2022). The built environment plays an important part in this, as buildings alone are responsible for 36% of global energy use and 39% of CO₂ emissions (UN Environment and IEA, 2019). The subject of this dissertation, Energy Positive Neighbourhoods (EPNs), represents a potential approach for reducing the effects of the built environment on climate change by increasing the energy efficiency of buildings and integrating renewable energy facilities closer to the points where energy is needed.

The definition developed by the Author in collaboration with the IDEAS team (in Publication 1) describes energy positive neighbourhoods as “those (neighbourhoods) in which the annual energy demand is lower than the 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.” In this dissertation, important aspects to be considered on the road towards these energy positive neighbourhoods are presented, including the reasons for ending up with this particular definition. In the course of the work, several practical methods and tools were developed and tested to address the gaps related to these important aspects, and these are also briefly described.

This chapter introduces the background to the dissertation by explaining the role of the energy positive neighbourhoods (EPNs) in the decarbonisation of the energy system and then stating the problem: the lack of a wide application of EPNs. It also presents the structure of the dissertation.
1.1 The need for energy positive neighbourhoods (EPNs)

1.1.1 Climate change calls for immediate action

In its Sixth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC 2021) predicts dramatic effects if we are not able to limit the global temperature rise to 1.5°C. Even with that, there will be serious effects: some weather events, such as heatwaves, storms and droughts are likely to become more frequent and widespread, and, in some cases, more intense. This is indeed happening, and was especially visible in 2021: exceptional wildfires occurred all around the world, as well as floods and droughts that have not been seen in 50 years or ever before, but also exceptionally cold weather in Europe and Alaska in April, snowfalls in the Pyrenees in July, just to mention a few examples (World Meteorological Organisation 2021, Washington Post 2021, News in 24 2021). The same trend has continued in 2022. The related impacts of these weather phenomena on humans are expected to be broadly negative, including reduced water availability, reduced food security and increased potential for diseases (FAO 2015, Hales et al. 2003).

Although not the only reason for the problems, climate change exacerbates human-induced natural phenomena and is already threatening the livelihoods of people e.g. in Madagascar (World Food Programme 2022). Unfortunately, it is also mainly those who are not the main contributors to climate change who have to pay the price. It is the poor, undeveloped countries that bear the greatest burden. It is also estimated that the increasing temperatures will affect human productivity, and cause losses in Gross Domestic Product (GDP), especially in developing countries (Kompas et al. 2018, Roson and Sartori 2016). However, it is not only about humans: e.g. in Australia, wildfires are causing a severe risk of extinction to some species such as koalas or kangaroos (National Geographic 2020).

Obviously, something needs to be done if we want to keep the earth liveable for humans and other current life forms. According to recent IPCC reports, it is still possible to turn the trend if brisk actions are taken immediately in all areas (IPCC 2021 & 2022).

1.1.2 Role of the built environment in climate change mitigation

CO₂ emissions caused by the energy demands of the built environment contribute significantly to climate change, and its harmful effects. It is estimated by the European Commission (2019a) that buildings account for 40% of the energy use in Europe and for 36% of the CO₂ emissions. Globally the relevant numbers are 36% and 39% respectively (UN Environment and IEA, 2019). This implies that buildings and the built environment will play an important role in achieving the ambitious decarbonisation goals as stated in the Green Deal documentation for Europe (European Commission 2019b) and in the Paris Agreement for most of the world (United Nations 2015a).

The way to reduce energy-related emissions is to improve energy efficiency and gradually move to a fully renewable energy system (IEA 2020 and 2021).
This change will however not happen overnight. According to World Green Building Council (WGBC), the building and construction sector could reach net zero carbon emissions by 2050 (WGBC 2020). According to the European Renovation wave initiative, up to 95% of buildings that will be in use in Europe in 2050 are already built (European Commission 2020). In addition, it is estimated that 97% of the existing buildings need to be renovated to achieve the decarbonisation goals in the EU (BPIE 2017). This indicates an enormous need to always take into account energy efficiency and renewable energy options when planning, both for new buildings and renovation activities. The big share of existing buildings also places challenges for the inclusion of renewable generation capacity into the existing built environment. In line with the Sustainable Development Goals (United Nations 2015b), the optimization of the costs should also be taken into account in this process.

1.1.3 Benefits of neighbourhood scale view

One promising solution for the challenges mentioned above is the development of energy positive neighbourhoods (EPNs), which could provide even the surrounding buildings and areas with renewable energy during the transition towards a fully renewable energy system, which is the ultimate goal.

Compared to the building scale, there are several benefits of widening the viewpoint to the neighbourhood scale. There could be better opportunities for demand response and more constant energy demand profiles than in an individual building, thus reducing the need for energy transfer and storage, which always also means additional costs, energy losses and emissions (Pucker-Singer et al. 2021). A neighbourhood may also consist of buildings with highly variable ages, and it could be easier to find places for renewable installations on the neighbourhood level than on the building site, especially when looking at buildings with historical value, which could prevent the integration of some of the solutions (Sougakis et al. 2020, Paiho, Hoang, & Hukkalainen, 2017; Verbruggen et al., 2010).

Cities play an important role in this transition, as currently, over 50% of the world’s population live in cities, and the rate is estimated to grow to almost 70% by 2050 (IEA 2021). Therefore, investing in actions at the city level can give the best return on investment on decarbonisation. However, also for the cities and municipalities, it makes sense to start the developments on smaller, neighbourhood or district scale, and then use the good solutions for further developments. Cities and communities have proven to be a good level for trying new solutions and distributing the lessons learned from smaller-scale trials. The report from the European Environment Agency (EEA 2019) concludes that cities have several advantages for developing sustainability solutions, related to governance, stakeholder relationships, infrastructure and institutional support mechanisms: They can realise small-scale trials before wider application (DeMaio, 2009) or experiment with slightly different approaches in various districts (Heiskanen and Matchoss, 2018). They have good opportunities to engage with the end-users and other relevant actors to encourage dialogue and feedback for
adjusting the innovations. Local authorities can also help by providing institutional support, such as facilitation, reducing risks, and providing political commitment or access to unused urban space (CKIC, 2015). It has also been found that cities have well-established networks to facilitate efficient distribution of the lessons learned and good experiences that could be applied in other cities, supporting the faster application of the best solutions (EEA 2019). All the above support the idea that neighbourhood or district level would be a good starting point for energy positivity, compared to single building or city level.

1.2 Problem: Slow application of EPNs

Clearly, there is an urgent need to take action to mitigate climate change. Apparently, EPNs could be a prominent solution, but they are not currently widely applied (JPI Urban Europe 2020, Kumar and Cao 2021). This is the problem for which this dissertation seeks solutions, by studying the needs and views of different stakeholders, by pointing out the most important aspects to consider to achieve a wide application of EPNs and by suggesting tools, methods and business models for supporting the process. Chapter 2 provides a deeper description of the problem identification and the viewpoints taken in this dissertation.

1.3 Structure of the dissertation

The structure of this dissertation is outlined in Figure 1:

The dissertation first gives an introduction to the subject (in Chapter 1): what this dissertation is about, why EPNs are needed, and what the problem is. It also describes the structure of the dissertation (Figure 1).

The problem identification in Chapter 2 presents the conceptual framework and the research questions based on a literature review. It explains the reasons for choosing the three dimensions as the focus of this dissertation. It also shows
that while the material is collected in several projects, each publication brings an essential viewpoint to the subject.

Next, in Chapter 3, the methods used to find the answers to the research questions are outlined. Chapter 4 presents the results and ties together the introduction and the research questions, providing the answers based on the research.

The discussion in Chapter 5 assesses the meaning and importance of the results and takes a critical look at the relevance of the results in comparison to the literature review and the research questions.

Finally, the conclusions and recommendations in Chapter 6 summarise the main outcomes: What are the steps towards the wide application of EPNs and how do the three dimensions relate to this? What needs to be a) studied further and b) changed to better promote EPNs?
2. Conceptual framework and problem identification

This chapter presents the background to the subject of this dissertation. It first explains the conceptual framework of the research by examining the key concepts in the field and their relations to the subject and each other. Based on the gaps and needs revealed by a literature review, the main research question is identified. In Chapter 1 above, the potential for using EPNs in resolving the decarbonisation challenge was outlined. This chapter first looks at what the literature says about EPNs and the related key concepts. The relevant Sustainable Development Goals are also listed (United Nations 2015b). The objective is to find out what are the problems that need to be solved to pave the way towards the wide use of EPNs.

2.1 Conceptual framework

2.1.1 Energy positive neighbourhood: history and definition

As the energy positive neighbourhood is the key concept in this dissertation, it is essential to explain what it is, starting with a short description of the development path.

In the efforts to mitigate climate change, the international community first started to look at how to improve the energy efficiency of buildings, especially through passive means, leading to the so-called Passive House concept (evolution described e.g. by Müller and Berker 2013). This trend was soon followed by the integration of renewables in buildings, and the introduction of different nearly or net zero energy building concepts (Marszal et al. 2011). In the next steps, the sight was broadened towards the area, the neighbouring buildings, still following the zero energy thinking (see e.g. Kumar and Cao 2021). Recently, different positive energy concepts have emerged, almost simultaneously for the building and neighbourhood levels (Kumar and Cao 2021).

The concept of energy positive neighbourhoods or districts has started to appear only recently in the scientific literature or other publicly available material. The situation is still largely the same in 2022 as during the time of writing the article on energy positive neighbourhoods in 2016 (Publication 1).
A literature search was carried out in May 2022 in Scopus, Science Direct and Google Scholar, with search word combinations of “energy positive neighbourhood” OR “plus energy neighbourhood” OR “positive energy neighbourhoods” OR “plus energy districts” OR “positive energy districts” (Figure 2). Some search alternatives also produced a reference to Positive Energy Blocks, which could be considered to concern the same ideas (e.g. Blumberga et al. 2020).

Figure 2. Search results with the words “energy positive neighbourhood”, “plus energy neighbourhood”, “positive energy neighbourhood”, “plus energy district” and “positive energy district” by year in Scopus, Science Direct and Google Scholar, without qualitative analysis, other than removing 7 irrelevant references from Science Direct in 2017 (see below). Eight of the eleven references in 2017 are to chapters in one single book.

Publication 1 is the most cited of the search results of Scopus, and the first scientific publication (with 46 citations in May 2022) on these concepts. The energy positive concepts have started to trend only recently (see Figure 2). Of the 110 results from the Scopus search, 86 were published in 2020 (16 hits) 2021 (47 hits) and 2022 (23 hits), and only 24 in 2019 or before. Only 7 publications were dated before 2016, the first appearance was a conference paper in 2011. All three publications from 2011 are conference papers from one FP7 project ENERSip, and they concentrate on the ICT solutions developed in that project, without providing a definition for EPN. One of them is cited quite frequently, often by the authors themselves (8 of 20 citations). The remaining four publications before 2016 were all conference papers, receiving less than 10 citations (3 to 6) by May 2022.

Science Direct gives 92 results, only three of which are dated earlier than Publication 1:

1) Martins et al. (2015), which mentions positive energy neighbourhoods as the goal for the methodology described in the article, “adjusting urban morphology elements, such as built density, geometry and implantation of
buildings”. (Positive energy neighbourhood is mentioned once in the article.)

2) Eder and Bednar (2015), which only mentions plus energy districts as a vision behind the need to develop solutions for energy-efficient buildings. One of them—an innovative façade system designed to increase the thermal comfort inside an office room—is presented in the article. (The term “plus-energy districts” appears once in the article.)

3) Lottaeau et al. (2015), which reviews the applicability of different LCA methodologies on the neighbourhood scale. (The term “positive energy neighbourhood” appears three times in the article.)

Of the 30 first publications on EPNs or similar concepts, 20 were produced by the FP7 project COOPERaTE (Control and Optimization for Energy Positive Neighbourhoods), 15 of which are references to a book prepared in connection with that project: 8 book chapters and 7 other references which are not applicable as publications (e.g. descriptions of copyright, index, preface, list of contributors). These irrelevant references were removed from the analysis. It is noteworthy that the COOPERaTE team only regarded electricity in their definition of an energy positive neighbourhood, which they presented in a book chapter in 2017 (Good, Martinez Ceseña and Mancarella 2017). In another four of the first 30 publications, the main reference for EPNs is Publication 1. The four remaining publications do not define the concept in any detail, just presenting it as a goal. Of the most recent occurrences, 4 are dated in 2021, 9 in 2020.

Google Scholar gave 666 results in May 2022, showing Publication 1 as number one in order of relevance. Many of the first appearances in Google Scholar are again related to the COOPERaTE project.

Not much more literature is available on Nearly or Net Zero Energy Neighbourhoods. A Scopus search on “zero energy district” or “zero energy neighbourhood” produced 58 results in May 2022, 30 of which are from three recent years (2020–2022). In their recent review article on zero emission neighbourhoods and positive energy districts, Brozovsky et al. (2021) conducted a systematic review on 144 scientific articles on Climate Friendly Neighbourhoods (CFNs), which included also low or zero carbon or emission concepts, in addition to different zero and plus energy neighbourhoods or districts. In total, 35 different terminologies were used in the analysed material, showing the novelty of this concept still in 2021. It is worth noticing that the major part of the material presented by Brozovsky et al. discussed zero energy concepts, with plus or positive energy concepts being less common. From the analysis of the concepts that were used for at least three studies, only 4 out of 13 terminologies related to positive energy concepts and these appeared mostly at the lower end of the appearances (3-5, only 1 with 13 appearances). In their conclusions, Brozovsky et al. recognise a need for clear, comprehensible and structured definitions, including KPIs, system boundaries, as well as definitions of the spatial scales. It is worth noting, that Publication 1 (which is listed as a reference in the review article) is dated earlier than any of the positive or plus energy definitions presented in more detail by Brozovsky et al. They also note that a clear definition is rarely included in scientific articles.
In their recent analysis, Kumar and Cao (2021) studied the literature addressing positive energy buildings or communities, which also includes EPNs. Their study confirms that the emergence of both zero and positive energy communities started trending after 2016. Interestingly, they underline several differences in the two concepts, especially related to the key stakeholders.

Some efforts have recently been taken to define Energy Positive Blocks or Positive Energy Districts:

- On the European level, JPI Urban Europe (2020) has launched a PED programme, aiming at initiating 100 Positive Energy Districts and Neighbourhoods in Europe. In their framework, they describe PEDs as “energy-efficient and energy-flexible urban areas or groups of connected buildings which produce net zero greenhouse gas emissions and actively manage an annual local or regional surplus production of renewable energy. They require integration of different systems and infrastructures and interaction between buildings, the users and the regional energy, mobility and ICT systems, while securing the energy supply and a good life for all in line with social, economic and environmental sustainability”. This definition concentrates on energy-efficiency and greenhouse gas emissions as the indicators, rather than the positive energy balance. The requirement for a good life and overall sustainability is included in this definition.

- On the global level, a new initiative was started by the IEA in 2020, by launching an international activity on Positive Energy Districts, which states that: “The basic principle of Positive Energy Districts (PEDs) is to create an area within the city boundaries, capable of generating more energy than consumed and agile/flexible enough to respond to the variation of the energy market because a PED should not only aim to achieving an annual surplus of net energy. Rather, it should also support minimizing the impact on the connected centralized energy networks by offering options for increasing onsite load-matching and self-consumption, technologies for short and long term storages, and providing energy flexibility with smart control,” (Hedman et al. 2021). However, creating a shared in-depth definition of PED is mentioned as one of the objectives of this task that started in December 2020 (Hedman et al. 2021). In May 2022 this in-depth definition was not yet publicly available. This initial definition does not mention the aims with regard to the user but rather takes the user comfort and friendliness as default. Additionally, no requirements in terms of the environment are included.

- Shnapp, Paci and Bertoldi (2020) look at the Positive Energy District with buildings as the starting point, due to their aim to examine the possibilities of the Energy Performance of Buildings Directive (EPBD) to support and enable PEDs. They suggest a very interesting approach to apply the definition of Net Zero Energy Buildings (NZEB) in the EPBD to districts. For the district definition, they suggest using the one
Conceptual framework and problem identification

from Renewable Energy—Recast to 2030 (RED II) (for district or community definition), which states the boundaries of a ‘renewable energy community’. Due to their approach starting from buildings, they exclude aspects such as the street lights and transport from the definition.

Definition of EPN as part of the dissertation

The literature review reveals the lack of a commonly agreed definition for energy positive neighbourhoods, especially at the time of writing Publication 1, and the discussion still continues today, in spring 2022. It can be stated that the work presented in Publication 1 is pioneering in this area, and therefore it is well justified to use the definition from Publication 1 as the basic concept in this dissertation. According to that, “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.” The definition also includes further explanations of balancing the local renewable supply with the energy demand, life-cycle aspects, energy demand components and renewable options (see more in ch 4.1.1.), making it more distinct and comprehensive than any of the above-mentioned recently suggested international definitions. It also underlines the need to look at the wider context throughout the life cycle to avoid sub-optimisation.

2.1.2 Key concepts in EPNs

Using the definition of Publication 1 as the basis for the key concepts related to EPN provides the following elements:

- energy demand
- local renewable energy sources
- connection to and co-operation with wider energy networks
- functional, user friendly environment
- environmental impact
- life-cycle aspects

Looking at the other definitions of similar concepts, mainly the PEDs, these can indeed be confirmed as the key concepts. Both of the above-mentioned definitions (JPI Urban Europe 2020 and Hedman et al. 2021) mention the interaction with surrounding energy systems and the need and/or means to match the demand and supply (by flexibility or storage). JPI Urban Europe also refers to emissions and a good life for all, as well as sustainability goals (social, economic and environmental). The same concepts appear also in the reviews by Kumar and Cao (2021) and Brozovsky et al. (2021). In some cases, transport or E-mobility are also mentioned. Life-cycle analyses have not received much attention in the literature, according to Kumar and Cao (2021). In the following, the relation between the key concepts and the sustainability goals are also noted.
When aiming at the wide use and maximized effect on the energy demand reduction and CO\textsubscript{2} emissions, it is also important to recognize which \textit{life-cycle phases} are most important in relation to these key concepts, when can they be affected and which \textit{stakeholders} are most influential on the one hand, and most affected on the other hand.

\textbf{2.1.3 Energy demand}

In connection with EPNs, energy is evidently a key aspect to consider and the main contributor to the environmental impact. In order to meet the climate targets, we need to reduce the energy demand and provide the remaining demand from renewable energy sources. In addition to minimising the CO\textsubscript{2} emissions, reducing the demand will improve the possibilities to fulfil the remaining demand with renewables. The central energy demand-related concepts in EPNs are:

- the energy demand of the buildings and neighbourhood
- energy efficiency
- the balance of the demand and supply of energy

\textit{Energy demand}

The energy demand in connection with neighbourhoods describes the amount of energy that is needed to provide the different services in the buildings and neighbourhood. This usually includes heating, cooling, lighting, cooking, home appliances and streetlights. It can also include the energy needs for transportation and waste management, as in the definition in Publication 1. Time schedules of the different demand components vary on a daily, seasonal and yearly basis.

Energy demand can be reduced primarily by \textit{reducing the volume of the energy demand} or by \textit{improving energy efficiency}. The reduction of the volume can be realised e.g. by reduction of heated area or the number of electrical devices, or by the building users’ behavioural choices (e.g. turning off the lights when not needed, reducing the room temperature etc.). When making these sorts of decisions, the needs and comfort of the building users need to be carefully considered.

The possibilities to reduce the energy demand are different in different life cycle stages and vary according to the stakeholder. The largest part of the energy demand happens in the operational phase of the building (Ramesh et al. 2010). However, the main decisions affecting this are taken in the planning phase, and the next good opportunity for improvement is when a major renovation takes place (Kolokotsa et al. 2009). In the planning phase, the city planning authorities play a major role, especially at the neighbourhood level, e.g. by setting the required energy efficiency level and defining the orientation of the buildings. Next, the architects, building planners and construction companies play an important role when planning and realising the building. In the renovation phase, it is the renovation companies and the building owners that have the greatest influence. In the operational phase, the role of the building users is emphasized. Their behaviour can be affected by planning the building in such a way that it
supports their activities with the least possible energy demand, but partly also by providing them with information on their energy use and their possibilities to reduce it, or to time it according to the availability of renewable energy (Santinelli et al. 2016, Bäckström et al. 2015).

**Energy efficiency**

Energy efficiency means the ability of the component to provide the service in relation to the energy demand, or, as the European Energy Efficiency Directive says: “the ratio of output of performance, service, goods or energy, to input of energy” (European Parliament 2015). High energy efficiency means low energy demand compared to average. This also applies to buildings.

When aiming towards a fully renewable energy system, the “energy efficiency first” principle is an essential step. The energy that is not needed never has to be supplied to the area. This is also the key statement in the Clean Energy for all Europeans policy package (European Union, 2019). However, life cycle aspects should also be considered in the planning, and not reducing the energy need at any cost to the environment or economy. When improving energy efficiency, it is important to consider the timing of the actions, especially when planning changes in an area. However, also in an individual building, careful optimisation of the order of energy efficiency measures and renewable installations is important. This dilemma is discussed by Farahani, Wallbaum and Dalenbäck (2019) proposing a methodology for techno-economic evaluation of different energy-renovation scenarios.

**Balancing the demand and supply of energy**

When trying to meet the remaining energy demand with renewables, the time and space distribution of the demand and supply become important aspects to consider in addition to the placing of the renewable facilities (Kirichenko and Kirichenko 2020, Lepadat et al. 2017). The time schedules of the different energy demand components (e.g. heating, cooling, lighting, cooking, streetlights) vary on a daily, seasonal and yearly basis. Different stakeholders have different possibilities to affect these demand components, mainly in the same way as the energy efficiency: depending on the life cycle stage and the physical scale - building or neighbourhood. The choice of renewable technologies also affects the possibilities to meet the demand, both on the component level and the time distribution: e.g. while solar thermal is not a good match with street lighting, it has considerably better efficiency than solar PV for heat production. The placing of renewable facilities and balance boundary on the building or neighbourhood scale also affects the possibilities for balancing the demand and supply: on the neighbourhood level, the demand curve is much smoother than on a single-family building level (see e.g. Parra et al. 2017). The different life-cycle phases of the buildings affect the possibilities of renewable energy integration. It is considerably easier and cheaper to include e.g. building integrated photovoltaic (BIPV) panels in a new construction than in connection to renovation, although new approaches with prefabricated facades will reduce this difference (e.g. Mørck 2017).
Trying to avoid transport and storage losses supports the idea of producing energy as close as possible to the place where it is used. Especially with the big share of existing buildings, the neighbourhood scale is a relevant scale for planning energy production facilities, making it easier to find suitable places for the facilities, regarding e.g. the orientation and shading for different solar technologies. Here, city planning again plays a crucial role, by enabling or preventing the optimal placement of renewable technologies in the area. The final decision on the provision of renewable facilities is usually made by the energy company or the building owners. Nowadays, a building planner or construction company can also make this decision on behalf of the building owner in case of new buildings and building integrated renewables.

An essential aspect affecting the balance is related to the intermittent nature of renewable energy sources, and the seasonal imbalance in their availability, as well as the variation of the energy demand on the seasonal and shorter term. One example (by Leskinen 1999) on the building level is shown in Figure 3, comparing the timely distribution of solar irradiation and heating demand in Finnish conditions. Another example, on a larger scale, is provided in Li et al. (2009) comparing the correlation between the combined availability of wind and solar power with the electrical power demand in New South Wales, Australia. In this example, it is noticeable that the availability of wind energy is the predominating variable on the correlation. This also underlines the importance of the availability of correct data: the better the data represents the local conditions, the better predictions can be made about matching of the demand and supply of energy in the area or building.

Good balancing of the demand and supply will also reduce the need for energy storages, thus limiting the energy losses and overall emissions of the system. In the life-cycle analyses of the environmental effects of using a battery energy storage system (BESS) to support PV integration in a DSO grid, Pucker-Singer...
et al. (2020) discovered that the life-cycle emissions of the system were only reduced with a very high share of PV production. The reasons were mainly due to the losses in the storage process and the emissions caused by the production of the BESS. It turned out that in the simulated cases, the grid was able to handle a large amount of PV without the need for curtailment.

2.1.4 Local renewable energy sources

In addition to the possibilities to balance the local energy demand and supply, the local availability of renewable energy will affect the choices of energy sources for an EPN.

The availability of renewable energy varies according to the location, and a thorough analysis needs to be done when planning the energy system. The wider context should also be considered in this planning: for example, if there is a better location for a wind turbine in the district next to the planned neighbourhood, which might be able to contribute to the energy needs for both of these neighbourhoods, then it is hardly the best solution to install the wind turbine on the area of the planned neighbourhood (provided that regulations etc. do not prevent the energy transfer between these two sites).

In the case of biofuels, it is also not always meaningful to require that the fuel should come from the area of the neighbourhood, especially in countries such as Finland, where 75% of the land area is covered by forests (Finnish Ministry of Agriculture and Forestry 2022). However, also in this case, the transport distance needs to be limited to minimise the CO$_2$ emissions (if the transport is not using renewable fuels). Even in Finland, the large cities cannot rely on wood as the main source of energy, although it would be a good solution for neighbourhoods in smaller cities and remote areas.

Waste is not usually considered to be a renewable energy source but could be considered a viable option for energy production in some specific cases. Additionally, using the waste from nearby neighbourhoods would make the production more stable. Especially the role of biowaste could be considered, depending on the scale of the neighbourhood. One example of the use of waste as an energy source is an industrial site in Belgium, where the wood-based waste from a furniture factory is used for CHP production for an industrial area (Al Koussa et al. 2020).

2.1.5 Connection to and co-operation with wider energy networks

In the context of energy networks, there are two key concepts to consider: energy networks and grid impact.

Energy networks

Energy can be transferred and stored in different formats, such as electricity or heat, but also in kinetic or chemical formats. In all conversions, transfer and storage processes, energy losses appear. These losses are due to the transfer of energy into a different format, most often to low-temperature heat. The losses are related to the change in the exergy content of the energy.
The most known and widely-used energy grid is the electricity network, which is most often divided into different voltage sections, usually operated by different types of actors: transmission system operators (TSOs) for the high voltage levels and distribution system operators (DSOs) for lower voltage levels. The EPNs will most likely connect to the low voltage level and therefore interact with the DSOs.

In Finland combined heat and power generation (CHP) has been proven to be a highly efficient way of utilising the full potential (or exergy content) of the energy source, and a well-working infrastructure for heat distribution exists. This is still a valid format even on the road to a fully renewable system, and facilitates utilizing the waste heat from different sources, e.g. cooling. Additionally, solar thermal is a much more efficient way of harvesting solar energy (with efficiencies close to 90%) than solar PV (max system efficiency around 22% in current commercial applications) (Moss et al. 2017, Neumeister 2022). A combination of bio-based CHP & solar thermal would be a good option for many small communities in Nordic countries, as CHP plants do not perform optimally with small loads, which mainly appear in summer. CHP plants also usually undergo maintenance breaks in the summer. With correct dimensioning, a solar plant with thermal storage could cover the heating load for the maintenance period (see e.g. Leskinen 1999). Instead, converting solar electricity to heating is highly inefficient. This can only be considered a viable option when there is a large amount of excess PV (photovoltaic) power available, which otherwise would be curtailed. Additionally, the emergence of photovoltaic thermal (PVT) panels speaks for the direct use of thermal energy instead of going through electricity.

A CHP plant does not necessarily call for a wider energy network, but at least local district heating is a prerequisite. The emergence of local energy communities is also paving the way for these smaller heat distribution networks (Bartolini et al. 2020).

Grid impact
The very idea of EPN is the ability to produce more energy than is needed in the area, contributing to the climate neutrality of the whole society. While the annual balance period is practical and widely used, it also needs to be ensured that the EPN does not burden the energy grids in shorter time frames.

Local renewable production also contributes to resilience, as far as the grid connections allow independent operation in the case of grid failures. Longer self-supporting times require the existence of demand response possibilities as well as storage facilities. This becomes even more important in remote and end-of-line areas. (Balducci et al. 2021)

Especially when aiming at limited effects on the energy grids, there is a need to strive for a good balance between the energy demand and supply both on short-term and seasonal levels. In their analysis Li, Allinson and He (2018) found that there can be significant variations in the shapes of household daily electrical load profiles between months. It is also important to notice that ignoring the seasonal variation in creating the load models can lead to inaccurate predictions of its effects.
Demand response or demand side management is a good way to balance the energy demand and supply. It can be handled automatically through agreements between the grid operator and the energy user, as is already the case in Finland regarding large industries with important electricity loads (Fingrid 2022, Honkapuro et al. 2015). A new, emerging approach is the use of aggregators in the middle. The aggregator estimates the best ways to answer to changes in the grid by either reducing or increasing the aggregated energy demand from several customers in accordance with the predicted availability of power in the grid (Lu et al. 2020).

2.1.6 A functional, user friendly environment

Providing a functional, user friendly environment should be the main aim of any construction process, otherwise it is not worth starting. The functionality requires that the environment supports human activities in daily lives and work. In addition to the functionality, user friendliness calls for a good quality indoor and outdoor environment: the thermal, acoustic and visual aspects as well as the air quality (Wei et al. 2020). The functionality is mostly provided by the architectural design, and only slightly related to the energy, e.g. through the availability of energy in time and space. The main energy-related aspect of user friendliness is related to the thermal environment, although the energy may also affect the other aspects, e.g. through the choices of energy sources. Even between the renewable sources, there are differences in the acoustic or visual qualities and air quality, in addition to the different needs for maintenance or operation. Thermal comfort is, however, the aspect that requires the most energy to maintain (e.g. Eurostat 2022) and it has the largest effects on the daily life of the user, once the choice of the renewable source is made and the installations are realised.

2.1.7 Environmental impacts

The Cambridge Dictionary (2022) defines environmental impact as “the effect that the activities of people and businesses have on the environment”. The environmental impacts of EPNs refer especially to the reduction or minimisation of negative impacts related to the energy demand and supply, through emissions. There can also be other (negative or positive) environmental impacts through the selection of the building site or construction, but these are not considered in this dissertation, which is mainly concentrated on the energy aspects. These other environmental impacts are related e.g. to natural value, water, waste, noise, aesthetics, or the use of resources (Lotteau et al. 2015, Li et al. 2010, Horvath 2004).

Emissions are the main environmental impacts of interest in connection with EPNs. These vary according to the time step of the evaluation, for instance, whether we are examining the life cycle emissions or only operational phase emissions, and which life cycle phases we consider in the analysis. The type of emissions considered in the analysis will also affect the choice of energy sources:
while nuclear energy is mostly considered CO$_2$ neutral, it also produces radioactive emissions that need to be addressed, and on the other hand, the wide use of wood in fireplaces may cause important NO$_x$ and particle emissions, although it is a renewable energy source. Here, the time aspect becomes relevant again: If the wood is mainly used during the time of peak consumption in winter, avoiding the use of fossil-fired backup plants, this could still be the best option from an environmental perspective. From the house owner’s perspective, having a fireplace also improves resilience, although it would normally only be used occasionally.

In this dissertation, the focus is on renewables, while nuclear energy is excluded. The current nuclear energy solutions are not applicable to the neighbourhood scale, and while the development of small-size reactors (SMRs) is ongoing, it is not foreseen as a near-future solution (Ho et al. 2019, Sovacool and Ramana 2015). On the other hand, while nuclear energy has very low to non-existent CO$_2$ emissions, handling the radioactive emissions, especially in connection to waste is still looking for final solutions (e.g. Lehtonen et al. 2020), and therefore nuclear energy solutions are not seen as a viable solution for EPNs at the moment.

Emissions are also relevant for the choice of energy conversion technologies. On a neighbourhood scale, different bio-based plants can be considered a viable option. Here, the plant type becomes highly relevant for the emissions: using a Combined Heat and Power (CHP) plant causes significantly fewer emissions per energy output than using e.g. a separate heating plant (see e.g. Dincer and Rosen 2015). On the other hand, CHP poses more challenges for the control and balancing of the demand and supply of energy in the area, requiring simultaneous control of both heat and electricity.

2.1.8 Life-cycle aspects

From the life-cycle perspective, two items deserve specific attention: the energy demand (and related emissions) and costs.

The operational energy demand is the most urgent part to be solved, as it currently represents typically 80-90% of the life-cycle energy use (Ramesh et al. 2010). However, it would be very short-sighted to look only at the energy demand and emissions during the operational phase. An extreme example is nuclear power: the radioactive emissions continue to appear up to thousands of years after the fuel is used in the power plant (U.S.NRC, 2019). However, renewable energy facilities also have effects on the energy need and emissions during the production, transport and dismantling (e.g. Koffi et al. 2017, Schlömer et al. 2014).

Additionally, when energy efficiency measures are increasingly applied to buildings, the embodied energy becomes more important regarding the emissions than in less energy-efficient buildings. At the near-zero energy level, the GHG emissions from the materials may represent over 50% of the 50-year life-cycle emissions (Ruuska and Häkkinen 2015). A life-cycle assessment, although highly relevant, is not included as a core aspect in this dissertation. It is a very wide area, and there are already an important number of studies available on
this topic (e.g. 3,995 results in Scopus for search with ‘LCA AND building’ and 298 for ‘LCA AND district’). This issue definitely needs specific attention when the challenges with the operational phase emissions have been duly tackled, and it is worth looking at it in parallel, especially in connection with new construction, in order to avoid sub-optimisation.

Life-cycle aspects are partly addressed in Publication 1, where the developed analysis tool facilitates a longer term assessment of the costs and emissions.

2.1.9 Key stakeholders for EPNs

Stakeholders are the key to promoting any technology-related solution. According to a recent study by JPI Urban Europe (2020), stakeholder involvement was perceived as the number-one success factor among the respondents from 61 analysed cases of Positive Energy Districts (PED, 29 cases) or projects with relevant PED features (Towards (To)-PED, 32 cases). PED as defined by JPI Urban Europe is relatively close to the energy positive neighbourhood concept described in this dissertation. The findings suggest that for a successful PED realisation, the citizens and end-users should be included already in the initial planning phases. In the same study, access to adequate funding and business models were recognised as the main barrier to a PED.

There are several ways to define the stakeholder. One of the most referred to, and relevant for building projects, is the definition by the Project Management Institute (2001), which states that stakeholders are “individuals and organisations who are actively involved in the project, or whose interests may be positively or negatively affected as a result of project execution or successful project completion”. In many other definitions (e.g. Freeman 1984, Donaldson and Preston 1995), the focus is on the organization rather than the project. Stakeholders can be individuals, groups or even organisations. In the case of building projects, environment or future generations can also be considered as stakeholders (Feige et al. 2011).

Feige et al. (2011) made a comprehensive analysis of the relevant stakeholders and their main concerns in different life-cycle phases of a construction project (Figure 4). This analysis is highly relevant for EPNs, and covers e.g. the interests of future generations and the role of environmental concerns in all phases.
The possibilities for the different stakeholders to affect the decisions vary in accordance with the scale (building or neighbourhood/district, see e.g. Kumar and Cao 2021) and life-cycle phase (Sztubecka et al. 2020). For example, the building user has limited possibilities to affect in the planning stage, while during the operational phase the building user can have an important role in the choice of energy demand profiles and renewables. City planners instead have a huge influence in the planning phase, but very limited ways to affect the energy demand after that. According to the analysis by JPI Urban Europe (2020), in addition to citizens and city planners, local energy suppliers and network operators also have an important role in PED implementation, as enablers or disablers of innovative energy concepts. The real estate industry (contractors and suppliers) can promote or limit the implementation through the extent of offering they provide. Due to the increased system complexity on the neighbourhood level, structured collaboration between the different stakeholders is the key for the realisation of energy-efficient communities, and requires an integrated project, with relevant contracts in place (IEA EBC 2014).

The studies by Camarasa et al. (2021) in 8 different European countries indicate that in EU residential buildings, potential adopters of the energy efficient technologies are not the only stakeholders involved in the technology selection. Although, in most cases, demand-side actors are the key decision-makers, they are in communication with multiple stakeholders, some of whom also hold a high level of influence over the decision (as key persuaders). The analysis also shows that the level of power and communication of different stakeholders varies substantially across building typologies, project types and countries.

Based on the findings presented above, the roles and needs of different stakeholders is the key aspect to consider on the way towards energy positive neighbourhoods. These are highly related to the different life-cycle stages of the project (Feige et al. 2011), as well as the different physical scales: the room, the building or the neighbourhood (IEA 2014, Kumar and Cao 2021).
2.1.10 Sustainability goals for EPNs

On the road towards energy positive neighbourhoods, it is of utmost importance to consider several aspects simultaneously, to address all the requirements for sustainable development that “meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development 1987). This entails balancing the three sustainability goals of people, planet and profit, taking into account also the time aspect (Lozano 2012).

During a long-lasting process, the UN Department of Economic and Social Affairs developed a framework to facilitate the follow-up of sustainable development, by setting 17 Sustainable Development Goals (United Nations 2015b). The aim is to guide development towards overall sustainability, for people, the planet and prosperity. Of the 17 goals, nine are at least somehow relevant to EPNs (see Table 1).

Table 1. Examples of the relations between the sustainable development goals and EPN concept.

<table>
<thead>
<tr>
<th>No</th>
<th>SDG Title</th>
<th>Contribution of EPN, examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No Poverty</td>
<td>Reducing the need for energy and energy costs as the result.</td>
</tr>
<tr>
<td>3</td>
<td>Good Health and Well-being</td>
<td>One of the main aims of EPN is a functional, healthy, user friendly environment.</td>
</tr>
<tr>
<td>7</td>
<td>Affordable and Clean Energy</td>
<td>In EPNs, the energy supply is from local renewable sources.</td>
</tr>
<tr>
<td>8</td>
<td>Decent Work and Economic Growth</td>
<td>Local renewable energy sources as a support for sustainable economic growth.</td>
</tr>
<tr>
<td>9</td>
<td>Industry, Innovation and Infrastructure</td>
<td>A local RES-based energy system will improve resilience of the infrastructure.</td>
</tr>
<tr>
<td>11</td>
<td>Sustainable Cities and Communities</td>
<td>EPN fulfills the aims of sustainable community.</td>
</tr>
<tr>
<td>12</td>
<td>Responsible Consumption and Production</td>
<td>Related to energy efficiency and RES.</td>
</tr>
<tr>
<td>13</td>
<td>Climate Action</td>
<td>The main aim is to reduce emissions.</td>
</tr>
<tr>
<td>17</td>
<td>Partnerships to achieve the Goal</td>
<td>EPN requires and promotes co-operation.</td>
</tr>
</tbody>
</table>

2.2 Central viewpoints based on the key concepts

When looking at the key EPN-related concepts presented above, some aspects constantly appear highly relevant regarding the energy demand, local renewable energy sources, energy networks, user friendliness and environmental aspects. These aspects which are the key for the promotion of EPNs can be grouped under three viewpoints or dimensions which are in the focus of this dissertation (see Table 2 on next page for a summary of the connections with the key concepts):

- Stakeholder (municipality – building owner – end user - others)
- Time frame (new & old buildings, development paths, intermittency)
- Physical scale (interior space, building, neighbourhood, neighbourhood in interaction with the surrounding environment)
These dimensions also have strong interrelations, and they tie together many of the important aspects of energy positive neighbourhoods (Figure 5).

Table 2. The connections between the key concepts and central viewpoints or dimensions.

<table>
<thead>
<tr>
<th>Key concept</th>
<th>Dimension</th>
<th>Connection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time frame</td>
<td>Physical scale</td>
</tr>
<tr>
<td>Energy demand; Energy efficiency</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Energy demand; Balance of demand and supply of energy</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Local renewable energy sources</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Wider energy networks</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>User friendly environment</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Environmental impact (emissions)</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Life-cycle aspects</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

The viewpoints on these dimensions in the four Publications are explained in subchapters 2.2.1 to 2.2.3.

2.2.1 Stakeholder

EPNs could offer a prominent solution for climate change mitigation, but they are not widely applied at the moment (JPI Urban Europe 2020, Kumar and Cao 2021). Several stakeholders are playing an important role in the application of
EPNs. In the following, the most important roles of the key stakeholders are listed, reflecting on their possibilities to have influence in different life-cycle stages and the ways these stakeholder are affected.

City planners and other municipality officials have the most influence in the planning phase, mainly on the district scale, although they may also influence the buildings, e.g. through the orientation of the building masses in the city plan, or requirements for the slope of the roof or the E-value. They also play an important role (as key persuaders) in the dissemination of information to the general public on the benefits of energy efficiency and energy positivity.

Energy companies have the greatest influence through the offering of the grids (electricity, heating, cooling, gas) in the area, and the choice of the energy sources for production plants. Recently, energy-as-service ideas have also started to emerge, where the energy company takes responsibility for the local renewable energy facilities, including storage (Ramos et al. 2020). The main physical scale is the district scale, and the most important decisions happen in the planning and renovation phases. In Finland, the municipality is often the owner of the local energy company, and there is often close cooperation with the city planning officials. During the operational phase, the energy company is also very interested in the short-term balance of the energy demand and supply, and the avoidance of additional investments also encourages them to advise their clients—the building users—on energy-efficient behaviour.

The building users are a central stakeholder group also in the sense that according to the definition of EPNs in Publication 1, the aim of the EPNs is to “provide a functional, healthy, user friendly environment”. They also have a large effect on the energy use in the operational phase, in which the main energy use and emissions occur (Ramesh et al. 2010). The building users are able to affect the timing of the energy use if they get the correct information for making decisions. From the energy point of view, the main physical level of interest in the case of the building user is the room and the building.

Building owners are often the same as the building users, especially in the residential sector, which represents the largest portion of the building stock (e.g. European Commission 2022 for Europe) and related emissions (UN Environment and IEA 2019). Providing a functional, healthy, user friendly environment is usually also the main focus of interest for the building owners, either for their own sake, or to ensure the value of the building (BentallGreenOak et al. 2021). Their influence is mostly visible in the operational phase (as users) or in the renovation phase when decisions on energy efficiency improvements or the acquisition of renewable facilities are made. Quite often the building owner also makes decisions in the planning and construction phase (especially concerning single-family houses). The decisions of the building owner can have effects on all physical scales: the room, building or district scale. The district scale effects relate e.g. to the placing of the renewable facilities and potential district-scale renovation.

The building designer’s role appears in the planning or renovation phase but strongly affects the energy efficiency and emissions of the operational phase.
The designer’s decisions can affect all physical levels: the room, building and district.

Renovation companies play an important role in the renovation phase, also by explaining the effects of the different solutions to the building owner. The knowledge level and quality of work have important effects on the future performance of the building.

The Publications constituting this dissertation address the roles and needs of several different stakeholders who are able to affect the application of EPNs on one hand, and who are most affected by the use of EPNs: city planners and other municipality officials, energy companies, building users, building owners, building designers, and renovation companies.

The role of the national and European level authorities is not specifically addressed in the analyses, only from the point of view of the effects of regulations on some choices for the other stakeholders. This is to limit the scope of the research, but the work on the roles and needs of these stakeholders is continued in other parallel and later projects by the Author with several colleagues (see e.g. Rekola et al. 2014, Häkkinen et al. 2016, Ramos et al. 2021, Tuerk et al. 2021). From Feige et al.’s (2011) list, the environment is covered in the sense that the aim is to minimise the negative effects on the environment, while the environment is not an actor that can play an active role in promoting EPNs. The same applies to future generations: they are deeply affected, but they cannot affect the application level of EPNs.

2.2.2 Time frame

A clear conclusion from the analysis of the key concepts is that it is important to look at the different time frame-related aspects in the assessment of the effectiveness of the actions taken to reach the EPN level, as well as in the performance assessment. The time aspects include the life-cycle analyses of emissions and costs, timing of the actions, as well as the seasonal and shorter-term variation of the energy demand and availability.

In this dissertation, the main focus regarding the life-cycle stages is on the planning and operational phases, which have the largest effects on the emissions. In the planning phase, the focus is both on minimising the CO$_2$ emissions in the operational phase, and on the timely matching of the energy demand and supply from renewables. In the planning phase also important decisions are made affecting the user friendliness of the building and neighbourhood. Two of the Publications (3 and 4) address the renovation phase, one on the building scale, other on the district scale.

2.2.3 Physical scale

The dissertation shows the differences between and the importance of looking at both the building scale and district scale when planning any actions. While from the building user’s perspective the performance of the building is of utmost importance, the neighbourhood scale provides better opportunities for demand response and a more constant energy demand profile than an individual house,
thus reducing the need for energy storages, which always means additional costs, energy losses and emissions (Pucker-Singer et al. 2021). A neighbourhood may also consist of buildings of highly variable ages, requiring specific solutions for energy efficiency improvements and RES installations. In this case, a building-level approach is a more viable option. The energy positivity aspect of the neighbourhood brings yet another physical scale that needs to be considered: the connections and connectivity to surrounding energy grids. The physical scale is the dimension that is different in each Publication. The different physical scales of the Publications are illustrated in Figure 6.

![Figure 6. Different scales of the dissertation: interior space (room); building; district/neighborhood; connected neighborhood (= energy positive neighbourhood).](image)

### 2.3 Problem identification

The presentation of the key concepts revealed three specific dimensions that will help in identifying and grouping the research gaps that need to be tackled for the promotion of EPNs: the stakeholder, the time frame and the physical scale.

In the current debate, the benefits of energy efficiency and renewable energy for different stakeholders are not fully understood (IEA 2014). These benefits vary from improved living conditions and increased productivity to poverty alleviation and energy security. The value of different benefits varies according to the stakeholder (e.g. depending on the position in the value chain and personal properties: age, gender, etc.), and this should be duly taken into account when presenting the potential roads towards energy positive neighbourhoods for these different stakeholders. A selection of Key Performance Indicators (KPIs) will help in communicating the benefits in an easily understandable way by facilitating the comparison of different alternative designs regarding the most important viewpoints.

To be able to present the benefits to the key stakeholders and to assess how well an EPN is reaching the decarbonisation and other sustainability aims, several steps are needed. First, a definition of EPN is needed to create a common understanding of the aims. The status of this work was presented above, in Chapter 2.1: a definition did not exist before the preparation of Publication 1. Second, the Key Performance Indicators (KPIs) need to be agreed on, to be able to measure whether the aims have been reached and to recognise the needs for improvement. Third, to serve the discussion between different stakeholders,
easily understandable ways to present the KPIs are needed. Chapter 2.3.1 looks at how these two latter issues are addressed in the current literature.

Next, the importance of looking from both building and neighbourhood scale is shown through a literature review. There are indisputable benefits of considering the district scale options when planning a refurbishment, but at the same time, the working and living conditions in each individual building need to be considered to maximise the well-being of the building occupants, and thus ensuring the best possible support for the human activities in the buildings. The age of the building may also affect the optimal choice of refurbishment actions for a particular building, depending e.g. the typical construction methods for different eras, and this needs to be considered on the building level in a neighbourhood with mixed-aged buildings. These physical scale-related aspects are discussed in Chapters 2.3.2, 2.3.3 and 2.3.4, moving from the individual room level through building level to district level.

2.3.1 Energy positive neighbourhood: focus on the concept and benefits

Assessing the performance of EPNs

Key performance indicators (KPIs) are needed to be able to assess the status of development and the progress of the neighbourhood towards the EPN status. The same trend as with the EPN definition continues with the KPIs for EPNs. There have been even fewer efforts made to this end. However, there are efforts related to net zero neighbourhoods (NZEBs) (Cao et al. 2013, Wiik et al. 2018) and Cellurale et al. (2019) suggest a set of KPIs for assessing the progress towards Positive Energy Districts (PEDs) regarding technologies, sensors, products, apps, ICT, the technology readiness level (TRL), the stakeholder type (which is necessary to involve to support planning and deployment of Smart Cities and Communities (SCC) solutions) as well as the engagement phase (planning, design, construction and management) and the engagement scale (functional unit, building, blocks of building, infrastructure, environment).

Additionally, some of the KPIs developed for Net or Nearly Zero Energy Buildings (e.g. Andersen 2018,) are relevant for EPNs, as one of the key requirements for the EPN will necessarily be the energy efficiency and low energy demand of the buildings. A neighbourhood will, however, require additional and slightly different indicators.

Moving to the other end of the scale, the CityKeys project presented 99 project indicators and 76 city indicators, covering aspects on five different themes for a smart city (People, Planet, Prosperity, Governance and Propagation) (Bosch et al. 2017). The smart city is a much wider concept than EPN, covering aspects of social and cultural capital, financial capital, natural resources, information and technology. The CityKeys indicator list can be seen as a selection of indicators, from which the stakeholder needs to choose the most relevant for the specific situation. While it is worth examining the situation from a wider perspective, it also needs to be taken care that the “Key” aspect in the KPIs is taken into account: the stakeholder needs to choose which are the most important things to be reached in the project or development, and then potentially use some additional indicators to check that the other requirements are also fulfilled. In the
final choice of the CityKeys indicator list, a set of criteria proposed by van Rooijen and Nesterova (2013) was used. These are also relevant for any indicator set, suggesting that the indicators should be assessed regarding their relevance, completeness, availability, measurability, reliability, familiarity, non-redundancy and independence.

**Calculation and communication of the KPIs**

Once the KPIs have been chosen, there is a need for tools to evaluate and calculate the KPIs. Here, the above-mentioned criteria on the measurability and availability of information become relevant for the choice of the calculation tool, as well as the relevance of the output for the different stakeholders.

To support the discussions and decision-making, it is important that the main stakeholders can easily understand the KPIs and their order of importance. The same principle is applied in energy labelling, e.g. for buildings or appliances (e.g. Haakana et al. 2018 and European Commission 2019c). Good labelling gives an impression of the level compared to the target at one glance. The labelling is also intended to encourage companies to develop solutions for EPNs as well as cities and communities to engage in the development.

For example, the labelling of home appliances has proven to be highly efficient at improving the overall energy efficiency of households. In a recent announcement, the state-owned sustainability company Motiva quoted the Energy Authority: "Four out of five European home appliance buyers say they take energy labelling into account in their purchasing decisions. Energy labelling and eco-design requirements have effectively improved the energy efficiency of households," (Motiva, 2021).

Another effect of labelling is value creation. Pennanen (2015) analysed the influence of energy efficiency classes on the prices of apartments in Finland. The conclusion was that the energy class has an increasing effect on the market value of apartments, even more than could be expected by energy use and energy price calculations. A recent newsletter article in Finland reporting the results of a questionnaire about the importance of environmental effects on the price development of homes gives similar indications: over half of the respondents believed that the environmental effects of the home will affect the future value of the home. The most important factors according to the study were the heating method (82%), good (traffic) connections (74%) and the energy class (68%) (HS 2021). Similar results for office buildings in the U.S. market are presented by Fuerst and Mc Allister (2011), suggesting that eco-certified (LEED or EnergyStar) buildings seem to have both a rental and sale price premium compared to buildings in the same submarkets.

Spider web diagrams are often used to visualize concepts with many dimensions, but they do not usually give information on the order of importance of the different dimensions, although such features have also been suggested (Porter and Niksiar 2018).

**Development needs related to the EPN performance assessment**

The literature review shows that there is a need for clear and specific Key Performance Indicators for energy positiveness on the neighbourhood level. There
also seems to be a lack of tools to assess the level of energy positiveness of the
neighbourhood as well as the energy, environmental and cost effects of the ac-
tions taken on the neighbourhood level. Further, it is shown that a simplified
presentation of the KPIs would be helpful in communicating the benefits of the
concept to different stakeholders, thus promoting EPNs.

2.3.2 Interior space - room view: focus on thermal comfort

One of the most important aspects that needs to be assessed on the building
level is the service level of the building, referring to the ability of the building to
provide a good environment for the building users. The indoor environment is
built from the thermal, acoustic and visual environments, as well as the indoor

Most of the energy in buildings is used for heating and cooling, aiming at
providing thermal comfort for the occupants. Several studies (e.g. Seppänen et
show that people also achieve the best performance and are the most productive
in optimal thermal conditions. Therefore, it would be beneficial to be able to
predict the best possible thermal environment to provide the best possible en-
vironment using only the necessary amount of energy for this purpose, and
nothing more.

Many approaches to assess and predict the optimal conditions for thermal
comfort have been proposed, such as the widely used PMV (Predicted Mean
Vote) method (Fanger 1982) or adaptive model (de Dear and Brager 1998), but
all of them seem to have shortcomings. One of them is the wide ranges they give
for thermal comfort conditions. A new approach to thermal comfort assessment
is suggested by Shukuya et al. (2009), but its applicability was not tested for a
Northern climate before the work presented in Publication 2.

It is worth noticing that also the district scale makes a contribution to produc-
tivity and the way people feel at work: the security aspects, adequate natural
elements etc. (Dempsey et al. 2011, Mclellan et al. 2015, Hamidi and Zandiat-
ashbar 2019). These aspects are however not further studied in this dissertation,
which concentrates on the energy aspects.

Development needs

The current thermal comfort indicators provide a very wide scale for potential
combinations of air and radiant temperatures, which are sometimes not in cor-
relation with practical experience. A new model is suggested, but its applicabil-
ity to Northern conditions is not tested.

2.3.3 Building scale view: focus on renovation

The building scale view in this dissertation focuses on the renovation activities
on the building level, as this phase offers the best opportunities to affect the
reduction of the energy demand and introduction of renewable facilities—the
aspects that have the greatest effects on emissions (IEA 2021). Again, to be able
to show the effects to the key stakeholders, easy-to-use assessment tools are
needed, as well as visualisation of results for the different stakeholders. In Finland, 60% of the building renovation projects are realised by small companies with 5-9 employees (Official Statistics of Finland 2021), so addressing their needs will help motivate them and their potential customers to improve energy efficiency and integrate renewable technologies in connection with the renovation activities.

There are a wide selection of tools intended for assessment of different aspects of the energy performance of buildings, and they are growing: during the writing of Publication 3, there were 124 software tools listed in the BEST directory intended for building’s energy performance assessment, covering aspects like energy efficiency, renewable energy and sustainability in buildings, 21 of which were categorized as suitable for energy conservation measures analyses. In 2022, the numbers were 209 and 36, respectively (IBPSA 2022).

These tools are suitable for different life-cycle phases of the building. There are important differences in the need for input data and the accuracy of the results. The review articles studied in connection with Publication 3 aim to assess and compare some methods and tools from different points of view. In these reviews, there are several focuses and premises: some articles compare and describe the methods, and give suggestions on the classification (e.g. Coakley et al. 2014, Fumo 2014, Foucquier et al. 2013). Many articles assess the different tools from the point of view of suitability for the analysis of Zero Energy Buildings (ZEBs) (e.g. Deng et al. 2014, Attia et al. 2013, Marszal et al. 2011). Some of the articles focus on the suitability to design of retrofit actions (Ma et al. 2012, Cetiner and Edis 2014, Lee et al. 2015), while in others the focus could be on suitability for early design phases (like Schlueter and Thesseling 2009) or certain types of buildings (Leaman et al. 2010). There are also reviews comparing the results of different tools through case studies (e.g. Schwartz et al. 2013, Srinivasan et al. 2014) or regarding their content and structure (Hong et al. 2015). As a conclusion in their extensive study on the energy simulation tools, Crawley et al. (2008) noted that it is not very easy to find detailed information on the capabilities of the tools, even despite active cooperation from the tool developers. None of these reviews gave a clear insight from the point of view of SMEs related to refurbishment projects.

Development needs

A thorough analysis of the availability and usability of energy performance simulation tools with the focus on the usability in refurbishment projects by SMEs was clearly missing. This may also indicate that such tools did not exist.

2.3.4 District scale view: focus on refurbishment

Similarly as for the building scale, the renovation or refurbishment is another phase after the planning and design phase that offers good opportunities to reduce the environmental effects also on a neighbourhood scale. As mentioned earlier, the district scale can offer some additional possibilities for the balancing of the energy demand and supply or the placing of renewable facilities. On the
other hand, the larger scale of projects may cause some additional challenges, e.g. for decision-making.

The main drivers for district scale refurbishment are summarised in Table 3. The benefits of building scale refurbishment are also relevant for the district scale (e.g. IEA EBC Annex 51 2013). These include energy and cost savings as well as reduction of greenhouse gas emissions, but also improved quality of life through improved comfort. On the district level, neighbourhood security and the sustainability of housing also contribute to this aspect (IEA EBC Annex 51 2013). The district-scale case studies analysed by IEA EBC Annex 51 (2013) showed that, although energy conservation measures in most studied cases required quite high capital investments, the total monthly costs for rent for tenants were often the same or only slightly higher. In addition, there were benefits for building owners in form of reduced risk. Other targets for district-scale refurbishment include issues such as better land use, improved recreation opportunities and improved safety of the district (IEA EBC Annex 51 2013).

The local use of renewable energy is one important aspect contributing to the profitability potential related to district and neighbourhood scale energy refurbishment. Optimal locations for the energy system components are easier to find on the neighbourhood level than on the building level, regarding for example solar energy, ground source heat pumps, storages, windmills etc. (Paiho et al. 2017, Verbruggen et al. 2010). In the future, the buildings will play a more active role in the energy system as prosumers: using, generating and storing energy. This will require management on the neighbourhood scale and eventually transition to smart energy grids (IEA EBC Annex 51, 2013). Bidirectional power flows and voltage deviations caused by high variation of renewable generation call for more accurate synchronization of the electricity needs and supply through demand-side management and storage (Salom et al. 2011, Van Roy et al. 2013). Here, district-scale refurbishment projects are advantageous because they provide an opportunity to improve the possibilities for energy resource sharing at the block or building group level (Salom et al. 2014). Adapting the local energy supply to the local energy demand also has other benefits, such as deferring investments to large energy infrastructures and involving end-users in energy investments (Mikkola and Lund, 2014).

From the building owners’ and users’ perspective, investment in energy refurbishment brings immediate and mediate impacts such as financial benefits or savings in energy and greenhouse gases (GHGs) In addition, energy refurbishments also lead to improvements in thermal comfort, heating cost reductions, user satisfaction and finally to value stability, extended lease periods and reduced risk of damage (Holopainen et al. 2016, Mörmann and Lützkendorf 2016).
When it comes to barriers to district scale energy refurbishment, they differ from those on the building scale. Häkkinen et al. (2017) summarise the critical barriers to district scale energy refurbishment based on interviews conducted in eight European countries. In total, 67 stakeholders were interviewed in Finland, Germany, The Netherlands, Slovenia, Lithuania, Latvia, Poland, and Austria. These stakeholders represented building owners with large portfolios, energy companies, designers, consultants, town planning and building permission authorities, renewable energy providers, contractors, developers and maintenance managers. Among many, the three most important barriers perceived by all interviewees in that study included (1) the presence and collective agreement of several owners to start district-scale refurbishment projects, (2) lack of activists or integrators to initiate district-scale projects and (3) institutional and legal obstacles related to town planning and building permission practices.

The lack of suitable process models or lack of experience of these models can also be a barrier to district scale energy refurbishment. Kyrö et al. (2012) and Hueskes et al. (2017) presented somewhat contradictory views on the suitability and advantages of Public-Private-Partnership models. Kyrö et al. (2012) highlighted the need for functional partnerships and stated that the so-called Public-Private-People Partnership (4P model) may be advantageous for the involvement of occupants in neighbourhood-scale energy refurbishment projects. In contrast, Hueskes et al. (2017) evaluated the degree and ways that the government can stimulate sustainability considerations in PPP infrastructure projects. The results suggest that a strong sustainability perspective appears to be incompatible with the contractual requirements of the PPP project structure, which requires measurable and enforceable performance indicators (Hueskes et al. 2017).

One of the main challenges of district-scale energy refurbishment seems to be the necessity to involve multiple actors representing different stakeholders in the value chain. People do not share the same value and this leads to challenges in successful urban development processes (Kyrö et al., 2012). As occupants tend to base their decision on financial issues and short-term preferences, the

<table>
<thead>
<tr>
<th>Drivers</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy savings</td>
<td>IEA EBC Annex 51, 2013</td>
</tr>
<tr>
<td>Reduction of greenhouse gas emissions</td>
<td>IEA EBC Annex 51, 2013</td>
</tr>
<tr>
<td>Better opportunities for optimal renewable energy solutions.</td>
<td>Verbruggen et al. 2010</td>
</tr>
<tr>
<td>Possibility to better manage load matching and grid integration issues.</td>
<td>IEA EBC Annex 51 2013</td>
</tr>
<tr>
<td></td>
<td>Salom et al. 2011</td>
</tr>
<tr>
<td></td>
<td>Van Roy et al. 2013</td>
</tr>
<tr>
<td></td>
<td>Salom et al. 2014</td>
</tr>
<tr>
<td>Neighbourhood security and the sustainability of housing.</td>
<td>IEA EBC Annex 51, 2013</td>
</tr>
<tr>
<td>Better possibilities for creating solutions for infill building projects.</td>
<td>IEA EBC Annex 51, 2013</td>
</tr>
<tr>
<td>Financial advantages, e.g. cost savings, value stability, extended</td>
<td>IEA EBC Annex 51 2013</td>
</tr>
<tr>
<td>lease periods, deferring investments to large energy infrastructures,</td>
<td>Mikkola &amp; Lund, 2014</td>
</tr>
<tr>
<td>involving end-users in energy investments.</td>
<td>Mörmann and Lützkendorf 2016</td>
</tr>
<tr>
<td></td>
<td>Sougakis et al. 2020</td>
</tr>
<tr>
<td>Interest of cities.</td>
<td>IEA EBC Annex 51 2013</td>
</tr>
</tbody>
</table>
role of the Public partner in the PPP partnership is very important with regard to energy efficiency goals (Kyrö et al. 2012).

The lack of applicable new business models also restrains the extensive implementation of systemic renovation strategies on the district scale in Europe (Green, Eriksson, Paulsson, & Silverberg 2015). Crosbie et al. (2015), found that a new type of service provider and new business models are needed for energy positive neighbourhoods; distribution network operators, energy service companies and district heating providers would be potential service providers to promote energy positive neighbourhoods.

Caputo and Pasetti (2015) recognised the problems of data availability, lacks in technical and non-technical preparation of municipal administrators and low involvement of citizens as barriers to urban energy refurbishment of buildings. Additionally, Pisello and Asdrubali (2014) underline the importance of positive involvement and correct awareness of inhabitants for the success of refurbishment projects. Delmastro, Mutani, and Corgnati (2016) also recognised as obstacles the complexity and quantity of information and the computational time needed in the assessment and comparison of alternatives on an urban scale.

The barriers found by Hoppe (2012) to introducing innovative energy systems (IES) in connection with the renovation of large social housing sites included the lack of trust between project partners, delay in project progress, financial feasibility considerations, lack of support from tenants, lengthy legal permit procedures, overly ambitious project goals, poor experiences in previous projects, and IES ambitions that are not taken seriously by key decision-makers. These findings are supported by the conclusions of Walker and Johannes (2003), who noted that ‘trust and commitment building is of fundamental importance in joint venture relationship management’.

Mosannenzadeh, Bisello, Diamantini, Stellin, and Vettorato (2017) studied barriers to the implementation of a smart energy city project. They addressed the lack of comprehensive political support, smooth cooperation, skilled personnel, and external financial support as important barriers. Mosannenzadeh et al. (2017) predicted the barriers by using a case-based learning methodology when implementing large-scale refurbishment projects. Namely, if the physical distance between two district scale refurbishment projects (one already executed, one planned to be refurbished) is less, the possibility of finding the similar barriers encountered in the previous project is higher and thus they can be avoided for the next planned refurbishment project. This method is useful in cases where there are multiple examples of such projects in the vicinity of a district planned to be refurbished or renovated. If the distance increases the variables would change too much, and critical barriers may not be found.

The main barriers recognised in the literature are summarised in Table 4.
### Table 4. Barriers to district-scale energy refurbishment recognised in the literature.

<table>
<thead>
<tr>
<th>Barriers</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lack of applicable new business models, especially for energy positive neighbourhoods, lack of activators or integrators.</td>
<td>Green, Eriksson, Paulsson &amp; Silverberg, 2015</td>
</tr>
<tr>
<td></td>
<td>Crosbie et al. 2017</td>
</tr>
<tr>
<td></td>
<td>Häkkinen et al. 2017</td>
</tr>
<tr>
<td>Presence of several actors representing different stakeholders, different values and interests of stakeholders, leading to lack of trust and smooth cooperation.</td>
<td>Häkkinen et al. 2017</td>
</tr>
<tr>
<td></td>
<td>Mosannenzadeh et al. 2017</td>
</tr>
<tr>
<td>Lack of political support, e.g. legal obstacles related to town planning and building permission practices.</td>
<td>Hoppe 2012</td>
</tr>
<tr>
<td></td>
<td>Caputo and Pasetti 2015</td>
</tr>
<tr>
<td></td>
<td>Häkkinen et al. 2017</td>
</tr>
<tr>
<td></td>
<td>Mosannenzadeh et al. 2017</td>
</tr>
<tr>
<td>Lacks in the technical and non-technical preparation of municipal administrators.</td>
<td>Caputo and Pasetti 2015</td>
</tr>
<tr>
<td>Problems of data availability, complexity and quantity of information and the computational time needed.</td>
<td>Caputo and Pasetti 2015</td>
</tr>
<tr>
<td></td>
<td>Delmastro, Mutani, and Corgnati 2016</td>
</tr>
<tr>
<td></td>
<td>Mosannenzadeh et al. 2017</td>
</tr>
<tr>
<td>Low involvement of inhabitants/citizens.</td>
<td>Pisello and Asdrubali 2014</td>
</tr>
<tr>
<td></td>
<td>Caputo and Pasetti 2015</td>
</tr>
<tr>
<td>Low awareness of citizens.</td>
<td>Pisello and Asdrubali 2014</td>
</tr>
<tr>
<td>Lack of skilled personnel.</td>
<td>Mosannenzadeh et al. 2017</td>
</tr>
<tr>
<td>Lack of external financial support.</td>
<td>Mosannenzadeh et al. 2017</td>
</tr>
<tr>
<td>Delay in project progress, financial feasibility considerations, overly ambitious project goals, poor experiences in previous projects.</td>
<td>Hoppe 2012</td>
</tr>
</tbody>
</table>

When presenting the benefits to different stakeholders, it is worth taking into account that presenting too many or irrelevant arguments to the decision makers may distract them from the main goals or raise suspicions about the motivation of the persuader (Fawcett & Killip, 2017). Determining the relevant benefits and barriers for the potential customer facilitates the development of a business model that could promote district-scale renovations. At the time of writing Publication 4, a thorough analysis of the importance order of the benefits and barriers from the point of view of the key stakeholders had not been carried out.

**Development needs**

A thorough analysis of the order of importance of the drivers and barriers for different stakeholders is needed to gain a view of the best ways to promote district-scale renovations. An increased understanding of this will help in developing the most appropriate business model for district-scale renovations.

#### 2.4 Gaps and needs

Based on the literature review, the following were recognised as the main gaps or points of concern that should be addressed in order to promote EPNs, taking into account the three dimensions of stakeholder (S), time frame (T) and physical scale (P):

Regarding the EPN concept:
- A comprehensive definition of EPN was missing (S, T, P).
- Lack of indicators for energy positiveness on the neighbourhood level (S, T, P).
• Need for easily understandable presentation of energy positivity level of a neighbourhood (S, P).
• Lack of easy-to-use tools for assessing the level of energy positiveness (S, T, P).
• Need to take into account the seasonal and daily variations of energy demand and availability in the calculations (S, T).
• Tools for assessing the energy, CO$_2$ and cost effects simultaneously on the neighbourhood level are missing. (S, T, P).

Regarding the interior space or room scale:
• The current thermal comfort indicators give a very broad scale for potential combinations of air and radiant temperatures, which are sometimes not in correlation with practical experience. A new model is suggested, but its applicability to Northern conditions is not tested. (S, P).

Regarding the building scale renovation:
• Lack of analysis on the usability and availability of energy performance simulation tools with the focus on the usability in refurbishment projects by SMEs (S, T).
• Lack of easy-to-use tools for assessing the combined effects of refurbishment actions (S, T).

Regarding district-scale renovations:
• A wide coverage assessment of the drivers of and barriers to district-scale renovations from different stakeholders’ perspectives is missing (S, P).
• The existing business models do not support district refurbishments, which however would facilitate the optimal timing of the actions and the placing of the renewable facilities (S, T, P).

2.5 Research questions

The literature review aimed to determine the research gaps and needs related to the lack of wide application of energy positive neighbourhoods. It can be concluded that taking into account the views from different stakeholders, as well as the time frame and physical scale perspectives will be essential for promoting EPNs. Looking only at one dimension will lead to overlooking some important aspects and will be likely to delay development towards a sustainable built environment. All of these dimensions are related to the need to present the relevant benefits to the different stakeholders and to get them committed to the promotion of EPNs. Based on the literature review, the following was chosen as the main research question to be answered in this dissertation:

**How can energy positive neighbourhoods be promoted?**
2.5.1 The perspectives in the Publications

The four Publications in the dissertation examine the research question from specific viewpoints, which can be formulated in the following questions addressing the concerns of different stakeholders:

- Publication 1: What do the stakeholders need to know in order to promote EPNs?
- Publication 2: How can it be ensured that the service level of the building is optimal while minimising the energy demand?
- Publication 3: How can it be ensured that the renovation actions on individual building level contribute to both energy and cost efficiency?
- Publication 4: How can district scale energy refurbishment be promoted?
3. Methodology

The main research question addressed in this dissertation is:

How can energy positive neighbourhoods be promoted?

In the Publications presented in this dissertation, the main research question is addressed from different stakeholder, time frame and physical scale perspectives. Publication 1 is the core element, looking from the EPN perspective in general. The other three publications concentrate on central problems from specific viewpoints.

There are different focuses on the time frame perspective:

Publication 1 starts with the city planning and current status of the neighbourhood, but also looks at the longer perspective by comparing different development scenarios. The KPIs developed in Publication 1 also consider the shorter-term (hourly) balancing of energy demand and supply.

Publication 2 looks at the design and operational phase of the building

Publication 3 and Publication 4 focus on the renovation phase, on the building and district scale respectively.

There are different views from the physical scale perspective (and relevant stakeholder perspective):

1) The service level of the building space (room), especially thermal comfort (building users & owners as main stakeholders) (Publication 2);

2) The most optimal renovation actions for individual buildings (building owner and renovation company as main stakeholders) (Publication 3)

3) District-scale renovation (building owner, energy company and aggregator as the main stakeholders) (Publication 4)

4) Planning of actions on the neighbourhood level to achieve a positive energy level (city planner, energy company, building owner as main stakeholders): a) where are we standing? b) comparison of different paths forward. (Publication 1)
In this chapter, the methods used to find the answers to the research questions are outlined. The overall approach of the dissertation follows the lines of constructive research (Kasanen et al. 1993), as visualised in Figure 7.

First, in all four Publications, the problems were formulated by studying the current status and previously suggested solutions through literature reviews. Next, the recognised gaps and needs were validated by stakeholder interviews and workshops in Publications 1, 3 and 4. Based on the outcomes of these studies, new indicators, tools and a business model were developed, using also a detailed analysis of the existing information and solutions as basis. In Publication 2, a new method for finding the human thermal comfort conditions for Finnish weather conditions was tested and included a comparison to two widely used methods. In the work described in Publications 1 and 3 the developed tools were also tested by intended users, and their feedback was collected through surveys, interviews and workshops to validate their capability to solve the problems. The business model developed in Publication 4 is still at the theoretical stage, based on a ‘qualitative analysis of the thematic findings’ (see Braun and Clarke 2006) of the stakeholder interviews and an analysis of existing material, and its applicability could not yet be tested.
Table 6. The methods and their contribution to answering the research questions.

<table>
<thead>
<tr>
<th>Research question</th>
<th>Methods</th>
</tr>
</thead>
</table>
| What do the stakeholders need to know in order to promote EPNs? (Publication 1)  | Background: Literature study on indicators on the energy performance and built environment  
Interviews with stakeholders in the IDEAS project to understand their needs  
Analysis of existing energy performance labels and rating tools  
Interviews on requirements for a decision support tool  
Development of definition and KPIs for EPN, and AtLas tool  
Validation: Workshops with stakeholders and project group in the IDEAS project |
| How can it be ensured that the service level of the building is optimal while minimising the energy demand? (Publication 2) | Background: Literature review on effects of thermal comfort on performance, energy efficiency and costs  
Background: Analysis on the methods used for assessing thermal comfort, including findings related to the new method as presented in the literature  
Definition of typical and extreme weather conditions in Finland  
Human Body Exergy Consumption rate calculations in typical and extreme weather conditions in Finland  
Calculation of thermal comfort predictions with PMV and adaptive comfort methods in the same weather conditions  
Validation: Comparison of the results of HBEC rate calculations with the two more traditional methods |
| How can it be ensured that the renovation actions on individual building level contribute to both energy and cost efficiency? (Publication 3) | Background: Interview on the issues that hinder the activities of SMEs in refurbishment projects  
Detailed analysis on the availability and usability of energy performance simulation tools as presented in literature  
Development of E-PASS tool  
Validation: Survey on the usability of the new tool |
| How can district-scale energy refurbishments be promoted? (Publication 4)         | Background: Current status of district-scale refurbishment  
Detailed analysis on barriers and drivers for D-SER as presented in the literature  
Interviews with actors concerning drivers for accelerating D-SER and the needed roles  
Development of an aggregator business model based on thematic findings of the interviews and literature |

The research methods are described in more detail in Chapters 3.1 to 3.5. A short introduction to the methods used for developing the tools, indicators and business models is given in Chapter 3.6.

Publication 1: What do the stakeholders need to know in order to promote EPNs?

Publication 1 is the core element of this dissertation, suggesting a definition for energy positive neighbourhoods, and developing the elements needed for operationalising it: the KPIs, the energy positivity label and the assessment tool. The tool described in the Publication provides an evaluation of the current situation of the neighbourhood, and the effects of future development choices on different energy, environmental and cost indicators. It is also suitable for assessing new developments. This is intended to help the city planners and energy companies in the decision-making, but also for supporting them in justifying
the choices to the stakeholders affected by their decisions, especially building
owners and users. Publication 1 therefore looks at the neighbourhood over sev-
eral time frames and from various stakeholder perspectives. The paper also ex-
aamines different life-cycle phases, but also seasonal and hourly balancing of en-
ergy demand and supply, and several stakeholder types.

Publication 1 addresses the following gaps and needs recognized in the litera-
ture review:

- A comprehensive definition of EPN was missing.
- A lack of indicators for energy positiveness on the neighbourhood
  level.
- The need for an easily understandable presentation of the energy pos-
  itiveness level of a neighbourhood.
- Lack of easy-to-use tools to assess the level of energy positiveness.
- The need to take into account the seasonal and daily variations of en-
  ergy demand and availability in the calculations.
- Tools for assessing the energy, CO$_2$ and cost effects simultaneously on
  the neighbourhood level are missing.

The other three publications shed additional light on some specific details of
EPN, concentrating on different stakeholder views, on different physical scales
and on some of the most important life-cycle stages, which were recognised dur-
ing the literature review as being key factors for the promotion of EPNs.

Publication 2: How can it be ensured that the service level of the building is
optimal while minimising the energy demand?

Publication 2 approaches EPN from the building and building user (or owner)
perspective, suggesting a new tool for the designer. The applicability of a new
way to evaluate the thermal comfort of a building is tested for Northern cli-
nates, looking also for attributes for the typical and extreme conditions affect-
ing thermal comfort. The new method is compared to two commonly used meth-
ods for assessing the thermal comfort level. The time perspective is related to
the effects of different summer and winter conditions. The tool can be used in
the planning phase, or for assessing the quality of an existing building. The view-
point in Publication 2 focuses on thermal comfort. If we can predict the best
possible indoor conditions for thermal comfort, we can use only the required
amount of energy necessary, contributing to the "functional, healthy, user
friendly environment" required in the EPN definition.

Publication 2 contributes to addressing the following gap:

- The current thermal comfort indicators produce a very wide scale for
  potential combinations of air and radiant temperatures, which are
  sometimes not in correlation with practical experience. A new model
  is suggested by a research group in Tokyo City University, but its ap-
  plicability to Northern climate conditions was not tested.
Publication 3: How can it be ensured that the renovation actions on individual building level contribute to both energy and cost efficiency?

In Publication 3 the aim is to evaluate the potential of existing energy performance assessment tools to support small companies in refurbishment projects and assess the needs for a new tool. The study concentrates on building-level refurbishments from the point of view of the building owners and the renovation companies. It looks for ways to ensure that the renovation actions on the individual building level contribute to both energy and cost efficiency and assesses the ability of the existing tools to support the decision making, especially from an SME point of view.

Publication 3 proposes solutions for the following gaps:

- Lack of analysis on the usability and availability of energy performance simulation tools with the focus on the usability in refurbishment projects by SMEs.
- Lack of easy-to-use tools for assessing the combined effects of refurbishment actions.

Publication 4: How can district scale energy refurbishment be promoted?

Publication 4 broadens the view of renovation to the district level and considers the views of several stakeholders by looking for the drivers of and barriers to district scale renovation. The study covers a wide range of stakeholders related to district-scale renovations and has a very strong emphasis on the stakeholder perspective.

Publication 4 seeks solutions to the following gaps:

- A wide coverage assessment of the drivers of and barriers to district-scale renovations from different stakeholders’ perspectives is missing.
- The existing business models do not support the district-scale refurbishments, which however would facilitate the optimal timing of actions and the placement of renewable facilities.

To determine the gaps and needs regarding the promotion of EPNs, literature reviews were carried out, and these findings are presented in Chapter 2. The literature review presented in Chapter 2 revealed that for some of the subjects there was very little material available (e.g., the EPN definition and KPIs), while for others, an important amount of material was available, but not analysed from the specific point of view that was in the focus of the research (e.g., the usability of the analysis tools for SMEs or the importance order of barriers to and opportunities for district scale refurbishment). On the other hand, there were shortcomings with the current analysis tools, while the new tool had not been widely tested (for human thermal comfort analysis).

In the next steps, the findings of the literature review were validated through further analyses of the literature and through stakeholder involvement. The different stakeholders play an important role in promoting EPNs, and therefore their perspective was sought through interviews or workshops in many of the
Publications, either to test the hypotheses or to gain an understanding of their main needs and concerns.

Once a comprehensive understanding of the problems and potential solutions had been carried out, the development towards these solutions could start. The literature also contributed to the development of the solutions, by providing more details on the specific challenges and information about the relevant background data for the analysis tools. The solutions include the definition and KPIs for EPNs, three analysis tools for different physical scales and purposes, and a business model, as well as the definition of typical and extreme weather conditions for Finland.

Finally, the tools developed to solve some of the gaps were tested by the stakeholders, and their feedback was collected through interviews and surveys. The applicability of the human thermal comfort assessment tool was tested by the Author and compared to two more traditional ways of thermal comfort assessment.

The results were compared to the original situation and data to draw conclusions concerning the added value of the development work and to recognise needs for further development.

3.1 Detailed analyses of the current information and solutions

A detailed analysis of the literature available about energy positivity on the neighbourhood scale was carried out to determine how EPNs were presented in the recent literature. At the time of writing Publication 1 (in 2015), there was only limited material available that addressed energy positivity on the neighbourhood scale. This material was however thoroughly studied and compared to the interview results to find the gaps in the field and the needs for the EPN definition. The definition was needed for the IDEAS project, as the very aim of the project was to illustrate how communities, public authorities and utility companies could be engaged in the development of energy positive neighbourhoods. The analysis also included a study of the relevant KPIs and energy labelling methods used in earlier developments, addressing increased energy efficiency and renewable integration in the built environment.

A literature review on the effects of thermal comfort on the service level and energy demand was carried out in connection with Publication 2. Publication 2 starts with a background study on the importance of ensuring thermal comfort for the building occupants and the effects on worker performance, energy efficiency and costs. The evidence concerning the benefits was sought through a detailed analysis of examples in the literature. From the available material (in 2014), 12 papers were chosen as adequate proof of the connections and these were quoted in the study.

In the research reported in Publication 3, the availability and usability of energy performance simulation tools were assessed with the help of a literature study,
covering 53 articles and other sources that reviewed and presented energy performance assessment tools and methods. The articles dated mostly in 2005–2015, while Publication 3 was prepared in 2015 and submitted in early 2016. The detailed analysis of the literature included qualitative research by outlining the types of tools and assessing their usability, especially in refurbishment projects.

To clarify the issues that enable or discourage the district-scale energy refurbishment (D-SER) of existing buildings, a detailed analysis was carried out on peer-reviewed literature between the years 2010 and 2018. Several scientific databases (Science Direct, Scopus etc.) were searched, using keywords such as nearly/net zero energy, refurbishment, renovation, renovation potential, buildings, urban/district/neighbourhood, joint venture, public-private partnerships, infill building, and joint ventures in renovation projects.

The analysis of the literature concentrated on the key elements of business models as described by Osterwalder and Pigneur (2010): key partnerships, key resources, key customers, revenue streams, and value propositions. Some of the most interesting key partnership models from the point of view of the study included joint ventures and public-private partnership (PPP) (Cui, Liu, Hope, & Wang, 2018; Hueskes, Verhoest, & Block, 2017; Tang, Shen, & Cheng, 2010). The potential of infill building as a ‘key resource’ from the ‘district-scale refurbishment’ point of view was investigated.

### 3.2 Interviews with the stakeholders

For the development of the EPN definition, the KPIs, business models and the AtLas tool, several rounds of interviews with local stakeholders on the different demo sites in the IDEAS project were carried out, supported by workshops. Altogether 20 interviews were carried out to clarify the requirements for EPNs, business models and tools, covering representatives of Finnish and French energy companies, municipalities, facilities managers, energy consultants, students and/or domestic users. In addition, the interviewees in Finland included a wider selection of stakeholders, with representatives from Finnish Energy Industries, Motiva and Sitra¹ (Huovila et al. 2013).

A set of interviews was carried out to determine which issues hindered the activities of SMEs in refurbishment projects (Publication 3). The 31 interviewees represented different areas of the construction industry in Finland with the focus on design and refurbishment. From this group, the interviewees were randomly selected without any bias from the researchers. The interviewees con-

---

¹ Finnish Energy Industries is an industrial policy and labour market policy association representing the electricity and district heating industry in Finland. (http://energia.fi/en) Motiva Ltd is an expert company promoting efficient and sustainable use of energy and materials. Its services are utilised by the public administration, businesses, communities, and consumers. (http://www.motiva.fi/en) Sitra is an expert organisation providing funding for innovation. (http://www.sitra.fi/en/about-sitra)
sisted of a group of 11 contractors, 9 engineers, 7 architects, and 4 building owners. The interviews were semi-structured, in which pre-formulated possible barriers were listed and the interviewees were asked to assess whether they were actually the barriers to the active involvement and roles of SMEs in refurbishment projects (response options were YES, NO, N/A). The interviewees were then asked to justify their selection. In addition, the interviewees were asked to specify the areas of the construction industry that were especially affected by the possible barriers. All interviews were individually conducted through teleconferences.

To shed light on the drivers and new roles that would be needed for accelerating district-scale energy refurbishments (D-SER), 25 expert interviews of pioneering architectural engineering and construction (AEC) industry representatives in Finland were conducted. These interviews were carried out face-to-face, recorded and transcribed verbatim for a detailed qualitative analysis. Each interview lasted between one and two hours. Prior to the interviews, a questionnaire was prepared and shared with the interviewees. Then, semi-structured interviews were carried out, so that the experts were asked to add a detailed explanation and elaborate on the reasoning behind their responses. The expert interviews concentrated on especially finding two things: 1) the order of importance of different drivers for district-scale refurbishment and 2) the new roles that would be needed to accelerate district-scale energy refurbishment.

The selection of the interviewees was based on a nationally renowned set of contractors, engineering companies and municipalities, who have initiated and participated in the refurbishment of multiple buildings, joint building ventures and infill buildings. In addition, the aim was to reach a diverse set of interviewees who represented different types of organisations to gauge the current practices in the AEC industry of Finland. Neighbourhood- and district-scale energy refurbishment approaches were not prevalent on a large scale in 2019, and they are still rare in 2022.

The results of the interviews were analysed to obtain thematic findings of the interviews combined with the information gathered through a detailed analysis of the literature. The ‘qualitative analysis of the thematic findings’ applied in this study is roughly based on Braun and Clarke (2006). The qualitative content analysis was different from the thematic analysis. The inductive approach was used, meaning that the defined themes were strongly related to the data itself, in addition, a semantic approach was used, meaning that the data analysis did not look beyond the scope. Along the lines of Braun and Clarke (2006), a four-step process was applied to obtain thematic findings: (1) becoming familiar with the transcribed verbatim text, (2) organizing the results by summarising the essential issues based on each interviewed stakeholder group, (3) searching for themes and analysing the occurrence of each theme per group, and finally (4) presenting the conclusions on the market interest for district-scale refurbishment.
3.3 Definition of typical and extreme weather conditions in Finland

The aim in Publication 2 was to test whether the calculation method developed by Shukuya et al. (2009) could provide additional information on the thermal comfort in Northern conditions, as it had only been tested for Southern and moderate climates (Isawa et al. 2003, Prek 2005, Shukuya 2006, Tokunaga and Shukuya 2011). To see the differences, it was decided to test it in typical and extreme summer and winter conditions in two locations in Finland: Helsinki (Southern Finland) and Sodankylä (Northern Finland).

The eight input values needed for the calculation of human body exergy balance are: (1) outdoor air temperature; (2) relative humidity of outdoor air; (3) room air temperature; (4) mean radiant temperature; (5) relative humidity of room air; (6) relative velocity of room air; (7) the activity level (metabolic rate); and (8) the clothing insulation value. The environmental temperature used for the calculation is the outdoor temperature, to facilitate the simultaneous analysis of the heating and cooling systems (Shukuya et al. 2009).

The calculations in Publication 2 were automated with a human-body exergy balance contour calculation tool developed by Asada et al. (2010), which as input uses only six of the above-mentioned input values and calculates the output values with different combinations of room air temperature and mean radiant temperature, both varying from 15 to 35 °C in 0.5 °C steps to create a set of values for a contour plot. For the relative humidity and the relative velocity of room air, there are recommendations to be found in the Finnish documentation, e.g. in the Indoor Air Classification (Sisäilmayhdistys 2008) section. There are also typical values to be found for the metabolic rate and clothing for the office environment (ASHRAE, 2003). However, there was no information to be found on the typical or extreme outdoor conditions (outdoor temperature or relative humidity of outdoor air). Therefore, this needed to be defined for the calculations in Publication 2.

The search for the typical daytime temperatures and the typical extreme temperatures started by studying the test reference year (TRY) data (Ilmatieteen laitos, Finnish Meteorological Institute 2021a) in addition to the statistical information from the Finnish Meteorological Institute (2021b and c). TRY is the hourly weather data used for the calculation of the energy certificate in Finland, and it represents a typical year in Finland. In summer, during the office hour (8–17), a typical mean temperature is about 2 °C higher than the daily (24-h) mean temperature, which in July is on average 17.2 °C for Helsinki and 14.1 °C for Sodankylä (Finnish Meteorological Institute 2021b). Based on this information, 20 °C was chosen as the value for the outdoor air temperature in typical summer conditions in Helsinki, and respectively 16 °C for Sodankylä. For the calculations, a “typical extreme” temperature was considered more useful instead of the highest ever temperatures (being 31.6 °C in Helsinki and 31.7 °C in Sodankylä, Ilmatieteen laitos, Finnish Meteorological Institute 2021c). For Helsinki, 25 °C was chosen as a representative for this typical extreme temperature, which would occur practically every summer for one or two weeks. For Sodankylä, 20 °C was chosen as the typical extreme summer temperature, being
the hourly temperature exceeded for about 240 h/year (Ilmatieteen laitos, Finnish Meteorological Institute 2021c).

Typical winter temperatures are more difficult to define, as there is a wide variation in the daytime temperatures in February (the coldest month). In Helsinki, this could be from some plus degrees to −15 °C. In the south of the country there are, on average, 6–10 days in each winter month, when the temperature is above zero (Nordlund 2021). This can sometimes happen even in Lapland (Sodankylä), during very mild winters. Finally, the average monthly temperature, −5 °C in Helsinki and −15 °C in Sodankylä were chosen as the representatives for typical daytime temperatures. The office-hour temperatures (from 8 to 17) are typically almost the same as the mean daily (24-h) temperatures in winter, so these can be used for the calculations as such.

Similar to the extreme summer temperatures, the lowest measured temperatures (lowest ever 34.3 °C in Helsinki and −49.5 °C in Sodankylä, Ilmatieteen laitos, Finnish Meteorological Institute 2021c) do not represent an average situation, so similar “typical extreme” temperatures to the summer cases were needed for the winter cases, too. In Helsinki, the temperature is below −15 °C for 164 h (corresponding to 6.8 days) according to the TRY data, so this could be considered a “typical extreme”. In Sodankylä, −28 °C is the temperature occurring for about one week’s time (157 h), so this is chosen as the representative for typical extreme temperature for Sodankylä.

### 3.4 Human Body Exergy Consumption rate calculations in Finnish conditions

Calculations on the human body exergy balance in Publication 2 are based on the human body exergy balance principle presented by Shukuya et al. (2009). According to this principle, the exergy supply to the body must equal the sum of exergy consumption within the human body, the exergy stored in the body and the exergy output as presented in Eq. (1), giving the general form of the exergy balance equation for the human body (Shukuya et al. 2009).

\[
E_{\text{input}} = E_{\text{consumed}} + E_{\text{stored}} + E_{\text{output}}
\]

A more detailed description of the theory is presented by Shukuya et al. (2009), and the limited description here only gives a very short introduction to the underlying theory of the balance which is derived starting from the exergy–entropy process.

As the very purpose of the thermoregulatory system is to keep the body core temperature at constant level, the \( E_{\text{stored}} \) component in Eq. (1) is very small compared to the other components. \( E_{\text{input}} \) and \( E_{\text{output}} \) can be further allocated to different components depending on the routes of the exergy transfer across the boundaries of the human body. The exergy input consists of the following five components: (1) exergy generated by metabolism; (2) exergy contained in the inhaled humid air; (3) exergy contained in the liquid water generated in the body core by metabolism; (4) exergy contained in sum of liquid water generated
in the shell by metabolism (as sweat) and dry air to allow the liquid water to disperse and (5) radiant exergy absorbed through the surface (skin and clothing). The exergy output can be divided into following four components: (1) exergy contained in the exhaled humid air; (2) exergy contained in the humid air leaving the body surface containing evaporated water from sweat, (3) radiant exergy discharged through the surface (skin and clothing) and (4) exergy transferred by convection from the surface to the surrounding air. (Shukuya et al. 2009)

The results of the calculations with the human body exergy consumption rate (HBEC) were compared to two more traditional ways to assess the thermal comfort: the PMV method (Fanger 1982) and the adaptive comfort method (de Dear and Brager 1998). The calculations using these methods were also realised for the typical and extreme weather conditions described above (in Chapter 3.3).

3.5 Survey on the usability of the E-PASS tool

In the research presented in Publication 3, the easy-to-use E-PASS tool (see ch 4.3.2) was developed based on the thorough analysis of the needs of the stakeholders in that study through a detailed analysis of the literature and interviews described above (Chapters 3.1 and 3.2). This tool will facilitate the comparison of the combined effects of different energy efficiency improvement measures for a building refurbishment. The main stakeholders are the building owners and energy service companies.

The usability of the tool was assessed with a web survey. The link for the tool and the survey was sent to 1,586 recipients identified based on the business line. The number of respondents was 223 (overlapping responses were not allowed). The targeted audience consisted of SMEs in the refurbishment market: building designers, contractors, project managers, house managers, facility managers, energy consultants (including registered energy certifiers). The web-survey was realised using the Digium-Enterprise tool for online surveys (Digium 2015). Respondents were asked to characterise themselves in terms of the size of the company, main business line, and experience in using energy performance assessment tools and their own activity in encouraging clients for improved energy efficiency in refurbishment projects. The respondents were also asked to test the use of the E-PASS tool and evaluate its usability.

3.6 New indicators, tools and business models

Based on a detailed analysis of the literature, the interviews and workshops, the research described in the Publications also aimed to develop practical solutions for the gaps revealed in the analyses. During that work, new indicators, tools and a business model were developed and tested to promote EPNs. These methods, tools and business model are described in more detail in Chapter 4, but a short introduction to the methods leading to these solutions is given here.
3.6.1 EPN definition, KPIs, label and assessment tool

In Publication 1, the definition of Energy Positive Neighbourhood (EPN) was developed to improve the different stakeholders’ understanding of the concept. In the same Publication, also the Key Performance Indicators (KPIs) for EPN are presented. These KPIs reveal the state of the development of a neighbourhood towards EPN status. They clearly show the stakeholders the distance of the current development to the target values. The Energy Positive Neighbourhood Label developed in the same research gives this same message in a visual way, in one glimpse. The AtLas tool developed in the same context supports city planners in comparing the different planning options. The main stakeholders are city planners (EPN definition, KPIs, AtLas tool), energy company representatives (EPN definition, KPIs, AtLas tool), politicians (EPN definition and label) and citizens (EPN definition and label).

To fill the gap of missing definition for the EPN, a process to develop the definition was carried out. The development of the definition included several steps: 1) studying the literature and other sources that presented a potential definition for EPNs 2) discussion with experts and 3) stakeholder interviews. The aim was to reach a definition that would help the development of the tools and business models in the IDEAS project, but also be general enough to be used in other projects and contexts. The main aim of the IDEAS project was to "illustrate how communities, public authorities and utility companies across the EU can be engaged in the development and operation of energy positive neighbourhoods and the economic and environmental benefits of doing so" (CORDIS 2022). To achieve this, the project team first needed to understand what an energy positive neighbourhood was, but they found that a definition did not exist at that time.

The development of the KPIs was carried out once the definition was developed. Based on the detailed analysis of the literature, the group of experts first drafted an idea of what indicators would be needed to show that a neighbourhood fulfills the EPN definition, supported by the input from stakeholder interviews. The KPIs were chosen to be relevant for the stakeholders in the IDEAS project, but also an assessment of their applicability and usability to other stakeholders was conducted, e.g. through presentations and discussions in conferences and workshops (e.g. SDEWES 2015, Crosbie 2014).

According to the stakeholder interviews, a simple visual presentation of the level of the neighbourhood in relation to the target would improve the possibilities to engage the different stakeholders for the development of the EPNs. This would be beneficial especially for the end-users, like the inhabitants in a residential area or students on a university campus. In the development of the EPN label, relevant existing energy performance labels were explored and analysed, and the importance of different KPIs for the label was discussed with the stakeholders. The aim was to provide enough, but not too much information, so that the message would be easily understandable at one glance. The label should easily show how well a neighbourhood is fulfilling the EPN requirements. The development of the visual presentation of the label was also part of the process.
3.6.2 Easy-to-use tool for SMEs to choose renovation methods

In the research presented in Publication 3, the easy-to-use E-PASS tool was developed based on a thorough analysis of the needs of the stakeholders in that study, through the detailed analysis of the literature and interviews described above (Chapters 3.1 and 3.2). It will facilitate the comparison of the combined effects of different energy efficiency improvement measures for a building refurbishment. The main stakeholders are the building owners and energy service companies.

The tool required information of the different building traditions of different eras: the materials, structures and U-values. Additionally the information of the current renovation practices had to be included, as well as information on typical energy solutions, both traditional and especially different renewable options. The resulting CO$_2$ emissions and costs gave the basis for the comparisons presented for the user of the tool.

3.6.3 Activator business model for district-scale renovation

In Publication 4, the development of an activator business model is described as a solution to overcome the main barriers of district-scale energy refurbishment. The development was based on a detailed analysis of the literature related to barriers and opportunities and interviews with architectural engineering and construction (AEC) industry representatives in Finland, as described in Chapters 3.1 and 3.2. In Publication 4 we concluded that in a district-scale energy refurbishment, the value proposition of a new type of actor—an activator—should be for the end-users and could be based on (a) saving or increasing the value of a residential flat, (b) improving the living environment and increasing the attractiveness of the district, (c) improving well-being, or (d) easiness of refurbishment process.
4. Results: Evidence of the role of the three integrated dimensions in promoting EPNs

Chapter 4 presents the results and ties together the introduction and the research questions, providing the answers based on the research.

The literature review in Chapter 2 revealed that on the road towards wide application of EPNs it is important to look at the barriers and opportunities from different perspectives regarding stakeholders, time frame and physical scale. This chapter takes a look at these different dimensions, and suggests the important considerations regarding each of them, based on the analyses in the four Publications included in this dissertation. This is realised by presenting the results of the studies based on the main research question presented in Chapter 2:

**How can energy positive neighbourhoods be promoted?**

As the stakeholders are the key for the wide application of EPNs, the main stakeholders related to the results are listed at the end of each subchapter. Throughout the research work, the underlying principle has also been to comply with the sustainability goals, keeping in balance the people-planet-profit triangle. The relation of the results to these points is also explained below.

4.1 Knowledge needs of key stakeholders for the promotion of EPNs

Publication 1 examines what the stakeholders need to know to promote EPNs. Different stakeholders have different opportunities to affect the actions towards energy positivity, and this depends also on the other dimensions mentioned above: the time frame perspective and the physical scale perspective.

City planners, energy companies, building users and owners represent some of the key stakeholders for the wide application of EPNs. Especially for new areas, city planners set the scene e.g. by ensuring space for the renewable installations (affecting the supply options) or defining the combination of building types in the area (affecting the energy demand: volume and timing). They also may have some influence on existing areas. Energy companies have a large role,
by providing the energy infrastructure (e.g. district heating network) or by offering renewable energy options for their customers, even as a service. They could also provide a service where the building users could participate in the demand response, which has been tested e.g. in the Toukovuori area in Porvoo (Bäckström et al. 2015). Building owners can decide on the energy efficiency and renewable installations in their buildings, affecting the possibilities to meet the local energy demand by renewable energy. Once the infrastructure is built, it is the building users who decide largely on how much energy is used in the building and when.

It is important that the messages to these different stakeholders are clear, understandable and relevant for each type of stakeholder. Fawcett & Killip (2017) noted in their report that “understanding how and why multiple impacts arguments are used, by whom, and to what effect is an important research topic, and complementary to ongoing quantitative research into impacts.”

### 4.1.1 Definition of Energy Positive Neighbourhoods

To be able to combine the efforts towards energy positive neighbourhoods, a common understanding of the concept is essential. Publication 1 describes the process of defining what is meant by an energy positive neighbourhood and the elements included in it, thus seeking to answer the following question related to the motivation of key stakeholders: “What do the stakeholders need to know in order to promote EPNs?”

The process needs to start with the aims, and this also needs to be included in the definition: why do we think energy positive neighbourhoods are needed? In Publication 1, a definition for EPNs is presented (see Figure 9). It is based on a literature review, stakeholder interviews and workshops, including a wide selection of stakeholders, as described in ch 3. During this process leading to the definition described in Publication 1, it was concluded that the main aim should be “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.”

It is worth noting that for this definition of EPNs, the role of the EPN is strongly seen as support to wider energy networks: “Their energy infrastructures are connected to and contribute to the efficient operation and security of the wider energy networks.”

Once the goal is set, the elements making up the definition are described, e.g. the boundaries for the time and energy components. It is also important to mention that not all energy supply counts in the balance: “the annual energy demand is lower than annual energy supply from local renewable energy sources.”

At the time of developing the definition in the IDEAS project, the existing definitions of EPNs seemed to miss the notion that local energy demand is met by locally produced renewable energy, which is central to the IDEAS definition, and they also seemed to lack the level of clarity in the more extensive IDEAS definition of an EPN.
The annual balance is considered relevant time scale for the definition, as it is typically used in the energy performance assessments of passive and zero energy concepts (see e.g. the Passive House Institute 2018, Marszal et al. 2011.) Additional clarifications were also needed to ensure that the wider perspective and life-cycle aspect are always considered, and sub-optimisation is avoided. In the definition, also the energy demand and supply components are described:

- Energy demand in the definition 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. (In the IDEAS project, the waste and water management and transport were however not included.)
- Renewable energy in the definition includes solar, wind and hydro power, other forms of solar energy, biofuels and heat pumps.
- The supply facilities for the energy should be placed where it is most efficient and sustainable.
- The transport distance of biofuels is limited to 100 km.

"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. 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 8.** Definition of EPN from Publication 1.

**Stakeholders and sustainability goals related to the EPN definition**

The EPN definition was developed in the IDEAS project in cooperation with stakeholders from academia and business. In this group there were city planners, building owners, city officials, energy company operators, researchers, ICT professionals, students, etc. and all of them also represented common citizens, as residential and professional building users. Having a common definition fa-
cilitated the discussion between the different stakeholders. The main stakeholders are the city planners, politicians, energy companies, building professionals and even citizens.

In the development of the definition, the sustainability goals guided the work, although the profit angle was less visible and was only mentioned in the efficient operation of the energy networks and location of the supply facilities.

4.1.2 KPIs for EPNs

For the stakeholders, it is also important to be able to assess how well a neighbourhood fulfills the EPN definition (i.e. the energy positivity level of the neighbourhood), and this creates a need for the main indicators of the energy positivity of a neighbourhood. For this purpose, a set of KPIs has been developed by Ala-Juusela et al. (2014) as described in Publication 1. The KPIs are based on the results from a literature review, stakeholder interviews and workshops including a wide selection of stakeholders, as described in Chapter 3.

Derived from the EPN definition, the most important indicator describes the overall balance between the energy demand and renewable energy supply in a neighbourhood measured using an On-site Energy Ratio (OER), which is the ratio between the annual energy supply from local renewable sources and the annual energy demand. (In an EPN, “the annual energy demand is lower than the annual energy supply from local renewable energy sources.”) It is worth noting that in this indicator, all energy types are accounted for on the demand side: heating, cooling and electricity. The OER was inspired by the On-site Energy Fraction (OEF) (Cao et al. 2013), which was designed to measure nearly zero-energy buildings. OEF measures the proportion by which the demand is met by the on-site energy supply (0<OEF≤1). The OER, instead, measures the ratio between the on-site renewable supply and local demand as this is more important in the case of EPNs (the OER should be >1 for the neighbourhood to qualify as an EPN).

However, it is not enough to consider only the overall annual energy balance. Instead, it is also important to take into account the balance between the supply and demand for different types of energy (i.e. heating, cooling and electricity), as well as the matching of the timing of the supply and demand of these different types of energy. In this way, the quality of the EPN regarding minimizing the peak demand hours can be assessed.

Therefore, the following indicators are suggested in addition to the OER and calculated for each energy type separately (x = h for heating, c for cooling, e for electricity):

- The Annual Mismatch Ratio (AMRx) indicates how much energy is imported into the area for each energy type on average;
- The Maximum Hourly Surplus (MHSx) is the maximum yearly value of how much the hourly local renewable supply overrides the demand during one single hour (by energy type) compared to the OER;
- The Maximum Hourly Deficit (MHDx) is the maximum yearly value of how much the hourly local demand overrides the local renewable supply each hour;
- The Monthly Ratio of the Peak hourly demand to the Lowest hourly demand (RPLx) indicates the magnitude of the peak power demand.

In addition to these energy demand and renewable supply related indicators, some additional indicators are needed, as the ultimate goal of an EPN is not just to reach energy positivity. According to 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”. These additional indicators include the following:

- The level of energy demand is measured by comparing the energy demand of the area to that of similar areas or e.g. using the energy classification of the buildings (if they represent the largest part of the demand).
- The environmental impact can be evaluated using e.g. CO₂ equivalent emissions or in some cases the amount of radioactive waste. The ways to assess the level of the EPN in terms of the environmental impact are a comparison to the emissions in similar areas, or e.g. by calculating the emissions avoided by using the renewable supply in the area compared to the case of using external supply.
- The distance biofuels are transported is mentioned in the definition as a condition and therefore it needs to be part of the evaluation of an EPN.

The On-site Energy Ratio (OER) is calculated as the ratio between annual energy supply from local renewable sources and annual energy demand (Ala-Juusela et al. 2014):

\[
OER = \frac{\int_{t_1}^{t_2} G(t) \, dt}{\int_{t_1}^{t_2} L(t) \, dt}
\]

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). A simplified expression can be presented as follows:

\[
OER = \frac{\text{Annual local supply in kWh}}{\text{Annual demand in kWh}}
\]

The Annual Mismatch Ratio (AMRx) for heating, cooling and electricity considers the average of the hourly mismatch ratios (Ala-Juusela et al. 2014):

\[
AMRx = \frac{\sum_{t=1}^{8760} HMRx(t)}{8760}
\]
The calculation of the rest of the indicators (Maximum Hourly Surplus (MHSx), Maximum Hourly Deficit (MHDx), Monthly Ratio of Peak hourly demand to Lowest hourly demand (RPLx)) is described in Publication 1, which is an attachment to the dissertation.

**Stakeholders and sustainability goals related to the KPIs**

The main stakeholders are the city planners and the different professionals involved in developing the neighbourhood, including the building and lot owners. The indicators enable them to see how well the neighbourhood is performing and to evaluate the effect of different actions (with appropriate tools, see below in Chapter 4.1.4).

In the development of the KPIs, the people and planet angles of the sustainability goals were well covered, while the profit angle was not considered in the development of the KPIs. Costs are included in the assessment tool, and there was a separate task for business models in the IDEAS project (Huovila et al. 2013).

### 4.1.3 Energy Positive Neighbourhood Label

In order for the KPIs to motivate the key stakeholders, the KPIs need to be interpreted for the stakeholders in an easily understandable way.

During the research presented in Publication 1, an Energy Positive Neighbourhood Label was developed in co-operation with the building users and owners, city planners and technology providers, through a series of interviews and workshops. The purpose of the label is to give an idea at one glance of the status of the neighbourhood on the road towards being an EPN, or the achieved level as an EPN. The outcome is a compromise between detailed information and an overview. Literature was scanned for existing examples of labels, e.g. the energy certificate of buildings (see Haakana et al. 2018 for current version), appliances and light bulbs (see European Commission 2019c for current versions).

The main KPI used for the label is the On-site Energy Ratio (OER), which combines all the energy demand and supply components. To improve the granularity, other KPIs are presented for each energy carrier separately. This idea stems from the energy labels used e.g. for light bulbs, which give an overview picture of the energy efficiency of the bulb and then give additional information about the lumen values etc. It is worth noting one logical difference to the energy label of the buildings, which is the lengths of the coloured arrows: it was considered more intuitive, if the more positive rating was shown with a longer arrow, compared to the energy label, which indicates the lower energy demand level with a shorter arrow (Figure 9).
Stakeholders and sustainability goals related to the EPN label

The main stakeholders are politicians, but citizens will also benefit from the simplified presentation. With the label, they will get an indication of the point on which their own community is situated on the road to becoming an EPN, and the main gaps, be it on the annual balance, time based sufficiency of the local renewable supply for each energy type or the peak demand. This provides a guideline on the order of the actions, or at least the assessments. The EPN label is also a very good tool for city planners, allowing them to present the benefits of the different planning options to decision makers.

In the development of the EPN label, the people and planet angles of the sustainability goals were well covered, while the profit angle was not considered in the label. Costs are included in the assessment tool, and there was a separate task for business models in the IDEAS project (Huovila et al. 2013).

4.1.4 Decision support tool AtLas

After the definition of EPN, the development of the KPIs and the EPN label, the next step is to look at what kind of tools would be needed to support the planning and assessment of EPNs. To be able to present the KPIs and the label, there are needs for tools that can calculate the KPIs and transfer this information into the label. According to the stakeholder interviews and workshops, several different ways to present the results are needed.

In the development of the planning and assessment tool, it was taken into account that 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. This was a clear requirement from all involved actors, including local government officials, urban planners, facility managers and energy companies. The developed decision making tool AtLas provides this information, presented with the help of the newly developed indicators for energy positive neighbourhoods described above, in addition to more traditional indicators for costs and emissions. It enables estimates of the cost and environmental impacts of different building types, building classifica-
tions 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 long-term impacts of energy consumption and production in buildings and districts can be simulated with the AtLas tool. Several possible solutions for urban planning and energy supply and distribution can be studied with the tool. 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 can span over several decades. The tool also incorporates simplified methods for energy analysis calculation in case no hourly energy demand data is available. For example, the energy classes of buildings can be used as basis for simplified energy demand specifications.

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; and a ‘Results’ spreadsheet which displays the results calculated by the tool in tables. Access to the different spreadsheets is provided through the AtLas ribbon with the navigation icons, which also contain links to simulation control and the language options (see Figure 11). The AtLas tool is available in English, French and Finnish, with detailed user guides in Finnish and French (the languages of the intended users at the IDEAS demo sites) (Hradil and Ala-Juusela 2014).

The Planning sheet (Figure 11) is a key element of the user interface. Here, the user chooses the actions (= the combination of changes to the district and the buildings) that are planned for the area from drop-down menus and inserts the new values that are realised after the action is completed. The user also inserts here the start date of the plan and its duration, as well as the start, duration and related costs for the individual actions. The drop-down menus are populated by the information stored in the Advanced sheet (e.g. the building types or the energy production options) (see Figure 11).

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, CO₂ emissions, costs or building codes change. If some site-specific data is available (e.g. on energy sources), this can also be used as input into the Advanced spreadsheet. 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.
Results: Evidence of the role of the three integrated dimensions in promoting EPNs

Figure 10. On the planning spreadsheet of the AtLas tool the user inserts information about the area in the white cells by hand or chooses the options from drop-down menus. (Hradil and Ala-Juusela 2014)

Based on interviews of potential users of the tool, an important amount of flexibility was built into the tool. The user can e.g. compare different 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. The tool facilitates the simulation of different scenarios for district’s energy demand and production (e.g. new wind farm), buildings floor area (e.g. new construction or demolition), energy efficiency level of the buildings (e.g. renovation) or building-integrated energy production (e.g. new solar panels on the roof), to mention a few.

The outputs are presented in formats that will help the user to present the relevant information to other decision makers and stakeholders. These include e.g. the energy positivity indicators and particular impacts in the form of CO$_2$ emissions, purchased energy and costs including required investments, normalized to different bases (e.g. the floor area, population or area of the district). The output options also include presenting the values separately by each energy type or in total, and as time-related or cumulative values. This makes the software highly versatile so it can support the decisions of facility managers, city planners or the planning of energy distribution networks.

The AtLas tool was tested for two neighbourhoods to assess and compare different future development scenarios and their impacts on the energy demand and supply as well as their environmental and economic impacts (Brassier et al. 2015 and Bäckström et al. 2015). The comparisons of the different future scenarios for the two sites confirmed that the KPIs developed in this work would indeed bring new insights to the decision making process and provide a powerful tool to compare the combined impacts of several very different actions.
**Stakeholders and sustainability goals related to the AtLas tool**

The stakeholders for the AtLas tool represent many different actors such as city planners, city officials, energy companies, building owners and common citizens. It helps them to understand the impacts of different planning options such as the energy efficiency of buildings and infrastructures or the renewable installations. The tool will mainly be used by the city planners, energy companies and building managers (for an area).

In the AtLas tool, all the sustainability angles of planet and profit are well covered, while the people angle is less visible, but still covered. The underlying assumption is that the districts are planned for the well-being of the people. The AtLas tool also helps city planners to present the economic and environmental goals to the decision-makers and common citizens. It can also be used as part of the energy management tools of a local energy company, showing the building users the level of energy positivity compared to an average neighbourhood in the same area or country.

### 4.2 Ensuring service level with minimised energy demand

The very purpose of the built environment is to support human activities. While looking at the neighbourhood-scale energy demand and supply, we also need to examine things on the building, or even individual room scale to ensure good performance of the buildings. According to the EPN definition, the very aim of the EPNs is indeed to “provide a functional, healthy, user friendly environment with as low energy demand and little environmental impact as possible”. On the building level, a central viewpoint in the EPN is to answer the question: “How can we ensure that the service level of the building is optimal while minimising the energy demand?” In this sense, optimal service level contributes to providing a functional, healthy and user friendly environment.

It is important to view the situation on the building scale, as this is the scope where the decisions on the energy efficiency and service level are taken. Often the energy efficiency and indoor environment targets coincide, but some energy efficiency measures can reduce the quality of the indoor environment, if careful design is not applied. It is also important that these measures are considered in a holistic way so that they do not undermine each other’s effects.

Sustainable building design aims to provide people with spaces that bring about long-term economic, social and environmental benefits. Increased labour productivity supports all these three aims: when people produce more with less resources and time, it will create economic benefits, but also less burden for the environment, and allow more time for social activities. In a matrix presenting the quantifiability and the time horizon on which the benefits are likely to occur, Rasmussen (2014) has placed an improved work environment (which includes thermal comfort) as a benefit which is difficult to quantify (intangible) but occurs soon after the realisation of the energy efficiency measure producing this impact.

In modern cities, people spend almost 90% of their time indoors (Klepeis et al. 2001). From the world population, as many as 56.2% of people live in cities,
and the share is increasing (World Economic Forum 2020). The indoor environment includes thermal, acoustic and air quality aspects, but also visual aspects play a big role in people’s perception of the indoor environment (Lechner et al. 2021). In residential buildings, space heating is the largest energy demand component, accounting for more than half of the IEA energy consumption, and up to 73% in some European countries (IEA 2020).

4.2.1 Solution: New method to evaluate thermal comfort

As noted in the literature review (Chapter 2), widely-used methods for evaluating thermal comfort (PMV & Adaptive model) give quite wide ranges for thermal comfort conditions (radiative temperature and air temperature). From the point of view of the service level, it is relevant to ask if and how the thermal comfort level in buildings could be assessed more precisely than with the current methodologies. A new method based on the human body exergy consumption rate has been developed by a research team in Tokyo City University (Shukuya et al. 2009), but it has not been widely tested to see if it would contribute to improving the predictions. It is also interesting to study how well it would be suited for analyses in Northern climate, as part of the development work.

In the research described in Publication 2, the applicability of this new method to evaluate thermal comfort was tested for a Northern climate. The method is based on the calculation of the human body exergy consumption (HBEC) rate. The assumption is that the best thermal comfort is found in environmental conditions giving a minimum HBEC rate. The results were compared with other, more common methods: the Predicted Mean Vote (PMV) method and the adaptive comfort model. The target was to show the benefits of this new methodology in comparison to currently used methods.

This method can be used to show the benefits of different energy efficiency measures or differences of available choices regarding thermal comfort (and productivity, as shown in later phases of the research of the author, Ala-Juusela, 2017). The main stakeholders are the building users and owners.

The analysis showed that the new method seems to give a more precise area for the combination of indoor air and radiant temperature than the usually used PMV method, or the adaptive model.

For the summer conditions, human body exergy analysis results seem to provide an explanation for the everyday experience of some experienced designers and researchers that some conditions on the PMV* = 0 line seem to give more satisfaction than others (Figure 12). Furthermore, the fact that the minimum human body exergy consumption coincides better with the PMV* = -0.3 line in summer conditions, where people’s preferred temperatures usually occur in summer, gives indications that a human body exergy analysis might present a better way to predict the optimal thermal conditions than the PMV* method. According to recent studies, people are also most productive in these conditions (e.g. Wu et al. 2012, Lan et al. 2012, Kosonen and Tan 2004, Loveday et al. 1995). This study was a first step on the way to develop a method for productivity predictions. In next steps, the method was applied for productivity calculations (Ala-Juusela, 2017).
Results: Evidence of the role of the three integrated dimensions in promoting EPNs

The adaptive model gives a relatively wide range of allowable combinations of the mean radiant temperature and room air temperature (Figure 13). According to the calculation results, the minimum HBEC rate occurs consistently at lower operative temperature points than the comfort temperature given by the adaptive model, but they all fall into the range of 90% acceptability given by the adaptive model.

If we can find the optimal conditions for human thermal comfort, we can use only the necessary amount of energy to provide the comfortable environment, and nothing more. The calculations confirm the findings of some earlier studies that minimum HBEC rate usually occurs in conditions where the mean radiant temperature is slightly higher than the mean air temperature. This would mean that in winter conditions, the room could be heated to a lower temperature than...
currently is usual, provided that a suitable radiant temperature can be maintained. It is estimated that, as a general rule, lowering room temperature by 1 °C produces up to 10% savings in energy (Palmer et al. 2012). In the summer case, the energy need for cooling would be minimized, if the optimal thermal comfort could be maintained by natural or hybrid ventilation.

**Stakeholders and sustainability goals for the new method of thermal comfort optimisation**

The main stakeholders for the new method of thermal comfort optimisation are the building users and owners, but it could also be used by the energy service companies for showing the effects of different energy efficiency improvement methods to the clients. Currently the method is not yet very user-friendly, as it requires detailed information about the thermal environment and important amount of calculation effort. This could be mitigated by developing a user-friendly calculation tool, with pre-defined values for typical conditions and characteristics.

On building scale, the decisions by the building user and owner have more influence on the energy use and balance between demand and supply, mainly through behavioural patterns.

The result is related to all sustainability targets: the well-being of people, contributing to better profits (through improved productivity), with least effects to planet. Once the productivity model is further developed and validated, this will facilitate the connection with cost optimization.

### 4.3 Energy and cost efficient renovation actions for a building

The research described in Publication 3 looks at the EPN on the building level (from a physical scale perspective) and for the renovation phase (time frame perspective): “How could we ensure that the renovation actions on the individual building level contribute to both energy and cost efficiency?” As one of the key findings in the literature review was that there are more assessment tools available for new buildings than for renovation, it is worth studying what kind of tools are available for assessing the effects of refurbishment actions. The research for Publication 3 was carried out as part of the MODER project. The aim of the MODER project was to increase business of engineering companies, energy managers and consultants in supporting municipalities and building owners for the refurbishment of buildings at district level. One important perspective in the MODER project was the one of the SMEs, so it was also relevant to study the needs of SMEs for the new tool. According to Official Statistics of Finland (2021) 60% of renovation projects were realized by small companies (with 5 to 9 employees).

#### 4.3.1 Energy performance assessment tools for refurbishment

The research described in Publication 3 included several steps: the qualitative research was realised by outlining the types of tools and assessing their usability especially in refurbishment projects. Conclusions were drawn concerning the
usability and shortcomings of current tools and a new energy performance assessment tool was developed especially for the use of SMEs in refurbishment projects. The underlying hypothesis was that the main challenge from the usability point of view is the difficulty defining the input values that characterise the building and the alternative refurbishment methods. In addition, qualitative and quantitative research was realised with the help of two surveys: 1) studying the barriers for SMEs in refurbishment projects and 2) the current use of tools and the usability of the new tool developed in the project.

The findings suggested that the main weaknesses of the existing tools were mainly the following:

- The tools are suitable more for evaluation of a realised project than for the use in the early phases of design
- Tools that are able to give the most realistic view of the building performance after the renovation actions either demand very detailed input data or are limited to certain types of buildings in selected environments and limited choices of user behaviour patterns.
- Overall, most tools are better suitable for the design of new buildings than for building refurbishment
- Especially it seems that emerging technologies for building retrofits are not typically included or cannot be accurately evaluated using existing tools
- Most tools intended for retrofitting cannot assess the integrated effects of several renovation actions combined
- There are no moderately easy-to-use tools that enable the simultaneous consideration of cost-efficiency and energy efficiency.

4.3.2 Solution: Easy-to-use tool E-PASS

In addition to a large scale assessment, it is also important to have easy-to-use tools for assessments on the building scale. While the AtLas tool described above provides long term assessments based on the energy classes, it does not indicate which actions will result in higher classes. Publication 3 presents the development of an easy-to-use tool for assessing the combined effects of different refurbishment actions. Again, the idea is that the user can start using the tool with very little existing information.

From the stakeholder interviews and detailed analyses of literature, it became evident that the right combination of ease-of-use and accuracy is important. This can be achieved with the help of a dynamic calculation engine, carefully defined local data and well-selected default values, combined with openness which enables the users to access the default values and give detailed true data when that is available. This combination makes it possible to realise both rough estimations in the early phases and more accurate assessments when better information is available.

Another important aspect derived from the analysis is that the possibility to simultaneously consider financial and energy aspects is very important for small companies who consult private clients in energy-efficient refurbishment. According to the interviewees, one of the main shortcomings of existing tools was
the lack of a holistic approach. Understanding of the overall long-term benefits of a refurbishment was considered to be a barrier to refurbishment.

On the basis of this information, a new tool was developed. The targeted user group are small companies such as architects, housing managers, consultants and contractors that work on refurbishment projects and need to support their clients in the early consideration of energy-related aspects. The aim of the tool development was to achieve 1) good accuracy based on dynamic hourly-based calculations and 2) simplicity of use based on building typology and related default values and availability of several refurbishment alternatives to be selected.

The tool proceeds through the following four steps: 1) Definition of the basic data for the building; 2) Assessment of results before measures (or optionally, refining the given default values for the building characteristics) 3) Application of measures 4) Assessment of results before and after measures (Figure 13).

A survey was implemented to assess the usability of the tool (see Chapter 3.5). The main part of the respondents represented SMEs. The energy performance was considered either very important or quite important for their customers according to 84% of the respondents. One of the most important findings based on the survey was that new, easy-to-use tools were welcomed by small companies: 72% said that the use of an energy performance assessment tool would be necessary in refurbishment projects and 59% said that they already use a tool. Regarding the general usability of the tools in refurbishment projects on a scale
Results: Evidence of the role of the three integrated dimensions in promoting EPNs

with 7 steps, the usability of their current tool was assessed excellent/good/moderate by 7/17/47% (in corresponding order) of respondents and by 13/39/30% of respondents for the new tool. The survey included questions about the adequacy of refurbishment alternatives, ease to change default values and clarity and intelligibility of the assessment result. The ease and clarity were assessed to be good but quite many thought that there should be even more optional refurbishment alternatives. The list should be broad and cover preferably all relevant options also including minor tasks and options that are related to changed user behaviour. In addition, it was clear that actors in small companies wanted the tools to be localized also in terms of the language of the terminology used in the tool. As a general assessment, 57% of the respondents said that they would very or quite probably start using the new tool.

Stakeholders and sustainability goals related to the E-PASS tool

The key stakeholders for the E-PASS tool are small refurbishment companies, which can help building owners understand the short- and long-term impacts of the different renovation actions combined.

The E-PASS tool covers the sustainability goals from the planet and profit angles. The people angle is included in the sense that the tool is intended to be easy-to-use and helps renovation companies and building owners to find the best options for renovation, which in optimal cases should also improve the quality of the building from the building user’s point of view.

4.4 Promoting district scale renovation

An essential aspect to examine when trying to promote the wider application of EPNs is to look at the drivers and barriers. In the research described in Publication 4, the most important drivers and barriers for district-scale renovation (D-SER) from the point of view of different stakeholders were studied. Based on these, a business model was developed to support district-level refurbishment to help paving the way towards energy positiveness.

Several benefits of district-scale refurbishment in comparison to building-scale refurbishment are presented in Publication 4. Most of these apply also in case of energy positive neighbourhoods, especially those aspects related to balancing demand and supply and the choices for placing renewable energy components and storages.

Planning refurbishment actions on the neighbourhood level provides possibilities to avoid investments in new energy supply facilities, especially on expanding areas, where new buildings are planned among or around the existing ones. If the older buildings can do with less energy, there is room in the local energy system for the energy demand of the new buildings, with less need for additional supply.
4.4.1 Drivers and barriers for district-scale refurbishment approaches

The results drawn from the detailed analysis of the literature, interviews with key stakeholders and thematic analysis of the data suggest that there is still little experience in the application of district-scale approaches and thus also a somewhat limited number of studies that assess the importance order of the potential drivers and barriers. District-scale refurbishment can offer the same benefits as building-scale refurbishment, including energy savings, reduction of greenhouse gas emissions and an improved quality of life through improved comfort. In addition, based on current understanding, district-scale approaches can offer better opportunities for efficient land use, optimal infill building, and optimal solutions for the application of renewable energy technology, better possibilities to manage situations where buildings play an active role in the energy system, and better possibilities for cost savings with the help of joint ventures.

There are also important barriers including the presence of several actors representing different stakeholders, different values and interests of stakeholders, low involvement of citizens, lack of applicable business models especially for energy positive neighbourhoods, the complexity and quantity of needed information and lack of comprehensive political support and skilled personnel. Many of the addressed barriers are related to the need for new roles and new ways of collaborative working.

4.4.2 Solution: New business model for district-scale refurbishment

As one of the main barriers to district-scale refurbishment found in the literature review and interviews in Publication 4 was the lack of an integrator and lack of applicable business models, an activator business model was drafted as a potential solution. The elements of the business model canvas (Osterwalder & Pigneur 2010) that could be addressed were the most potential customer types (mainly in terms of building/district characteristics), value proposition, potential revenue streams, role and type of the activator. It also became evident that the municipality should have a central role in promoting and facilitating district-scale refurbishment by supporting with the help of flexible town-planning, open information, strong support for citizen participation and also by providing some incentives for starting the process. The role of energy companies as a key partner was also considered, but their role was seen more as a knowledge provider and supporter. (Figure 14)
It was concluded that the value proposition should be for the end-users and could be based on (a) saving or increasing the value of a residential flat, (b) improving the living environment and increasing the attractiveness of the district, (c) improving well-being, or (d) easiness of refurbishment process. Most potential clients would be the big rental housing owners especially in the suburban districts from 1970s. They could act as engines for the wider application of district scale refurbishments. However, private housing companies form half of the overall customer segment. Therefore, it is recommended that the municipalities as important building owners should be active, show an example and encourage others.

The role of the activator was seen as very demanding, and requiring many skills ranging from process understanding, networking and collaboration in addition to having expertise in energy solutions and technologies. Here, the emphasis given to technical vs. collaboration skills varied among the interviewees. The activator role could be taken by the kind of actors who were interviewed in connection with the study: contractors, project managers, and engineering companies. Many of the interviewees also showed a clear interest in the role and had already thought of possibilities for making a business out of it. There were however still some challenges, such as the relatively low business potential and the doubts concerning being perceived as a trustworthy actor as a private company.

Stakeholders and sustainability goals related to the activator business model

The main stakeholders for the activator business model are municipalities, building owners, contractors, project managers and engineering companies.

The activator business model contributes to balancing the three angles of sustainability: people–planet–profit.
5. Discussion

This chapter assesses the meaning and importance of the results and takes a critical look at the relevance of the results in comparison to the literature review and the research questions.

The problem that lies behind the basis of this work was the slow pace of implementing EPNs (JPI Urban Europe 2020, Kumar and Cao 2021), which if implemented could make a strong contribution to climate change mitigation, as explained in Chapter 1.1.3. Based on the initial analysis, some aspects constantly appeared highly relevant regarding the key concepts related to EPNs (Chapter 2). These aspects are key for the promotion of EPNs and can be grouped under three dimensions: the stakeholder, time frame and the physical scale. It is therefore relevant to examine the EPN concept in terms of these dimensions.

The main question for which the dissertation sought answers to was: How can energy positive neighbourhoods be promoted?

There are slightly different stakeholders who make decisions in different life-cycle stages (Feige et al. 2011) and on different physical scales (IEA 2014, Kumar and Cao 2021). Design and renovation are the stages where the most effective decisions are taken concerning the energy efficiency and CO₂ emissions of the operational phase (Kolokotsa et al. 2009), which is currently the phase causing most of the CO₂ emissions (Ramesh et al. 2010).

First, to encourage the key stakeholders to develop and make wider use of EPNs, it is important to have a common understanding of what we are aiming at, suggesting a need for a definition and indicators for EPN (Brozovsky et al. 2021), which were addressed in Publication 1.

In the development of EPNs, it is also important to look at the building level, starting by ensuring that the service level of the building is optimal while minimising the energy demand. As heating and cooling account for a major part of the energy demand of buildings (Eurostat 2022), accurate predictions of the effects of the indoor environment on thermal comfort are needed. This was addressed in Publication 2 by testing a new calculation method of human thermal comfort prediction for Northern conditions.

As a neighbourhood aiming to achieve energy positivity could consist of both new and existing buildings, renovation is a relevant point to consider. On the one hand, it is important to ensure that the renovation actions on the individual building level contribute to both energy and cost efficiency, which was the core point of the research in Publication 3. On the other hand, similarly to the energy positivity, there are indications that district-level refurbishments would provide additional benefits compared to the building level. It has to be noted that even
in this case, the actions for each building need to be planned in regard to the needs and qualities of that individual building. The research in Publication 4 studied the importance order of drivers of and barriers to district-scale renovations from the point of view of different stakeholders, and how these could be taken into account in the development of business models that support the district-level refurbishment and pave the way towards energy positiveness.

In order to support the wide application of EPNs, relevant methods, tools and business models are also required and the developments of these in connection of the research are described in the Publications.

The following were recognised in the literature review as main gaps or points of concern that should be addressed to promote the wider application of EPNs, taking into account the three dimensions of the stakeholder, time frame and physical scale tackled in the four Publications:

- A comprehensive definition of EPNs was missing (Publication 1).
- There was a lack of indicators for energy positiveness on the neighbourhood level (Publication 1).
- A need existed for easily understandable presentation of energy positivity level of a neighbourhood (Publication 1).
- There was a lack of easy-to-use tools for assessing the level of energy positiveness (Publication 1).
- A need existed to take into account the seasonal and daily variations of energy demand and availability in the calculations (Publication 1).
- The current thermal comfort indicators have a very wide scale for potential combinations of air and radiant temperatures, which are sometimes not in correlation with practical experience. A new model is suggested, but its applicability to Northern conditions was not tested (Publication 2).
- There was a lack of analysis on the usability and availability of energy performance simulation tools with a focus on usability in refurbishment projects by SMEs (Publication 3).
- There was a lack of easy-to-use tools for assessing the combined effects of refurbishment actions (Publication 3).
- A wide coverage assessment of the drivers of and barriers to district-scale renovations from different stakeholder’s perspectives was missing. (Publication 4)
- The existing business models do not support district-level refurbishment, which however would facilitate the optimal timing of actions and the placing of the renewable facilities. (Publication 4)

In the following, the solutions developed during this research work are assessed in relation to the main research question and the gaps revealed in the literature review.
5.1 The solutions in relation to stakeholder, time frame and physical scale

In the research presented in this dissertation, new methods, tools and business models were developed and tested to promote EPNs (Figure 15).

The development targets were based on a detailed analysis of the literature, interviews and cooperation with the different actors relevant to the individual studies. Therefore the combination of the tools and methods presented here is not all-inclusive regarding all stakeholders, but they contribute to explaining the benefits and comparing the different options on the road to wide application of EPNs to some of the key stakeholders. In Table 7, the relevance of the developed methods, tools and business models to the different dimensions (stakeholder, time frame, physical scale) are presented.

Table 7. The solutions presented in this dissertation in relation to the different dimensions.

<table>
<thead>
<tr>
<th>Solution</th>
<th>Dimension</th>
<th>Stakeholder</th>
<th>Time frame</th>
<th>Physical scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPN definition</td>
<td>City planners, politicians and citizens</td>
<td>Old &amp; new buildings, static (one year)</td>
<td>Neighbourhood</td>
<td></td>
</tr>
<tr>
<td>EPN KPIs</td>
<td>City planners, politicians</td>
<td>Old &amp; new buildings, takes into account the hourly match over one year</td>
<td>Neighbourhood</td>
<td></td>
</tr>
<tr>
<td>EPN Label</td>
<td>Politicians and citizens</td>
<td>Old &amp; new buildings, takes into account the hourly match over one year</td>
<td>Neighbourhood</td>
<td></td>
</tr>
<tr>
<td>AtLas tool</td>
<td>City planners, politicians, neighbourhood level developers</td>
<td>Old &amp; new buildings, takes into account the hourly match over one year, over a time span up to 50 years</td>
<td>Neighbourhood</td>
<td></td>
</tr>
<tr>
<td>HBEC method</td>
<td>Building user &amp; owner, designer</td>
<td>Old &amp; new buildings, static</td>
<td>Building</td>
<td></td>
</tr>
<tr>
<td>E-PASS tool</td>
<td>Building owners, energy service companies, renovation companies</td>
<td>Existing buildings, renovation, static, but takes into account combined effects of measures</td>
<td>Building</td>
<td></td>
</tr>
<tr>
<td>Activator business model</td>
<td>Contractors, project managers, engineering companies</td>
<td>Old and new buildings, concentrating on refurbishment</td>
<td>Neighbourhood</td>
<td></td>
</tr>
</tbody>
</table>

5.1.1 Stakeholder roles and interests

In the research presented in this dissertation, the roles of different stakeholders were studied in a selection of situations and life-cycle phases. Different
stakeholders are more relevant to different life-cycle stages, with different abilities to make decisions that will affect the energy use or the share of renewables in the energy mix. Additionally, there is a difference between the most relevant stakeholders on the building and neighbourhood scale. On the building scale the building owner and user have a lot of opportunities to affect the level of energy positivity, while on the neighbourhood level they have limited possibilities. On the neighbourhood scale, the municipality instead plays a big role, while on the building level its role is mostly limited to the energy efficiency requirements, and the requirements and possibilities for placing the renewable systems. Collaboration often yields the best results, where the different points of view are taken into account in a balanced way. Here, the activator type of business model gives its clearest benefits.

Building users

Building users play a very important role in the energy efficiency of the built environment, and also the possibilities for balancing the demand and supply. They are interested in the quality and safety of the environment (indoor and outdoor), the functionality of the spaces, and reduced living costs, to mention a few aspects (e.g. IEA 2014, Feige et al. 2011).

Most users are not willing to use a lot of time for studying the state of their neighbourhood or building, so they need easy-to-use user interfaces and easily available information on how their choices will affect the aspects mentioned above. On the other hand, there are indications that many people are inspired by the feeling of being connected with the community (Mihailova et al. 2022). In the demonstration sites of the IDEAS project, the people were very interested in comparing their own energy efficiency to others in the neighbourhood, and also the energy efficiency (or energy positivity) level of their neighbourhood to other neighbourhoods (Bäckström et al. 2015).

Building users have less influence on the neighbourhood-scale decisions. From the developments of this dissertation, building users will benefit most from the HBEC tool, helping to ensure thermal comfort. The choice of the renovation actions suggested by the E-PASS tool will also affect the functionality and comfort of the building. The EPN label will show building users the level of energy positivity of the area, and thus connect the user to the neighbourhood. The EPN definition will help building users to interpret the content of the EPN label. One aim of the activator business model is to increase the cooperation of the stakeholders, helping to take into account also the needs and viewpoints of the building users.

Building owners

Building owners are often the same as the users, and are interested in the same aspects, at least in Finland. Of the Finnish building stock, 65% are owned by private households, either directly or through housing companies (Ympäristöministeriö 2017). Commercial owners are interested in preserving or increasing the value of the building. This is affected also by the same aspects as mentioned for building users, but in this case, e.g. the reputation of the area or neighbourhood also plays a major role. Large rental building owners often seek
to increase the value of investments (short return of investment, ROI) and reduce the running costs. By investing in energy efficiency and renewable choices, they have the opportunity to reduce the risks of increasing energy prices (Tuominen and Seppänen 2017). The E-PASS tool will help in comparing the costs and the energy effects of renovation actions.

Nowadays the owners of commercial buildings are more and more different than the building user. The building user is however most affected by the quality of the building: the usability, the visual, acoustic, thermal and indoor air quality. The indoor environment has a large effect on the well-being and productivity of the building user, and should therefore be an important aspect for an organization trying to gain the value of the activities realized by the building users. However, nowadays even this organization may not be the one owning or operating the building, but instead may be a professional investor. Investors are getting increasingly interested in the increased value of buildings created by good IEQ (BentallGreenOak et al. 2021). New tools for assessing the effects of the building on the well-being and productivity of the building users will help in finding common ground between the building owners, operators and building users (people and organisations). The HBEC-rate tool is one step towards this.

Building owners have less influence on the neighbourhood-level decisions, unless they are large owners, e.g. cities or other rental building owners. They might still be interested in the value of the neighbourhood, where the EPN label would be one way to evaluate this. The activator business model will also help the building owners in cooperation, decision making and finding new ways to get the best results from district scale renovation with minor own effort.

*Municipalities (authorities)*

Municipalities have a major role on the neighbourhood scale (Häkkinen et al. 2019). However, also concerning building-scale renovation, the municipality may have a large effect, e.g. through permission processes for renewable or storage installations or building permits regarding the renovation. This is especially relevant for buildings or areas of historical value or those which are close to natural reserve areas (Peeters et al. 2020).

The municipality’s role starts in very early stages, with land use planning and requirements for building permits. One important aspect is also the example given by municipalities as building owners. Municipalities often own buildings in a central place in the community, which are often visited by the general public. By setting an example of energy efficiency or renewable energy installations, they have the opportunity to speed up the process towards energy positivity. Municipalities are often regarded as impartial in their information provision, as usually it is believed that they are not trying to sell anything. According to the studies described in Publication 4, the municipalities are also careful to preserve this position, and that is why they see their role as an activator to be a bit problematic, as this may lean too much to the business side of things.

The AtLas tool will help the city planners to choose optimal ways to move towards EPNs, and in presenting effects and justifications to other stakeholders. The benefit of the activator business model from the point of view of municipalities is one point of contact, which simplifies e.g. the permission process.
Construction companies (building professionals)

Traditionally, it is the perception that construction companies are mostly interested in low investment costs for buildings, but currently, the trend seems to be that they are interested in helping the customers to keep the value of the property. Some forerunners have also started to commit to life-cycle contracting. One way to increase the interest of construction companies in energy efficiency and renewable integration are the requirements set by the municipality for the competition for the plot ownership or rental rights. The AtLas tool and EPN Label will help municipalities to show the benefits to the construction companies (and their clients). The activator business model will integrate the construction companies in the cooperation. The role of the activator could even be taken by the construction company.

Engineering companies

Engineering companies could bring in the new solutions, but it seems that they prefer to stick to well-known and tested solutions, which is very understandable, as they want to minimise the risks to their customers. In this field there are also forerunners, aiming for overall sustainability. This kind of actor could realize the activator business model.

Energy companies

For energy companies, as big changes are taking place in the energy sector, it has become more and more interesting to avoid investments in new energy infrastructure. The payback period of the investments are typically long, and also the infrastructure has a very long lifetime, e.g. 20 to 50 years, and it is hard to predict how long the equipment will be useful in the future environment. Additionally, energy companies are moving towards providing energy as a service, as then they would have more flexibility in making decisions on the placement of new plants and other infrastructure. In this new way of thinking, energy companies could play an important role in an energy positive neighbourhood. They could benefit from the analyses made with the AtLas tool.

5.1.2 Time frame: short or long term

Variation of the energy demand and availability

In our definition of the KPIs for EPN (Publication 1), we established indicators for mismatch ratios, which indicate the average amount of energy imported into the neighbourhood. The background for this was the need to balance the demand and supply not only on annual basis but also on a shorter time scale, e.g. hourly and seasonal. This is needed to “contribute to the efficient operation and security of the wider energy networks” as mentioned in the EPN definition.

The intermittent nature of the availability of renewable energy will create increasing challenges when the share of renewable production increases. These challenges will appear as excessive production and the need of curtailment as well as challenges in the security and stability of the (mainly electricity) grid. This can be addressed by demand response and storage solutions. While several proven and cost efficient solutions for short-term energy storage exist both for
heat and electricity, there is still a lack of cost-efficient solutions for seasonal storage. In the Northern climate the seasonal imbalance of e.g. solar energy availability and energy need is even more evident than in the Southern climate. This seasonal imbalance also creates challenges for the use of e.g. Battery Energy Storage Systems (BESS), as the batteries are often quite sensitive to the state-of-charge and typically in a Northern climate PV plays an important production role during summer, when BESS would be mostly full, while during winter they would be mostly empty (a practical example from Slovenia is presented by Jerele et al. 2020). It is worth noting that improved energy efficiency and demand response are often more cost efficient solutions than storage, as there are always losses in storing energy (Pucker et al. 2020).

Age of the building & timing of actions towards energy positivity

Most of the current approaches, including planning and assessment tools, seem to focus on new developments (according to analyses by Ma et al. 2012, Cetiner and Edis 2014, Lee et al. 2015). Additionally, the current examples of EPN or similar solutions are mainly new developments (JPI Urban Europe 2020). The parallel existence of new and old buildings in an area affects the measures that can be taken, and the timing of those measures. In new buildings, the freedom of choice for the actions that can be taken is much wider than for existing buildings. For existing buildings there might be limitations due to the historical value of the building, but also from the structural point of view. In existing buildings, also previous renovations affect the possibilities to carry out new actions, as well as the economic timing of the new actions. Therefore, when designing an EPN, the designer needs to plan the order of the actions regarding new energy solutions and energy efficiency improvements. If the energy system is upgraded first and the energy efficiency is improved then, the new energy system may be oversized for the new needs (e.g. in case of heat pumps).

The transfer towards energy positivity takes time. There should be tools that support the planning of the timing of the different investments. Rasmussen (2014) made a framework for assessing the non-energy benefits of energy efficiency improvement from investment point of view. In that framework the benefits were categorised according to the quantifiability of the benefit and the time the benefit would be likely to occur after the action has been taken. If the decisions are only taken based on easily quantifiable benefits and for the short term, some important benefits may be overlooked. One example is the improvement of labour productivity due to the improved working environment, which is mentioned as a typical benefit that is hard to quantify, but the benefits of which appear typically soon after the refurbishment (Rasmussen 2014).

From the solutions developed during the research presented in this dissertation, the AtLas tool will support the assessment of the most suitable actions and their timing on neighbourhood level, while the E-PASS tool will help in choosing the optimal actions for the renovation of an individual building.
5.1.3 Physical scale: building or neighbourhood

When aiming to achieve energy positivity, it is important to look at the most potential places for harvesting the renewable energy, and the possibilities for using the energy inside the neighbourhood. For example, often the district-scale solutions for heating are more efficient than building-scale solutions (EPA 2022). Additionally, the possibilities to match the demand and supply are usually better on a larger scale (Li et al. 2009).

Some decisions and actions can be made on the building scale and some on the neighbourhood scale, but they affect each other strongly in some cases. For example, the heating system of the building affects the choices available for district heating: if the heating system in the buildings needs high temperatures, this limits the choices of heating supply for the district heating network (or then the building needs additional heating to upgrade the heat). In many cases, the most efficient placement for renewable energy installations can be found on the neighbourhood level rather than on the building level.

The AtLas tool will support the assessment of most suitable placing of the renewable energy installations (neighbourhood or building level), and the activator business model will help in realizing these on the district level.

5.2 Points in need for further attention

In order to promote energy positive neighbourhoods, the relevant benefits for the key stakeholders need to be presented in an understandable way. There is a good line of research showing several benefits of energy efficiency (compiled well in IEA, 2014), but in a recent study it was underlined that it is important to choose the most important benefits from each stakeholder’s point of view, in order to keep the message convincing (Fawcett and Killip, 2016). According to the studies described by Fawcett and Killip, "multiple benefits arguments are most persuasive when linked to the values and priorities of decision-makers and politicians, most of whom do not value energy efficiency as a benefit in itself".

The KPIs for an EPN were one of the things developed in the work described in this dissertation (Publication 1). These indicators refer mainly to the energy balance and share of renewables on the site, while other, existing indicators are suggested for evaluating the energy efficiency and environmental impacts. Although the economic aspect is not mentioned in the EPN definition as such, it is naturally also important that economic sustainability is taken into account when planning an EPN. Therefore, it is recommended that the EPN indicators are supported with economic indicators, such as Life Cycle Costs (for new developments) or the Levelised Cost of Energy (LCOE). In the AtLas calculation tool, the costs and CO\textsubscript{2} emissions were also included. The cost efficiency depends on the stakeholder: it is different for the building owner than e.g. the DSO. Already in the Author’s Master’s Thesis (Leskinen, 1999) it was concluded that at that time, solar thermal collectors would have been a more cost efficient solution from the point of view of the end consumer (district heating customer), as in their heating bill they also pay in some way for the heating system of the

85
heat provider, in addition to the fuel cost, while in the heating company’s balance the solar heat only reduced the need for fuel.

Additionally, the balancing indicators could be developed further, as the value of the energy is not the same at all times, and for all stakeholders—demonstrating again the importance of taking into account the three dimensions in the performance analysis. With the intermittent nature of renewable energy, there are times when there is more renewable energy available than there is demand for it. At these moments the energy has less value than on those moments when there is a shortage of energy. Just taking into account the relation of demand and supply in the area with the mismatch indicators developed in Publication 1 does not reveal this imbalance. A new indicator could be developed, which takes into account e.g. the market price of energy through a factor.

A more challenging work is to develop indicators for the functionality, health or user friendliness of the neighbourhood, which are mentioned as the aims of the EPN. The health and user friendliness could include indicators for the Indoor Environment Quality (IEQ), regarding the thermal, visual and acoustic comfort and indoor air quality.

New interests emerging in relation to the social dimension are the aspects of energy citizenship and social justice. An energy positive neighbourhood could also facilitate the active participation of citizens in the energy system, as owners and operators of the renewable energy installations, or active participants in the balancing of the demand and supply. Ideally, the social justice would be ensured already by the design, so that the equality of citizens would be guaranteed irrespective of their financial situation.

One aspect that has gained too little attention in the current discussion is the quality of energy, expressed by the exergy content. Full electrification is nowadays being promoted as an excellent solution for a fully renewable energy system. However, it cannot be considered a sustainable use of resources if only the high-quality content of the energy source is used. Although the final goal is a fully renewable world where all the energy can be provided with renewable sources via smart control of the system and storage solutions, this cannot be realized with limited choices of systems. Relying only on electricity will limit the choices of energy carriers and storage types, straining some natural resources more than a more distributed strategy. For example, in Finland, there is a lot of bioenergy available, for which the combined heat and power production would be the most efficient way of using the most exergy content of the energy source.

A good indicator for this would be the exergy analysis, which is already being developed by some research groups (see e.g. Kılıç 2017 and 2019, Jansen et al. 2019). Already the energy conversion efficiency reveals a lot of the efficient use of the source: using bioenergy only for electricity production yields efficiencies around 40-50% at maximum, while using a CHP plant gives around 80-90% efficiency (EPA 2022). With solar energy the efficiency of PV-cells is at maximum 14%, while solar collectors give maximum efficiencies of 90% or even more. The ideal situation would be to use the most suitable source for each situation and need. This of course puts pressure on the system design and may also limit the flexibility of the system for different situations.
This brings us to one of the indicators which has not been discussed much above: the resilience of the neighbourhood. The energy positiveness contributes to this requirement, but it would also be important to develop analysis methods and tools for the ability of the system to maintain functionality in different exceptional situations. For example, the indicators could include an indicator on how long (1 day? 2 days? 1 week?) the neighbourhood could survive without connection to the external grid. Resilience is gaining more emphasis due to the increased occurrence of extreme weather phenomena that will take place in connection to climate change.

The robustness of the system is one point of concern in resilience: How much maintenance is needed? Are the spare parts easily available? Does the maintenance require special knowledge? Are there ways to get around the broken part of the system? The robustness of the system and its components is also an economic and environmental aspect. This is underlined in remote areas: a malfunction of one tiny component (e.g. an electricity meter) may require a visit of two experts in two cars, meaning the use of resources (time and fuel) and production of CO$_2$ emissions (from the cars) if the system does not remotely reveal the reason for the loss of power. Another example is the reduced availability of some of the tested storage systems in the STORY project, where malfunctions in the management systems resulted in long down times of the battery energy storage systems (Garde et al. 2020). In a more renewable-based energy system, this would mean important losses of renewable energy, as its use could need to be curtailed if the storage is not available.

The changes in regulation and business environment could create challenges for a very rigid energy system. Instead, it would be recommendable to strive for a flexible solution, which would have enough resilience to adapt to the changes in the environment. On the other hand, this could lead to ignoring some of the solutions just in case. To avoid this, different scenarios should be assessed, and contingency plans prepared already in the design phase.

The time frame dimension is also highly relevant for the economic considerations (Pombo, Rivela and Neila 2016), or the “profit” aspect of sustainability. If only the investment costs are compared, it gives a distorted image of the cost effects in the long run. However, trying to estimate the long term effects of the different choices will also create a lot of uncertainties. One interesting solution to this is suggested by Tuominen and Seppänen (2017), presenting a method to estimate the effects of risk reduction related to energy cost development.

The research in Publications 3 and 4 was based on the contributions from the Finnish stakeholders and situation, so the conclusions are limited to the Finnish situation. Applying the tools to other countries would need further analysis of the local situation. E-PASS can be localised by providing the local information with Excel templates. The survey results indicate that more renovation options should be included in E-PASS tool even for the Finnish case.

---

2 This is a real-world example that actually took place in summer 2021 on the summer cottage of the Author.
3 An H2020 project Coordinated by the Author.
AtLas tool was developed for Finnish and French environments, and the applicability to other countries would require collection of data about the local building stock, renewable options as well as information of costs and CO₂ emissions of locally used energy sources.
6. Conclusions and recommendations

This chapter presents the final conclusions of the work, presenting the key aspects to consider in order to achieve a wide application of EPNs. The initial analysis of the literature suggested that stakeholders are the key for promoting EPNs (e.g. JPI Urban Europe 2020), and that it is also important to look from the different perspectives of the physical scale (building and neighbourhood level), taking into account the time frame-related aspects. The main stakeholder, time frame and physical scale dimensions in the Publications are visualised in Figure 16.

Figure 16. The life-cycle phases and physical scale dimensions (building/neighbourhood) with the main stakeholders of the Publications contributing to this dissertation.

It is worth noting that the views and needs of the different stakeholders formed the starting point in all four Publications, on different physical scales:

- Publication 1 describes the research and development realised during the IDEAS project, which aimed to “illustrate how communities, public authorities and utility companies across the EU can be engaged in the development and operation of energy positive neighbourhoods and the economic and environmental benefits of doing so” (Crosbie and Dawood 2016).
- Publication 2 presents and estimates the capabilities of a new tool for the assessment of thermal comfort conditions in the Nordic climate, aiming at achieving the best potential thermal conditions, focusing on the well-being of the building user, the profitability for the building owner and the support for the building designer and manager.
• Publication 3 looks at the existing tools that could be used by a renovation company to find the optimal renovation actions, and suggests a new tool that takes into account both energy and cost efficiency, and facilitates the presentation of the options for the building owner.
• Publication 4 seeks a deep understanding of the drivers of and barriers to district renovation from the point of view of the different stakeholders and suggests a business model that could take into account the most important of these.

6.1.1 Main findings and conclusions

When trying to promote EPNs, it is important to communicate to the stakeholders the most relevant messages in the most relevant phases of the life-cycle. However, first it is important that all stakeholders share a common vision and understanding of what an EPN is and what the aims are, and therefore a definition is essential in this communication, to facilitate an efficient and fruitful cooperation. The neighbourhood-level solutions require much more co-operation and coordination than building-level solutions.

It can be concluded that easily understandable information and easy-to-use tools are essential for promoting of EPNs. It is important to ensure that the EPN fulfils the needs of the users and show that this is achieved with minimised energy use and maximised contribution from renewable energy sources, with reasonable cost effects.

The literature reviews in the Publications revealed a lack of tools for calculating and visualising the most relevant information for different purposes. The needs for the information and tools were determined through stakeholder interviews and workshops. The needs for the tools are different at different life-cycle stages and depending on the stakeholder. Some of the required tools were developed in connection with the work for the dissertation and one existing tool was tested for Northern conditions.

At the beginning of the life cycle, the most influential stakeholders are the city planners and decision makers, who set the scene and aims for the neighbourhood in the city context. On the other hand, also the local energy company may have an important influence on the possibilities of the EPN to interact with the surrounding energy grid(s). Viewing the situation on the neighbourhood scale gives more flexibility in terms of placing the RES technologies, as far as the regulations allow this. These stakeholders need tools to compare different scenarios regarding their effects on the energy and environment, both for the new areas, and areas where substantial changes are planned. They also need to communicate this to other stakeholders to find common agreement on the best ways forward. The AtLas tool is one example which facilitates the comparison and presentation of scenarios to other stakeholders (such as citizens, construction companies, decision makers or regulators). According to the stakeholder feedback, the KPIs included in the AtLas tool helped to contextualize the benefits of the EPNs, and the EPN label supported the visualization.

Next, the building (and neighbourhood) needs to be planned to support the activities of the building user. Here, the designer has a great influence, but needs
Conclusions and recommendations

to comply with the requirements from the building owner, who is by default interested in the building users’ interests, and most often the economic viability. In this context the building scale is more important from the building user’s point of view, but can also contribute to society through improved productivity (e.g. Rasmussen 2014, Wu et al. 2012, Lan et al. 2012, Kosonen and Tan 2004, Seppänen et al. 2004, Roelofsen 2002). Today, also commercial owners are often interested of the building’s value to the user and energy efficiency. The HBEC method facilitates the designer to combine these two aspects by finding the optimal indoor conditions for thermal comfort, thus limiting the energy use to the minimum necessary. According to the findings in Publication 2, this method seems to provide more accurate predictions of the combination of temperatures than traditional methods.

The HBEC tool will also facilitate the assessment of the building’s thermal quality during the operational phase, and the effects of potential renovation actions on the building scale. The Publications contributing to this dissertation examined the operational phase mainly in relation to major changes such as renovation, new city plans for infill building, or new RES facilities planned on an existing area.

For the renovation phase, the main stakeholders are the building owners and renovation companies in the case of individual buildings. As revealed by the studies in Publication 3, the challenges that the SME companies have faced are that most of the current tools that are publicly available require very detailed data on the building, and they are often not able to assess the combined effects of several renovation actions. The simultaneous assessment of economic and environmental effects was also a feature required by the stakeholders. The easy-to-use E-PASS tool facilitates quick assessments with limited input data, but the user can also feed in more detailed data, if available. E-PASS tool helps the renovation company to show the environmental and cost effects of the different options to the building owners.

When aiming for district scale refurbishment, the group of involved stakeholders grows remarkably. According to the analysis carried out in Publication 4, this was also regarded as the underlying reason for many of the barriers noted by the different stakeholders, e.g. that the stakeholders have different ideas of the aims and the ways to reach them. The activator business model is one way to mitigate this situation by supporting co-operation between different actors.

6.1.2 Recommendations

Some recommended steps on the road towards wide application of EPNs can also be suggested based on the research, combining the information collected from background material, the stakeholder input from the workshops and interviews, and the tests with the new tools (with the main stakeholders to take action) (Figure 17):

1) Reduce the energy need as a first step and pick the low hanging fruits first, which will also increase funding opportunities for the later steps. At the same time, make sure that the service level of the building is kept at a good
Conclusions and recommendations

level. (Stakeholders to take action: city planners, service providers, designers, building owners and users.)

2) Look around: is the renewable source available at better cost efficiency somewhere in the neighbourhood rather than on the individual building or lot? (Stakeholders to take action: planners, building owners and users, aggregator, construction companies, energy companies.)

3) Take into account the needs of different stakeholders. (Stakeholders to take action: planners, building owners, aggregator, construction companies, energy companies.)

4) In the planning, take into account the timing of the actions to achieve the optimal result. (Stakeholders to take action: city planners, construction companies, planners.)

5) Choose the analysis tool according to the life cycle stage and the data availability. (Stakeholders to take action: planners, building owners, aggregator, construction companies, energy companies.)

6) Communicate the benefits clearly for different stakeholders. Choose the most relevant ones. (Stakeholders to take action: planners, building owners, aggregator, construction companies, energy companies.)

As noted above, these steps are to be taken by different stakeholders, which underlines the importance of collaboration. The goals towards a fully renewable world or decarbonisation can only be met through teamwork and balancing the needs of different stakeholders through discussions and negotiations. The tools and indicators developed in connection with this dissertation will support this process, providing a basis for the decisions and discussions.

Figure 17. Steps towards EPNs.

The dissertation suggests several ways on how the views from different stakeholder, time frame and physical scale perspectives could be taken into account to promote energy positive neighbourhoods, but there are still some challenges
to overcome on the road to feasible energy positive neighbourhoods. Further work is suggested on the additional economic and social indicators, including the resilience and robustness of the neighbourhood. The HBEC tool could be further developed in a more user-friendly format, with a basic dataset included in the tool. The activator business model developed in connection with this dissertation was so far only suggesting the content of the main elements and has to be further developed for the needs of actors that will take the lead for it.

6.1.3 Potential impacts

According to the IPCC Sixth Assessment Report, it will still be possible to limit the global warming to 1.5°C in the long term, going only slightly over 1.5°C in the mid-term (IPCC 2021). This entails strict actions for reducing CO$_2$ emissions. As the building sector is one of the main contributors of CO$_2$ emissions, it also has good opportunities for reducing them. In its suggestion for a global pathway to net-zero CO$_2$ emissions in 2050, the IEA confirmed that will be possible to reduce the emissions enough to meet the 1.5°C limit required in the IPCC report, with the building sector leading the way by reaching net-zero emissions by 2050 (IEA 2021). This requires that over 85% of the building stock should be zero-carbon-ready and should consume only 20% compared to current needs for heating and cooling. EPNs would facilitate this by also providing the surrounding areas with renewable energy.

Over half of the world’s population currently lives in urban areas, and in developed countries the share is almost 80% (UNCTAD 2022). The urbanization rate is still growing, although at a slower pace in developed economies. However, with the high number of the world population and the large amount of existing building areas, even a small increase means an important increase in the energy demand, unless the aim is zero or positive energy balance. Taking only Finland as an example, it is estimated that the volume of building stock (residential and service buildings) will increase by 150 Milj.m$^3$ or 23% from 2022 to 2050 (Mattinen and Heljo 2016). With current trends in energy efficiency and energy source choices, the amount of purchased energy would however remain at about the same level, with only a minor decrease by 2050. If we assume a simplified energy positive scenario, in which new neighbourhoods would contribute to providing energy to other buildings instead of using energy, this could mean important reductions in the purchased energy for the building stock, and an even more important reduction in CO$_2$ emissions, assuming that with their positive energy contribution they would replace fossil fuels from the grid.

The discussion on the different definitions of EPNs and similar concepts will help in clarifying the goals, and it has really taken off during the writing of this dissertation. The Author is participating in this discussion through ongoing projects, and through close collaboration with the IEA EBC Annex 83 team,\(^4\) con-

\(^4\) With close VTT colleagues leading the work of Annex 83, and previous work-related connections to other international colleagues in the core team.
Conclusions and recommendations

Contributing with the definition prepared as part of the work described in this dissertation. The wide group of stakeholders included in the preparation of the EPN definition and KPIs will help to ensure that the new definitions represent the views of several types of stakeholders. Once there is a good common understanding of the concept, it will be easier to reach the goals and start actively promoting EPNs.
References


References


Dijing and Questback. (2015). Tool for Online Surveys. Available at: https://www.questback.com/


Hradil P. and Ala-Juusela M. (2014). *Prototype of the urban planning decision support tool.* Deliverable 4.2 of IDEAS project.


References


References


References


Energy Positive Neighbourhoods (EPNs) offer a solution for reducing the effects of the built environment on climate change, by increasing the energy efficiency of buildings and integrating renewable energy facilities closer to the points where energy is needed. EPNs also support surrounding areas on their way toward climate neutrality. However, EPNs are not yet widely in use. The Dissertation identifies the means to promote EPNs.

Based on the findings from the literature review and cooperation with stakeholders, a set of key performance indicators, calculation tools and a business model were developed, engaging the key stakeholders in the process. A clear definition of EPN was missing, and that was formulated first. The feedback from the stakeholders confirmed several benefits of the solutions and showed that easily understandable information and easy-to-use tools are essential for promoting EPNs, facilitating fruitful cooperation needed for that.