THESIS FOR THE DEGREE OF LICENTIATE OF ENGINEERING

On the Uptake of Energy Efficiency Technologies in European Residential Buildings

Om Upptag av Energieffektivitetsteknologier i Europeiska Bostadshus.

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ABSTRACT

Climate change is a pressing global concern. Without action to reduce greenhouse gas (GHG) emissions, global warming is likely to exceed 2°C above pre-industrialised levels. In December 2015, during the United Nations Climate Change Conference, COP 21, the European Union (EU) and its 28 Member States signed a binding target to reduce GHG emissions by 40% by 2030.

Residential buildings constitute approximately 75% of the European building stock, accounting for circa 30% of the EU´s overall energy demand and emissions. They also represent one of the biggest sources of energy saving potential, holding a crucial role in achieving EU carbon targets. Despite technology options to decrease residential building's energy demand to nZEB standards are readily available and, in many cases, economically viable, they are not being deployed at the required rate to achieve greenhouse gas emission reduction targets. The divergence between the technoeconomic potential and actual market behaviour, so-called 'energy efficiency gap', suggests that, in the European housing context, the economic viability of energy efficiency technologies - specifically the cost of potential energy savings (commonly considered as the only financial benefit) - is not sufficiently acknowledged or appealing to motivate the necessary investments. In order to bridge the energy efficiency gap and favour the low-carbon transformation of residential buildings in Europe, additional national policy measures need to be developed. Policy instruments can be classified into push- (e.g. regulatory and control instruments), and pull-mechanisms, (e.g. economic or fiscal incentives and support tools for voluntary action). To ensure their effectiveness, these instruments should be designed based on solid comprehension of the current national market conditions and dynamics. Hence addressing the market barriers existing in the respective countries in the uptake of energy efficiency technology measures.

Various sources point out at the lack of scientific knowledge in this arena. In this light, the goal of this licentiate thesis is to gather information to contribute to the scientific expertise and support the reduction of the energy efficiency gap. The first part of the work is, therefore, dedicated to better understand the intellectual base in the uptake energy efficiency technology in the European residential building stock and settle a specific field of study for the Ph.D. project. This is done via a bibliometric analysis. 954 scientific articles and their references are analysed, a visual knowledge structure of the field is modelled, and key papers are identified. Results from this process show that this field has gained considerable momentum in the past decade but still lacks a comprehensive pan-European cross-country understanding.

Based on the knowledge gaps and research needs defined by the literature review, complimented with discussion with market experts, research questions are formulated. These questions demand for empirical evidence in the uptake of energy efficiency measures in residential buildings in Europe. To collect this testimony and address the research questions, an online survey is designed and operationalized. The methodology aims for country-scale information and cross-country comparability of the results. Given the complex and fragmented nature of the residential building market and different phases in the building's life cycle, a stratified sample approach and survey intelligence are developed. The stratified sample consists of three stratification axes, based on the three main elements or agents of the building projects. These are stakeholder, building typology and project type.

The survey has been distributed in Germany, United Kingdom, France, Spain, Italy, the Netherlands and Poland. The status of the survey distribution in each country as of April 2019 is presented in this Licentiate.

Finally, conclusions obtained from the development of the overall methodology are described, as well as selected research contributions. This is followed by the description of future work within the scope of the Ph.D. project and connection to other research fields.

Keywords: *residential building stock, energy efficiency, technology, measures, building stock modelling, multiple impacts, Europe*.

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ACRONYMS AND NOMENCLATURE

In alphabetical order:

BS – Building stock

BSM – Building-stock modelling

BSMs – Building stock models

BSO – Building Stock Observatory

CO_2 – Carbon dioxide

EC – European Commission

EE – Energy efficiency

EED – Energy Efficiency Directive (2012/27/EU)

EEM – Energy efficiency measures

EET – Energy efficiency technologies

EETM – Energy efficiency technology measures

EPBD – Energy Performance of Buildings Directive (2010/30/EU, revised 2018/844/EU)

EPC - Energy performance certificates

EU – European Union

GHG – Greenhouse gas

INDC – Intended Nationally Determined Contributions

LMD – Large multi-dwelling houses

MDB – Multi-dwelling buildings

nZEB – Nearly zero-energy in buildings

RH – Row houses

RQ – Research question

SDB – Single-dwelling buildings

SDH – Semi-detached houses

SFH – Single-family houses

SMH – Small multi-dwelling

SOTA – State-of-the-art

TH – Terraced houses

LIST OF PUBLICATIONS

This licentiate thesis is based on the following journal and conference papers, referred to as papers I-V:

I. C. Camarasa, C. Nägeli, C. Salzer, S. Saraf, Y. Ostermeyer (2015), "Specific Barriers to Massive Scale Energetic Refurbishment for Sample Markets in Europe", *Conference Proceedings. 8th Conference of the International Forum on Urbanism (IFoU).*

II. C. Camarasa, C. Nägeli, M. Klippel, Y. Ostermeyer, S. Botzler (2018), "Uptake of energy efficiency technologies in European residential buildings: A bibliometric analysis", *Energy and Buildings*. Paper accepted.

III. C. Camarasa, C. Nägeli, M. Jakob, Y. Ostermeyer, S. J. von Geibler, K. Bienge, L. Hannes (2018), "Empirical evidence in the uptake of energy efficiency technologies in the European residential building stock.", *Building Research & Information*. Paper submitted.

IV. C. Nägeli, C. Camarasa, M. Jakob, G. Catenazzi, Y. Ostermeyer (2018), "Synthetic building stocks as a way to assess the energy demand and greenhouse gas emissions of national building stocks", *Energy and Buildings*. Vol. 173 pp. 443–460.

V. M. Österbring, C. Camarasa, C. Nägeli (2018), "Prioritizing deep renovation for housing portfolios", *Energy and Buildings*. Paper submitted.

Papers I-III constitute the backbone of the Licentiate storyline. Papers IV and V complement the storyline, completing its understanding.

Author´s contribution

The scope of the contribution for each paper is listed below:

Papers I-III: The author of this thesis is responsible for initiating this paper, planning and conducting the research design and performing the analysis. The research design and writing of the paper was done in close collaboration with the co-authors.

Papers IV: The author of this thesis supported the corresponding author in the writing of the paper.

Papers V: The author of this thesis supported the corresponding author in the development of the research design and writing of the paper.

CONTENTS

1. INTRODUCTION

1.1. Motivation

In the past two centuries there has been an increase in anthropogenic greenhouse gas (GHG) producing actions, such as industry, agriculture and transportation [1]. In 2014, the Intergovernmental Panel on Climate Change (IPCC) reported that scientists were more than 95% certain that global warming is mostly being caused by increasing concentrations of greenhouse gases (GHG) and other human activities [2]. Without action to reduce anthropogenic greenhouse gas (GHG) emissions, global warming is likely to exceed 2°C above pre-industrialised levels [3]. This increase in temperature can have a huge impact on the world's landscape and sea levels, deriving in extreme heat waves and droughts, among other backlashes.

The European Union (EU) acknowledges global warming and is acting accordingly. At the United Nations Climate Conference (COP21) held in December 2015 in Paris, the EU and its 28 Member States were one of the first countries to submit its INDC[*], aiming at reducing GHG emissions by 40%[†] by 2030, in line with the objective of impeding the increase of global warming above 2°C. This binding target was set in accordance with "Lima call for Climate Action", approved by the EU Environment Council and submitted to the UNFCCC Secretariat on 6 March 2015 [4–6].

In Europe, buildings are responsible for approximately 40% of energy consumption and 36% $CO_{2eq.}$ emissions. Residential buildings constitute approximately 75% of the European building stock, accounting for circa 30% of the EU´s overall energy demand and emissions. Furthermore, about 35% of the residential stock is over 50 years old and more than 70% is considered to be energy inefficient [7]. Given this situation, the EU has appointed two main decrees: (1) the Energy Efficiency Directive (EED) [8], and (2) the Energy Performance of Buildings Directive (EPBD) [9]. Among its requirements, the revised EPBD demands all buildings -including residential- to be nearly zero-energy by 2050 [10]. According to Article 2(2) of the EPBD, nZEB means *"a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby"*.

As an EU directive, the EPBD needs to be transposed by each EU Member State into their national legislation, reflecting the comprehension of their own national, regional or local conditions [9]. This entails that Member States must prepare national plans for increasing

[*] Intended Nationally Determined Contributions (INDCs).
[†] Relative to 1990 levels.

the number of nZEBs, which shall include a detailed application in practice of the definition of nZEB, intermediate targets for improving the energy performance of buildings (differentiated according to the building typology) and information on the policies and financial or other measures. According to [12], currently more than a half of the Member States have already implemented a definition in some form and some are under approval. Several countries (such as Belgium, Denmark, France, the Netherlands) provided a definition that comprises both a numerical target for primary energy use (or end energy/ useful energy demand) and are considering the share of renewables in a quantitative or qualitative way. Only a few Member States have a definition under development.

Technology options to decrease building's energy demand to nZEB standards are readily available and, in many cases, economically viable [3,13,14]. The promising performance and economic potential of these technologies has also been acknowledged in residential buildings at an EU level [15–17]. A study developed by [17] showed that in various cases, and depending on the exact national nearly zero-energy building definition, nZEBs can be located beyond cost optimality. However, annual construction rates in the residential sector are still around 1%. Furthermore, most EU Member States suffered a decrease in the rate of new build in the recent years [18], echoing the impact of the financial crisis in the construction sector as well as the EU focus in refurbishment. In terms of retrofit activities, an average of 0.4-1.2% of the EU residential building stock is renovated each year [7], out of which less than 5% is reaching nZEB standards [12] –not even a third of what would be needed to reach the aforementioned EU's carbon ambitions [19]. This implies that, despite their availability and economic viability, energy efficient technologies are not being deployed at the required rate to meet EU's greenhouse gas emission reduction targets. This divergence between the technoeconomic potential and actual market behaviour has been coined as the 'energy efficiency gap' or 'energy paradox' and implies that non-technical market hurdles are preventing the large-scale diffusion of these solutions [20]. The 'energy efficiency gap' also suggests that, in the European housing context, the economic viability of energy efficiency technologies -specifically the cost of potential energy savings (commonly considered being the only financial benefit)- is not sufficiently acknowledged or appealing to motivate the necessary investments [21].

In order to bridge the energy efficiency gap and favour the low-carbon transformation of residential buildings in Europe, national policy measures need to be developed. Policy instruments can be classified into push- (e.g. regulatory and control instruments), and pull-mechanisms, (e.g. economic or fiscal incentives and support tools for voluntary action) [22]. As seen in [14] (Annex 1), in order to ensure their effectiveness, these instruments should be designed addressing the market barriers and drivers existing in the respective countries. This requires a solid comprehension of the current national market conditions and dynamics, particularly in relation to the uptake of EETM [23]. However, according to various sources [24,25], there is a lack of scientific knowledge in this area. In light of this, the motivation of this licentiate thesis is to further understand the scientific ground in terms of market conditions and dynamics influencing the uptake of EET in the European residential building stock and, how this differs for different EU Members States and building typologies. Based on this understanding, the identification of knowledge niches and formulation of research questions within the aforementioned area will be addressed within the scope of this Ph.D. project, to ultimately, contribute to the scientific front in this field.

1.2. Structure of the thesis

The thesis is structured into the following chapters:

In chapter 2, the scientific state of knowledge is characterized and narrowed down to specific research topics. The goal is to better understand the scientific base in the uptake of energy efficiency technology in the European residential building stock and define a specific field of study for the Ph.D. project. This chapter concludes with a summary of the current state of scientific understanding and the identification of specific knowledge gaps.

Based on the knowledge gaps identified in chapter 2, chapter 3 formulates the research questions to be answered during the course this Ph.D. project. It also outlines the research scope and respective limitations.

Chapter 4 is dedicated to the development of a methodology to gather empirical evidence to answer to the research questions. To this end, an online survey is developed. The survey design and operationalization are described in detail.

In chapter 5, the status of the distribution of the survey as of April 2019 is described as key result of the research work of the last year (2018).

Chapter 6 reports the conclusions obtained from the development and distribution of the survey in relation to the research questions.

Finally, chapter 7 describes the future research within the framework of the Ph.D. project. This includes an overview of the methodologies that are planned to be applied on the data analysis to answer to the research questions, as well as connection to other research fields.

The Licentiate comprises the following annexes:

- Annex 1: Uptake of energy efficiency technologies in European residential buildings: A bibliometric analysis
- Annex 2: Specific Barriers to Massive Scale Energetic Refurbishment for Sample Markets in Europe
- Annex 3: BMB project description
- Annex 4: Survey Methodology.
- Annex 5: Survey Questionnaire

2. STATE-OF-THE-ART IN THE UPTAKE OF ENERGY EFFICIENCY TECHNOLOGIES

2.1. Objective

Based on the motivation, the first step of the research (and goal of this chapter) is to define the state-of-the-art (SOTA) in relation to the uptake of energy efficiency technology measures (EETM) in residential building projects in Europe. The objective is three-fold:

- Understand the frontier of scientific knowledge in the field
- Define knowledge networks, trends and niches
- Identify research gaps and needs, to be used as a basis for further work within scope of the Ph.D. project.

This information is obtained through a bibliometric analysis, a well-established research method for analysis of written publications such as books or journal articles. The development and results from this process have been described in depth in the journal paper II "Uptake of energy efficiency technologies in European residential buildings: A bibliometric analysis". The complete paper can be accessed in Annex 1 of the Licentiate.

2.2. Research Method

2.2.1. Systematic literature review through bibliometric analysis

The main difference between inductive and deductive research approaches is that while a deductive approach aims at testing a theory, inductive research is concerned about the generation of new theory emerging from the data [26]. Inductive research, also known as inductive reasoning, 'initiates with observations of previously researched phenomena and then theories are formulated as a result of observations' [27]. On the other hand, deductive research approaches typically start with a theory-driven hypothesis which guides the data collection and analysis [28]. As the goal of this chapter is to study and build upon the intellectual base in the field of technology diffusion, deductive research is considered as the most suitable approach.

Deductive research consists of four main steps: (1) 'Preliminary theory study', (2) 'Formulating hypotheses', (3) 'Observation of existing knowledge', and finally, (4) 'testing the hypotheses'. In this chapter, the step 3 ('observation of the existing knowledge') is performed through a systematic literature review. This means a study with a clear stated purpose, question, defined search approach, and exclusion criteria producing a characterization of articles. Systematic literature reviews are based on a scientific, replicable and transparent protocol with the aim of minimizing human error and bias in the synthesis, and outlining of the analysis [29,30]. Due to this minimization of the human error and bias, systematic literature review has been identified as a suitable approach for the analysis. According to [31], the main steps in a systematic literature review are: (i) identification of articles through the database, (ii) data selection, after the screening for eligibility and, (iii) data analysis and conclusions. To further reduce the bias in the selection and mapping of the article titles, this systematic literature review is conducted through a bibliometric analysis. As stated by [32], bibliometric analysis is a powerful quantitative tool to explore knowledge networks based on published literature. It has been widely used for studying the structure and development of various research fields [33], including energy and climate change [32]. The method includes statistical analysis of published articles and citations to measure their impact [34]. This type of analysis was found to be the most suitable approach for the scrutiny of the data, as it enables us to perform an entire quantitative assessment of knowledge structures and research trends within a field without having to select or dismiss any title for the selection and mapping or representation. Hence, reducing potential bias in the analysis process. Figure 1.1 visualizes the main steps in this process.

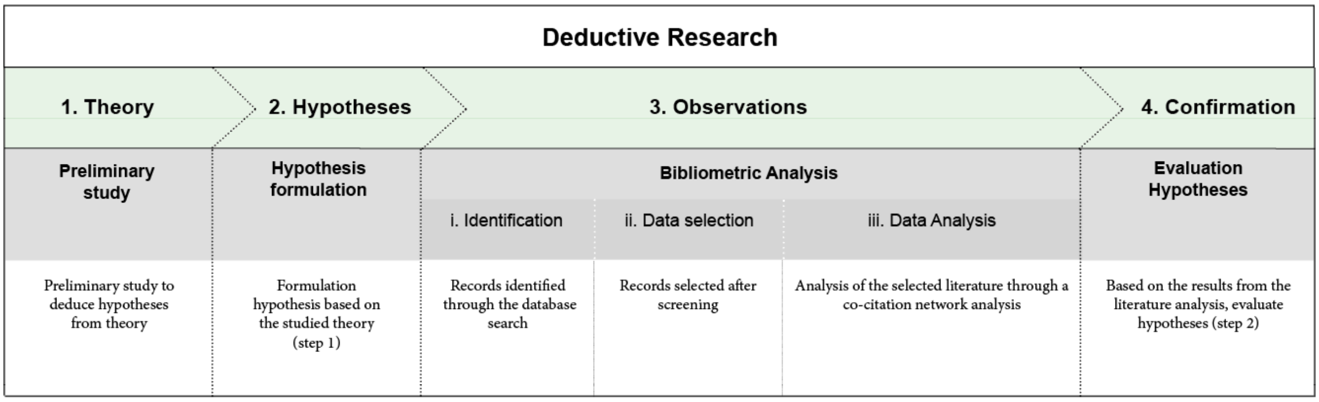


Figure 1.1 Steps in the research method.

In summary, by means of a bibliometric analysis, this chapter provides an image of the research network structure in the field of EET uptake in residential buildings in Europe. This method helps to describe the SOTA, as well as identify emerging trends and future investigation needs, potentially to be developed until the end of the Ph.D. project.

2.2.2. Citation Network Analysis

Bibliometric analysis is an approach to statistically analyse bodies of literature, such as books or articles [35]. Within bibliometric analysis, citation analysis is a very often used method. It is based on constructing a citation graph or network, representing the citations between documents. As described by [36], the system of networks provide additional information of the structures of the different themes within a topic. Furthermore, specific thematic clusters can be displayed by bringing together strongly interconnected authors. Within citation analysis, there are different approaches for analysing the network of citations in a group of publications [37]. They all construct a network that links documents, but the way of selecting and representing the edges and the nodes differs between the approaches [38,39]. The most common citation-based mapping approaches are described below:

- **Direct citation** provides straight references between cited documents. According to [40], 'Direct citation clusters documents more evenly across the time window and tends to cluster a larger number of documents than either bibliographic coupling or co-citation processes'. Following figure 1.2, paper A links C and D.
- **Bibliographic coupling** was introduced by M.M. Kessler in 1963. It occurs when two works reference a common third work in their bibliographies. This method is used to extrapolate how similar the subject matter of the two works is [41]. According to [40], bibliographic coupling is able to cluster very recent papers but clusters fewer of the very old papers. Following figure 1.2, paper A and B would be connected due to the common citation of D.
- **Co-citation analysis** gained recognition in the 1970s as a technique for "mapping" scientific literatures and finding latent semantic relationships among technical publications [40]. In 1973 H. Small concluded that co-citation analysis as a subject similarity indicator has two applications in information retrieval: firstly, to provide a list of new documents of highly co-cited articles based on the citation indexes and, secondly, to provide a list of more important "core" publications of earlier materials for a specific field, which may be a profile for that field and therefore, the basis of a selective dissemination of information (SDI) system. Following figure 1.2, references C and E would be linked through papers A and B, both citing D.

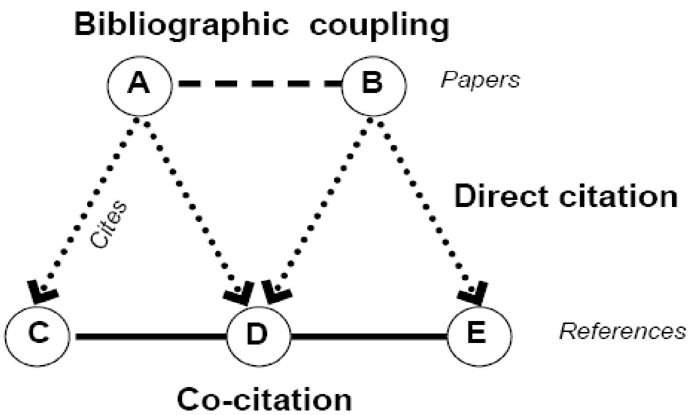


Figure 1.2: Schematic overview of different approaches to citation network analysis; adapted from [42].

There have been many attempts to compare the accuracies of these bibliographic mapping approaches [29]. One of the most relevant comparative studies was developed by [40], in which they concluded that the direct citation network is the least accurate approach of all to map the research front. They also stated that co-citation can be a useful tool for mapping the structure of science [53] and a valuable approach for identifying key authors in a field [54]. Given that the aim of this exercise is to provide as accurate as possible picture of the research front in the field, co-citation is identified as the most suitable approach for the analysis. The steps in the implementation of the co-citation analysis and results are presented hereafter.

2.3. Theory (preliminary study) and hypotheses

According to deductive research, the first step in the analysis is a preliminary study to gather a general comprehension of the research landscape in the field. To this end, white and grey literature is examined, including open databases, European Union legislative and policy documents, technical data sheets and specifications, reports from non-governmental organizations (NGOs) and research projects [28-39]. The insights gathered from the theory were complemented by discussions with experts in the field. Findings from this preliminary study led to formulate initial hypotheses.

Three relevant topics were identified within the literature in relation of the uptake of energy efficiency measures in residential buildings in Europe: (1) technological measures for energy efficiency, (2) decision-making processes behind the implementation of energy efficiency technologies and (3) multiple impacts of EETM. Findings within each topic, as well as respective hypotheses, are synthesised below.

2.3.1. Technological measures for energy efficiency

2.3.1.1. Empirical evidence

The building´s physical composition -along with user behaviour and local climate- is one of the most important factors affecting the building´s energy consumption [43]. Policy instruments, such as building codes and standards, aiming at effectively reducing dwelling´s energy needs, should be designed based on a thorough understanding of the building stock morphology and physical characteristics [51]. Furthermore, they should contemplate and target plausible EETM to reach NZEB standards. Hence, assembling knowledge on buildings´ physical properties and feasible EETM on a building stock level is an essential first step in the process towards decarbonising national building stocks.

In terms of energy efficiency building data, the EU Building Stock Observatory (EU BSO) is the EU´s main initiative generating and collecting data on buildings, as well as their energy efficiency status across European Member States [46]. Since 2014, the EU BSO gathers information on the building stock characteristics including energy consumption, technical systems, energy certification schemes, financing vehicles for building renovations, as well as other socio-economic aspects like energy poverty. The EU BSO offers a publicly available database, a data-mapper and various topic-specific factsheets. However, the database is currently fragmented and incomplete. Nearly 86% of all intended datapoints are presently missing. For several EU Members factual evidence of what technology measures are Implemented, at what rate and in which settings is completely unavailable for some or all typologies. In addition, there is no consistent methodology to obtain the existing datapoints which lead to questions on the consistency of the present information as well as the cross-country comparability of the available indicators.

2.3.1.2. Building stock modelling (BSM)

Building stock modelling (BSM) is an emerging field which aims to model the development of larger building stocks by a variety of methods. BSMs can be applied to describe pathways for reducing GHG emissions and energy demand by considering the conflicts and synergies between various strategies and technological solutions at a stock level [47–49]. With regards to the existing knowledge gap in the field of EETM- BSMs can also offer an alternative to bridge building information gaps at a stock level. For instance, paper IV from the appended papers demonstrates how generating a disaggregated synthetic building stock allows for a discrete representation of various building states. This enables a more realistic representation of past building stock alterations, such as refurbishment, compared with commonly used archetypes, and not relying on more extensive data sources and being able to accommodate a wide variation of data types[47].

BSMs can be applied at different scales: from transnational to national [50–53], and from urban [54,55] to district scale [56], using data from various levels of disaggregation. Most BSMs assess the stock using representative buildings in terms of archetype or sample buildings [57]. Archetype buildings are artificially constructed buildings considered to represent a certain class of buildings in the stock (typically segmented according to building type, age, and/or size) [58]. Sample buildings, however, are existing buildings taken to be representative of a given section of the stock [51]. Both archetype and sample building modelling make it easy to describe and analyse the building stock even with limited data availability, and furthermore, to create new scenarios relatively quickly [59,60]. However, they present restrictions in terms of the complexity that can be modelled. They are especially limited in the representation of heterogeneity in the building stock in terms of size, building state, occupancy, and user influence [38]. These modelling approaches are sensitive to assumptions from representative buildings, because any error in the description is extrapolated in the aggregation process [64]. Thus, the uncertainty of results can be substantial, although this is not often reflected or assessed in modelling practices [65].

There has been a rise in BSMs being developed for urban building stocks [65,66]. Typically, urban BSMs forego the use of representative buildings and use individual building microdata such as 3D city models, building registries, and/or energy performance certificate data, which is combined using GIS. However, these models rely on archetypical information to fill data gaps for many building characteristics (e.g., U -values and heating system efficiency) [67]. More recent approaches use probabilistic data to define uncertain parameters [29], based on which it is possible to calibrate and validate models on a building level using energy consumption data [61,68,69]. This is especially crucial to adequately represent previous energy efficiency measures in the stock, to not overestimate future reduction potentials [65]. However, missing micro-level data such as 3D building models, building physical components and systems makes it difficult to transfer advances in building stock modelling from an urban to a national scale.

❖ ***Hypothesis I: Technological measures for energy efficiency***

There is insufficient empirical evidence of ***what technological measures for energy efficiency are being implemented in residential buildings in Europe****, on a national and cross-national level.*

2.3.2. Decision-making behind the uptake of energy efficiency technologies

The ‘energy efficiency gap’ implies that non-technical barriers are hindering the uptake of energy efficiency technologies. In order to understand what the reasons behind these barriers are, a better understanding of behavioural aspects from demand-side´s perspective is needed. That is to say, studying what they do, why they do it, who are the influences and influencers behind these decisions –in relation to choosing an energy efficiency technology. Furthermore, push and pull mechanisms should be able to address these behavioural aspects and work in favour of them. Hence, to reduce the gap between techno-economic potential and actual market behaviour, policy measures need to address market-specific behavioural factors, namely drivers pushing positive reaction towards energy saving measures [70].

❖ ***Hypothesis II: Decisions behind energy efficiency technology measures***

There is insufficient empirical evidence of ***decisions behind the diffusion of energy efficiency technologies*** *in residential buildings in Europe, on a national and cross-national level.*

2.3.3. Multiple impacts of energy efficiency technology measures

Recent studies [71–74] identified ‘mistrust in the technologies’, ‘lack of information’ and ‘long payback times’, as the main barriers in the adoption of energy efficiency and low carbon technologies in the European housing sector. These findings, along with the existing ‘energy efficiency gap’ suggest that the cost of potential energy savings -typically considered as the only financial benefit- is not sufficiently acknowledged or appealing to motivate the needed amount of energy efficiency investments [21]. However, the adoption of energy efficiency technologies offers a wide range of potential positive side-effects, beyond the direct energy savings. Some of these are: asset value increase, energy poverty alleviation or local job generation[75–77]. When properly quantified (i.e. monetized), these side-effects can sometimes (even) surpass the costs of direct energy savings [75]. Several sources, including the European Commission, argue that the quantification of these side-effects could support the prioritization and adoption of energy efficiency technologies and should, therefore, be included in the decision-making frameworks, such as energy performance certificates (EPC) or policy decision tools [3,78,79]. Nevertheless, in practice, they are seldom contained [80].

❖ ***Hypothesis III: Multiple Impacts of energy efficiency technology measures***

There is insufficient empirical evidence of the ***positive side-effects of technological measures for energy efficiency in residential buildings in Europe, and how the***

monetization of these benefits could impact energy efficiency investment decisions*, on a national and cross-national level.*

2.4. Observations: A Bibliometric Analysis

The next step of the method is ‘Observations’. This step has been conducted through a bibliometric analysis. The process followed for the bibliometric analysis is described below:

2.4.1. Procedure

2.4.1.1. Identification: Document retrieval

Scopus and Web of Science (WOS) are the most widespread databases on specific scientific fields, thus frequently used for searching scientific literature [55]. Web of Science from Thomson Reuters (ISI) was the only citation database and publication which covers all domains of science for many years. However, Elsevier Science introduced the database Scopus in 2004, which rapidly became a suitable alternative [56]. As defined by [48], Scopus purportedly has listed some conference proceedings. Given that conference proceedings are out of scope in this study, the collection of publications was finally based on the literature source Web of Science Web of Science™ Core Collection.

The search terms used to obtain the final results of this study were: energy efficiency, residential building and technology diffusion. The selection of these terms was based on the findings from the preliminary study, as these appeared to be the most often mentioned keywords fitting our scope. The search was limited to the 28-member countries of the EU* and journal publications in the last ten years (2008-2018). Special attention was given in the screening and analysis process to studies published after the 30th of November 2016, date in which the European Commission proposed an update to the Energy Performance of Buildings Directive, to help promote the use of smart technologies in buildings [57]. English was selected as the language of the articles. Most cited articles were checked, and relevant studies were included in the review. Table 1.1 shows the synthesis of the search parameters in the paper retrieval.

Table 1.1 Search parameters for document retrieval.

Parameters	Selection
Search query	(((energy W/4 efficiency) OR (save W/4 energy) AND ((residential W/4 building) OR (dwelling OR home OR house)) AND (technology W/4 diffusion OR uptake)))
Document type	Articles
Time span	2008 - 2018
Citation Index	SCI-EXPANDED, SSCI and ESCI

* The United Kingdom was included in the study as for the time it was conducted the United Kingdom remained as a full member of the EU and rights and obligations continued to fully apply in and to the country.

Language	English
Countries	Austria, Belgium, Bulgaria, Croatia, Republic of Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden and the UK.

2.4.1.2. Data Collection

As a result of this paper recovery method, 1281 papers were identified, out of which 327 were dismissed after the screening, due to duplication or lack of relevance within the scope of this study. The full final paper set consisted of 954 peer-reviewed articles. To identify what papers could be useful to test each one of the hypotheses, a keyword search method was conducted, using the following terms:

- **Hypothesis I (Technological measures for energy efficiency):** *Technology, solution, measure, diffusion, uptake.*
- **Hypothesis II (Decision-making behind the uptake of energy efficiency technologies):** *drivers, barriers, motivations, decision, process*
- **Hypothesis III (Multiple impacts of the diffusion of energy efficiency technologies):** *impacts, benefits, effects, risks, adverse, detriments.*

The results from each of these searches generated a subset of papers, hereafter respectively referred to as subset 1 ‘Energy efficiency measures’ (hypothesis I), subset 2 ‘Decision-making’ (hypothesis II), and ‘subset 3 ‘Multiple impacts’ (hypothesis III). The screened papers comprising the full paper set were subsequently classified and analysed in terms of the country, year published and subset.

2.4.1.3. Data Analysis: Co-citation Analysis

The retrieved essays were then exported as a BibTeX format for further filter and analysis [58]. Following, the results were imported to RStudio for the co-citation analysis [59]. RStudio v.3.51 was utilized as a tool to map and visualize the data and networks from the three established topic areas. Within RStudio, the Bibliometrix package was applied, as it is a useful R-tool for comprehensive science mapping analysis [60,61]. As described by [62], this package also provides various functions for facilitating the understanding and interpretation of network patterns, including analysing the different architectures of a bibliographic collection through conceptual, intellectual and social structures. Biblioshiny, a user-friendly web-interface for Bibliometrix, was later utilized to customize the size of the labels and colour palette for better readability of the graphs. The distinct colours of the circles and lines correspond to the different clusters of papers. The clusters are generated by the Walktrap algorithm [63], which is very often used in bibliometrics with the aim of grouping or clustering and can effectively cover over 80% of the links in the network [64]. The results from the Walktrap algorithm were inspected and the clusters were labelled by extracting and studying the titles and abstracts of the papers.

There are various aspects that can be considered when analysing the results from a co-citation network. In this study, the focus is on whole-network features, by describing the overall density or tightness of the network; structural features, by naming main clusters (topics) within the network and, node-based features, by analysing characteristics from the nodes (papers), namely their centrality. In a network, three main conditions define its centrality: (i) degree, meaning the number of relationships from each node; (ii) closeness, as for the shortest paths among nodes; and (iii) betweenness; nodes that lie on the shortest path between other nodes. According to [65,66], this can discover relevant sources in scientific knowledge by looking for cited references that both (a) accumulate abundant citations (in bibliometric terminology, 'high in-degree'), and (b) are located in the centre of the network (in bibliometric terminology, 'high betweenness-centrality').

In this way, to characterize the intellectual structure of the full paper set, a co-citation network is developed. Through the analysis of the network, it was possible to find the most often cited papers and citation patterns that had taken place. Then select the papers with the highest 'betweenness-centrality' and 'in-degree' of each cluster, herein called 'key papers'. These papers were analysed in-depth to extract and synthesise the main findings. Based on these insights, the SOTA is characterized and the hypotheses are tested.

2.5. Results from the observations

2.5.1. Descriptive Analysis

Results from the descriptive analysis show that, out of the 954 papers that compose the full paper set, 312 titles focus on technology solutions for energy efficiency measures, 105 of them are related to decision-making behind these measures, and 445 papers address the multiple impacts of the diffusion of these technologies. Figure 2.1 shows the diagrammatic overview of the proportion of each subset entails from the overall paper set and the overlap among the topics. As can be depicted from figure 2.1, the main overlap takes place between subset 'Energy efficiency measures' and 'Multiple impacts'.

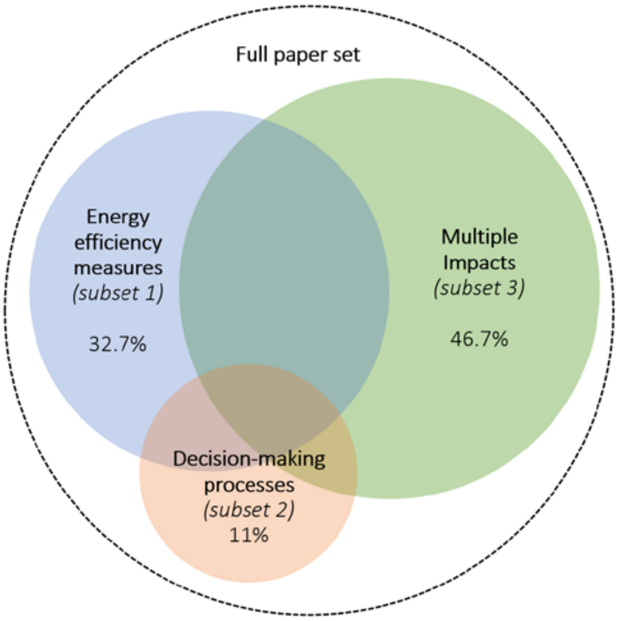


Figure 2.1: Venn diagram of subsets percentages within the full paper set (n = 954 papers) and overlaps among them.

Table 1.2 shows the summary of the statistics of each subset and the full paper set. The highest citation index (an indicator of citations between publications) belongs to subset 3 'Multiple impacts' with 20.34 -a higher average than the one for the complete paper collection, which indicates that publications in this topic have been more cited than the others. Subset 2 'Decision-making' ranks last in terms of the highest number of publications per year (n=24), being less than half than subset 3. The average publication per item is also the lowest in 'Decision-making' (n=13.53).

As can be depicted from figure 2.2, there has been a rapid development of publications in the field of technology diffusion from 2012 onwards, being subset 3 ('Multiple impacts'), the one with the highest increase. This trend has continued to grow until 2016, with a total of more than 160 publications. The only exception to this trend is subset 2 (‘Decision-making’), which after 2010 started to decrease the number of publications per year, seeming of less interest than in 2009/2010.

In terms of the European countries addressed* (see figure 2.3), the country with the highest number of publications for the whole paper set is the United Kingdom (n = 135), closely followed by Italy (n = 130). Spain and Sweden are the next countries with the highest number of publications (n= 95, n= 71, respectively), followed by Germany (n=57). These values, however, vary when analysing the statistics of each subset individually. For instance, Italy is the country with the greatest number of publications for subset 1 (n=50) and scores very close to the UK in subset 3 and so does Spain and Sweden.

Table 1.2 Search statistics from the literature search

Set	**No. of documents in the search**	**Total citations** (without self-citations)	**h-index**	**Average citation n per item**	**Highest number of publications per year** no. (year)
Subset 1 (energy-efficiency measures)	312	4,861	37	16.32	60 (2016)
Subset 2 (decision-making)	105	1,399	21	13.53	24 (2016)
Subset 3 (multiple impacts)	444	8,744	42	20.34	77 (2016)
Full set	*954*	*15,648*	*54*	*17.37*	*164 (2016)*

* The country identification is based on the institutional affiliations of the authors.

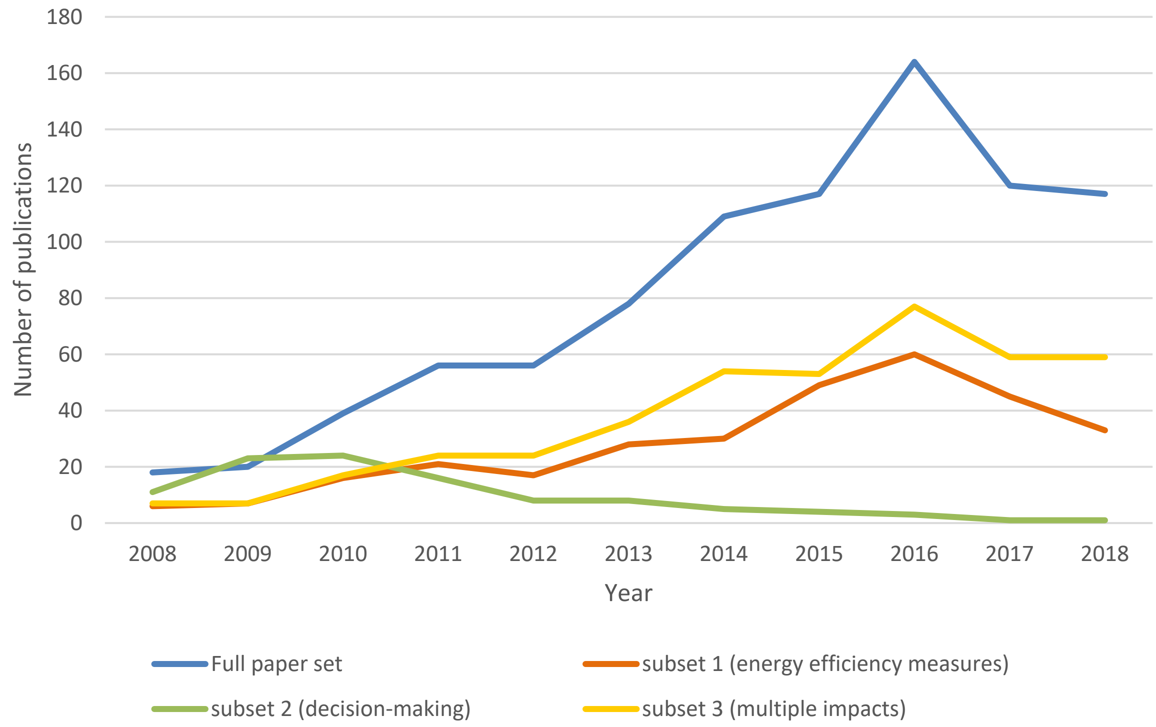


Figure 2.2: Number of publications per year. Period 2008-2018.

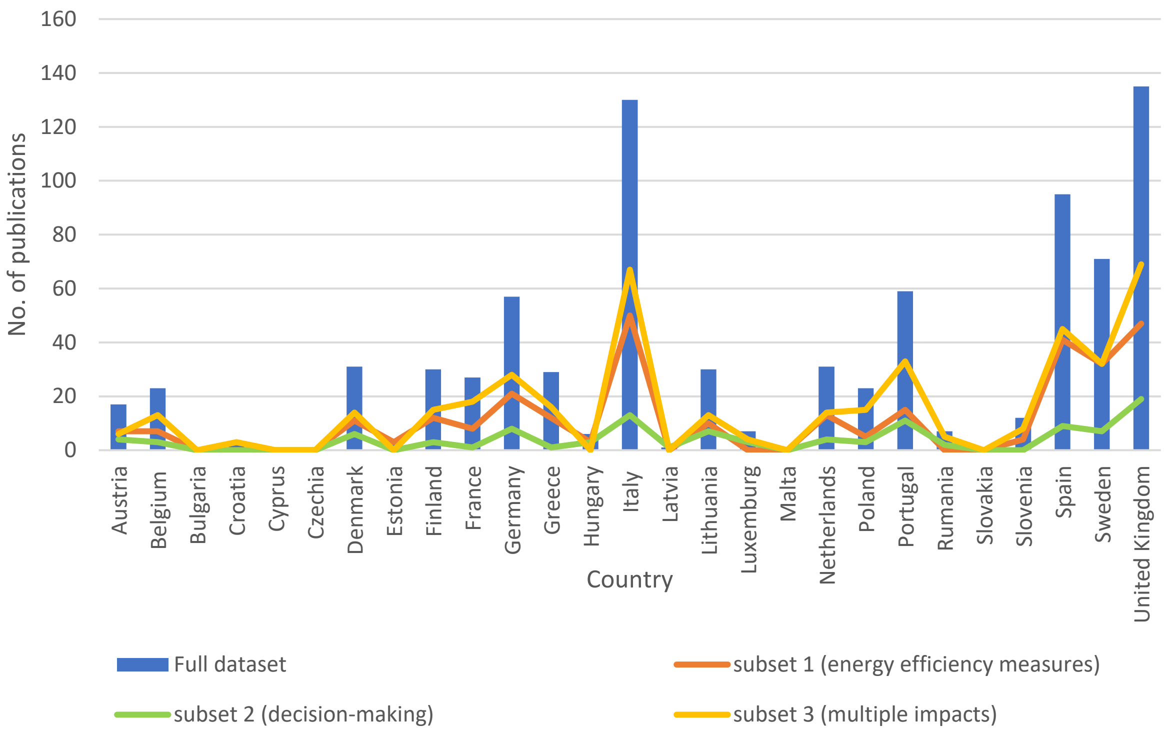


Figure 2.3: Number of publications per country from full paper set

2.5.2. Co-citation network

The results of the co-citation network from the full paper set is displayed in figure 2.4. Within the network, each node or circle represents a paper. The lines connecting the circles are the links between the citations. The nodes with the highest number or links (in-degree) are the most cited ones. They also appear as more central within the graph. Each cluster is indicated with a colour and labelled with a title based on the content of the papers.

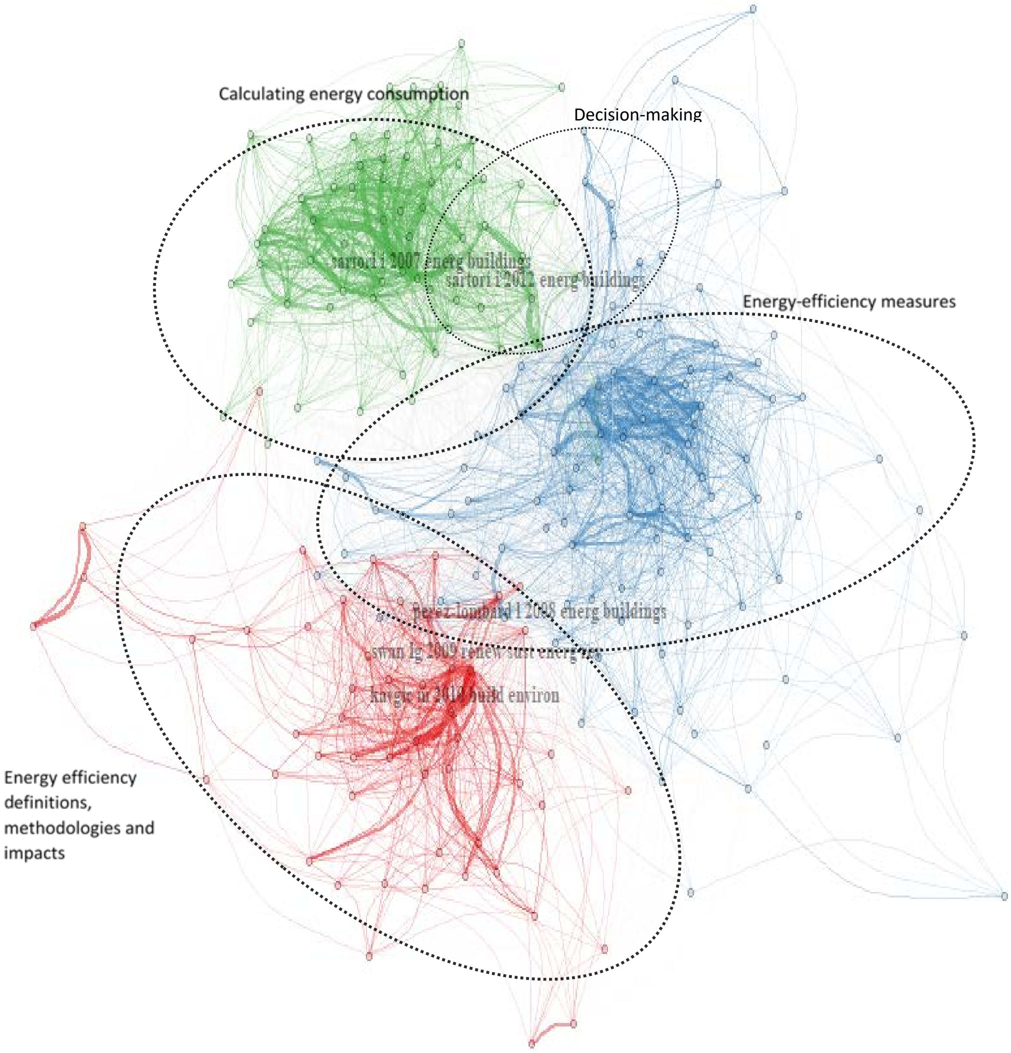


Figure 2.4: Co-citation network of the full paper set: main clusters and key papers.

The co-citation network of the full paper set consists of three main clusters (figure 2.4); ‘Calculating energy consumption’ (in green), ‘Energy efficiency measures´ (in blue) and ‘Definitions, methodologies and impacts of energy efficiency’ (in red). ‘Decision-making’ matters are addressed both in ‘Calculating energy consumption’ and ‘Energy-efficiency measures’, constituting a fourth cluster in the network. Each main cluster has high density, although they are not highly interconnected among each other. The cluster with the highest betweenness-centrality is ‘Energy efficiency measures´, which means that it has the highest number of co-citations among authors. The biggest overlap takes place between ‘Calculating energy consumption’, ‘Energy efficiency measures’ and ‘Decision-making’, a logical link given the complementary understandings of the topics. ‘Energy efficiency definitions, methodologies and impacts’ is also linked with ‘Calculating energy consumption’. The densest cluster and, thus, the one with the highest number of betweenness centrality per paper is ‘Calculating energy consumption’. Results from the network also indicate that, although topics arising from the hypothesis are present, they are not the sole aspects contained in this field.

2.5.3. Technological measures for energy efficiency

Out of the subset ‘Energy-efficiency measures’, many studies present tools or simulations to support the development of zero-energy in buildings (nZEB), mostly on retrofit measures – a logic approach given the age profile of residential buildings in Europe [81]. Common technological options in this research field are: HVAC, lighting, insulation, glazing or building controls. Being the building envelope and lighting solutions one of the most often assessed technologies [82]. Between the fastest developing technologies are control automation and smart metering devices. As stated by [82], ‘these devices allow the control of the energy demand/supply through ICT technologies considerably decreasing energy consumptions. Control systems relate to heating, cooling systems and ventilation, but are frequently applied to lighting (e.g. daylight and occupancy control). Furthermore, they allow data collection for performance calculations and dynamic simulation modelling’. In a nZEB design, all technologies should be applied in a cost-optimal manner. Most sources agree that the optimal solution can vary depending on: (1) deterministic aspects, such as the building typology or available energy sources; as well as (2) stochastic matters, such as the climatic zone, technological preferences and financial conditions. Due to the latter, cost-effectiveness is one of the most common subjects of studies in this subset.

As for the modelling of the stock, the literature shows that most of the building stock models currently developed are lacking empirical evidence and therefore need to be based on many assumptions. These findings were subscribed by the study developed in collaboration with [47].

2.5.4. Decisions behind energy efficiency technology measures

According to [70], the main disciplinary approaches to decision making in the context of residential energy use are: conventional economics, behavioural economics, technology dissemination, social psychology and sociology. Most of the literature from subset ‘Decision-making’ focuses on conventional economics or social psychology. Within social psychology, most papers address a single technology and/or a specific stakeholder perspective, being demand-side actors (such as a property owners or tenants) a key stakeholder group in these type of analyses [83,84]. Key paper [85], investigates how regulatory changes and contractual solutions can help solve the landlord/tenant dilemma in relation to sustainable renovation of residential buildings, and how the general awareness of sustainable renovation can be increased. Results show that there are plenty of opportunities to overcome this issue, but it can only be done through integrated policy instruments, making use of tools like energy performance contracting and energy labelling (e.g. EPCs). Key paper [86], on the other hand, presents an approach for 'decision support tool to automatically generate building retrofit alternatives and rank them using energy performance analysis, user requirements, relevant benchmarks and regulations. The model uses multi-criteria-based decision making with potential for approaching near optimum solution as it is intended to use dynamic databases for the components alternatives and genetic algorithms for the self-learning combined with fast computing.' The target groups of this tool are architects, project managers, building owners, facility managers and building contractors. The tool has been developed aiming to support their decision-making process. In order to help decision-making frameworks based on multi-criteria analysis (MCA), [87] suggest a generalized roadmap for MCA where the steps of the MCA process be accompanied by corresponding people and tools. These kinds of tools can be used in to support the inclusion of multiple impacts into decision making frameworks.

2.5.5. Multiple Impacts of energy efficiency technology measures

Scientific literature presents a wide range of side-effects related energy efficiency measures in residential buildings, namely job creation, air pollution reduction, indoor air quality, energy poverty alleviation, among others [78]. These effects can be positive (so-called co-benefits or multiple benefits), or negative (so-called associated risks or detriments). Most studies explore the positive effects of energy efficiency measures arguing that these surpass any potential adverse consequence [88,89]. Ky paper [90] defines co-benefits as "the term co-benefits includes all effects of energy related renovation measures besides reduction of energy, CO_2 emissions and costs". It also classifies co-benefits into four main clusters: economic (e.g. job creation, increase of GDP, energy prices, etc.), social (e.g. energy poverty alleviation, reduction of health expenses, etc.), environmental (e.g. reduction of CO_2, reduction of local air pollution) and energy delivery (e.g. optimised utility services and energy security). Side-effects of energy efficiency measures can affect stakeholders directly involved in the residential buildings (e.g. through an increase in the value of the asset), as well as society as a whole (e.g. by decreasing local air pollution, increasing public budget or improving industrial productivity).

[91] asserts that reliable estimation and quantification of energy benefits are essential in a sustainable building retrofit decision-support system for the selection and prioritisation of retrofit measures. However, the identification and quantification of these ramifications are often complex. This is due to the fact that it is objected to uncertainty and depends on many variables, such as local circumstances and implementation practices. As a consequence, in practice, these effects are either ill assessed or not even considered in decision-making frameworks, such as public energy efficiency strategies or financing judgement schemes [92]. This might partially explain why no study was found dedicated to quantifying to what extent do these effects really impact the different stakeholder groups or how do they affect the investment decisions, on a country or cross-country scale.

Paper V presented in this licentiate thesis showcases a practical demonstration of the multiple benefits that can involve deep refurbishment and upgrading of a building to nZEB standards. In this investigation, the taxation value increase is assessed due to deep renovation in residential building portfolios in Gothenburg (Sweden) by applying a package of energy efficiency measures as well as reinstatement of existing piping and sewage systems across all buildings. Results show average energy savings across the portfolio of 51% to an average cost of 6273 SEK/m^2 living area. While energy savings account for 21% of equivalent annual cost on average, there are seven buildings where more than half the annual equivalent cost of renovation is covered by energy savings. Similarly, the average change in assessed building value due to renovation is 9% of investment cost while the range for individual buildings is 0-23%.

2.6. Evaluation of Hypotheses & Discussion

Results from the study show that, overall, in the past decade this field has gained considerable momentum. However, the network structure displays a scattered and fragmented field in many domains. This fragmentation is especially visible on a geographical level (i.e. Member States). A fact that is subscribed by the descriptive analysis of the results. While countries such as Italy and UK show an active and comprehensive research activity in this front, other states have few or no identified publications in some arenas. Furthermore, it still lacks a comprehensive cross-country understanding in this field. No relevant study was identify providing this understanding with a standard methodology applied to different EU countries.

2.6.1. Hypothesis I: Technological measures for energy efficiency

The network structure of the subset ‘Energy-efficiency measures’ suggests it is a consolidated topic of research due to the high number of nodes and edged (i.e. co-citations). These results are validated by the statistical figures, showing a high number of publications per year with an increasing trend in the last decade. Most studies addressing this subject focus on the identification of what measures are most feasible for a specific building type/context or develop methods to help identify the best possible options. Key publications focus on investigating technical and cost-effectiveness of these solutions as well as providing decision-making tools for stakeholders involved in the planning and construction of the building. However, no scientific papers were found providing empirical data as to what measures are or have been implemented in residential buildings in the EU. Namely, broad statistical values on diffusion rates of energy efficient technologies, on a country or cross-country level. It is assumed that such studies exist, though have not necessarily been developed or published within the scientific community but rather by private companies such as multinational technology suppliers.

2.6.2. Hypothesis II: Decisions behind energy efficiency technology measures

This topic area is the least developed of the three, verified by the fact that the Walktrap algorithm does not even recognise it as an individual cluster and that the number of publications is decreasing yearly since 2008 (already the lowest then). Most of the literature resulting from the search addressed conventional economic factors (such as cost-benefit issues) or social psychology (such as drivers and barriers). Most papers address a single technology and/or a specific stakeholder perspective, being demand-side actors, like property owners or tenants, a key stakeholder group in these types of analysis. This said, no reference was found that offered a country or cross-country comparability of any of these parameters. As with the conclusions from hypothesis I, it is assumed that such studies exist, though have not necessarily been developed or published within the scientific community.

2.6.3. Hypothesis III: Multiple Impacts of energy efficiency technology measures

The exponential growth in number of publications since 2008 recognises ‘Multiple impacts’ as a hot topic. This can be partially attributed to the Energy Efficiency Directive demanding the integration of multiple impact assessment into long-term renovation and low-energy building strategies [8]. Also, to the numerous efforts of global organizations and initiatives such as the IEA, WBCSD or IPCC, highlighting the fact that reliable quantification and monetization of energy efficiency measures are essential to boost investments and foster the low carbon transformation of the built environment.

Most sources studied in the literature review agree that further research is needed to quantify and monetize these impacts. Furthermore, several sources argue that additional efforts should be undertaken to integrate these into decision-making frameworks [93], such as investment scenarios or construction projects offering a decision-support system in the selection technology choices [94,95].

2. RESEARCH QUESTIONS AND LIMITATIONS

3.1. Research question

The knowledge gaps and research needs and niches identified through the literature review (chapter 2) were complemented by discussions with market experts. This process led to the definition of the specific boundary of the Ph.D. project, and formulation of the following research questions (RQs), specified by three sub questions each:

I. **What energy efficiency technology measures are being implemented in residential building projects, for different building typologies across EU country members?**
   i. Why didn't they implement (even) more efficient technologies?
   ii. What are the motivations behind the projects?
   iii. What are the preferred co-benefits of the energy efficiency technology measures, for the stakeholders actively involved in the technology selection?

II. **What is the stakeholder setup in the process leading to the selection of the energy efficiency technology measures of different residential building typologies across EU country members?**
   i. Which stakeholders are involved?
   ii. What is their level of interest and influence in the selection of EET?
   iii. What is the level of communication among each other in the selection of EET process?

III. **What are the perceived barriers and drivers for specific energy efficiency technologies for different building typologies across EU country members?**
   i. What technologies are considered most promising for different building typologies?
   ii. What would be needed to upscale these technologies at a higher rate?
   iii. How does this vary across stakeholder groups?

3.2. Scope and limitations

Within the scope of this licentiate thesis, a methodology is developed to gather empirical evidence in respects to the above research questions, laying the groundwork for future research within the scope of this Ph.D. project. The final data collection and analysis, however, will be completed for the final Ph.D. thesis and is, therefore, out of the scope of this Licentiate.

The focus of this study is the uptake of EET in residential building projects in Europe. In this light, special attention is drawn to those elements affecting or related to the energy efficiency performance of the building or dwelling and respective technology components. This excludes any further urban spaces or functions from the system boundary of this investigation.

4. EVIDENCE IN THE UPTAKE OF EFFICIENCY TECHNOLOGIES IN RESIDENTIAL BUILDINGS IN EUROPE

4.1.Objective

Building upon the research questions, the next step in the research process (and respective goal of this chapter) is to develop a methodology to gather factual evidence in the uptake of energy efficiency technologies. According to the motivation and research needs identified through the literature review, the methodology should attain country-scale information and allow cross-country comparability of the results. The development and results from this process have been described in depth in the journal paper III '"Empirical evidence in the uptake of energy efficiency technologies in the European residential building stock".

4.2.Research Method

4.2.1. An online survey as a research tool

Surveys are used to gain insights into what people are thinking or doing [96]. Although they are not the only ways to gather information, they do present advantages as compared to other research methods. For instance, they can cover large populations and geographies at a competitive cost. Given that this study aims to gather evidence around residential building projects on a country and cross-country scale, a survey method was identified as the most appropriate research tool.

There are many channels to conduct a survey; via phone, by email or over the internet, among other methods. To generate data on a national scale, a vehicle was needed that could enable to reach many stakeholder groups and be able to easily adapt to the different perspective and answer variables. An online survey was, hence, identified as the best option as: (1) it facilitates a large geographic coverage and (2) allows to set up an interactive questionnaire, adapting itself to the different respondent´s perspectives.

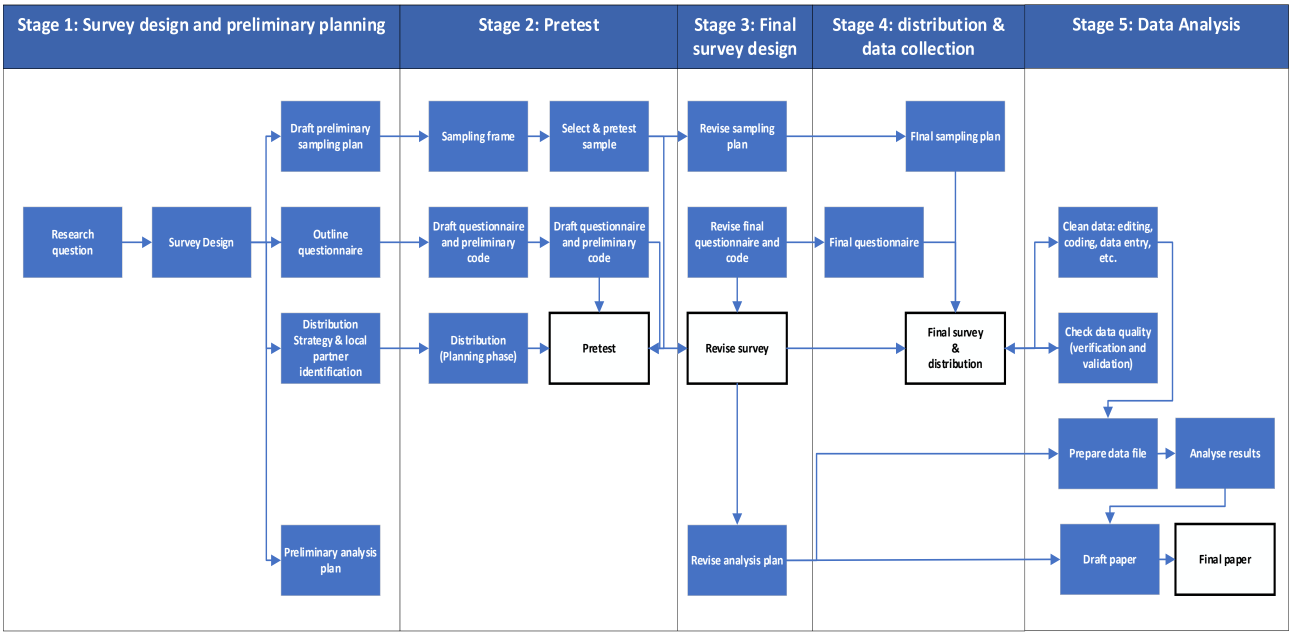
4.2.2. Survey procedure and main stages

Based on the study of the literature and discussions with market experts, a survey design was developed. To test the validity of the survey design and examine any potential flaws in the research conception, a workshop was organized gathering stakeholder representatives from all relevant groups in the building value chain (i.e. supply-side actors, demand-side actors and enablers). More than 20 participants attended the workshop. The input validated the survey design and served as a valuable basis for drafting the quantitative questionnaire. The final questionnaire layout was drafted and reviewed by market experts and pre-tested by stakeholder representatives from 8 different European countries[*]. The pre-test phase helped to identify inconsistencies, coding errors, unclear questions as well as data gaps. Once these errors were amended, the final online survey was completed.

The distribution of the survey was operated by academic partners and national market research institutes the respective countries. The starting date for the distribution of the survey, however, varied across countries. For Italy and Spain, the distribution date tool place between November 2018 and January 2019, and is already closed. For the rest of the countries (Germany, the United Kingdom, Poland and the Netherlands) the distribution of the survey phase is still ongoing.

The overview of the main stages in the survey procedure and how they interact is displayed in figure 4.1. In the following sections of this chapter the final survey design, pre-testing phase, distribution strategy and data collection methods are described in detail. Yet, as aforementioned, the data analysis lies out of the scope of this licentiate thesis.

Figure 4.1: Main stages and interactions of the survey. Adaptation from [96]



[*] Due to the research project requirements, the scope of the original survey was larger than the one presented in this thesis. Further details on the aim and scope of the project can be found in Annex 3. BMB Project Description.

4.2.3. Survey design and operationalization

When designing a survey, the principal elements to consider are: the definition of population, the sample population, its quota, the questionnaire and the distribution strategy [96]s. The following section presents a detailed description of each of these aspects and how they have been operationalized within the scope of this study.

4.2.3.1.Population

According to the OECD, the survey 'population' or 'universe' represents the entire group of units which is the focus of the survey study. The population could consist of all the people within a country, or those in a geographical location, or a special ethnic or economic group -depending on the purpose and coverage of the study. A population could also be comprised of non-human units such as farms, houses or business establishments. In this case, the survey universe consists of **residential building projects in the EU**.

4.2.3.2.Stratified sample approach

Once the universe or population has been defined, a coherent next step in the design of the survey is to define the sample [96]. A sample is, by definition, a subset of a larger population [97]. Stratified sampling is, therefore, a process mostly used in market research that involves dividing the population of interest into smaller groups, called strata. Samples are then pulled from these strata, and analysis is performed to make inferences about the greater population of interest [98]. As asserted by [99], stratified sampling is used when:

- The target population of interest is significantly heterogeneous
- To highlight specific subgroups within his or her population of interest
- To observe the relationship(s) between two or more subgroups; and,
- To create representative samples from even the smallest, most inaccessible subgroups of the population

Due to the purpose and scope of this study, a stratified sample was considered as the most appropriate approach as; (1) the population of interest (all residential building projects in the EU) is significantly large and heterogeneous, and (2), there is a need to represent even the smallest subgroups of the population (e.g. deep refurbishment projects).

Based on the universe defined for this study (i.e. residential buildings in Europe), the sample was divided into the following three stratification axes, as they are the three main elements or agents building projects are composed of:

(I) Stakeholder group
(II) Building typology
(III) Project type

How these have been conceived within the survey questionnaire is described in the following section.

I. Stakeholder group

Stakeholders play a crucial role in building projects and the respective uptake of EET. They are the agents responsible for deciding if and (if so) what technologies are implemented in the building. It is, therefore, very relevant to understand what stakeholders are involved in this process leading to the selection of the technology, what are their main drivers and barriers, as well as their level of interaction with each other. When looking at the building value chain (see figure 4.2), it is clear that the stakeholder setup that entails it is complex and fragmented. Many stakeholders are involved in different phases of it and it is, therefore, sometimes difficult to identify who is exactly behind the decision and what is their influence in the decision process. Based on discussion with stakeholders involved in the building value chain, as well as market experts, table 4.1 identifies stakeholders directly involved in energy efficiency residential building projects and, therefore, included in this study These have been classified according to their perspective in the project.

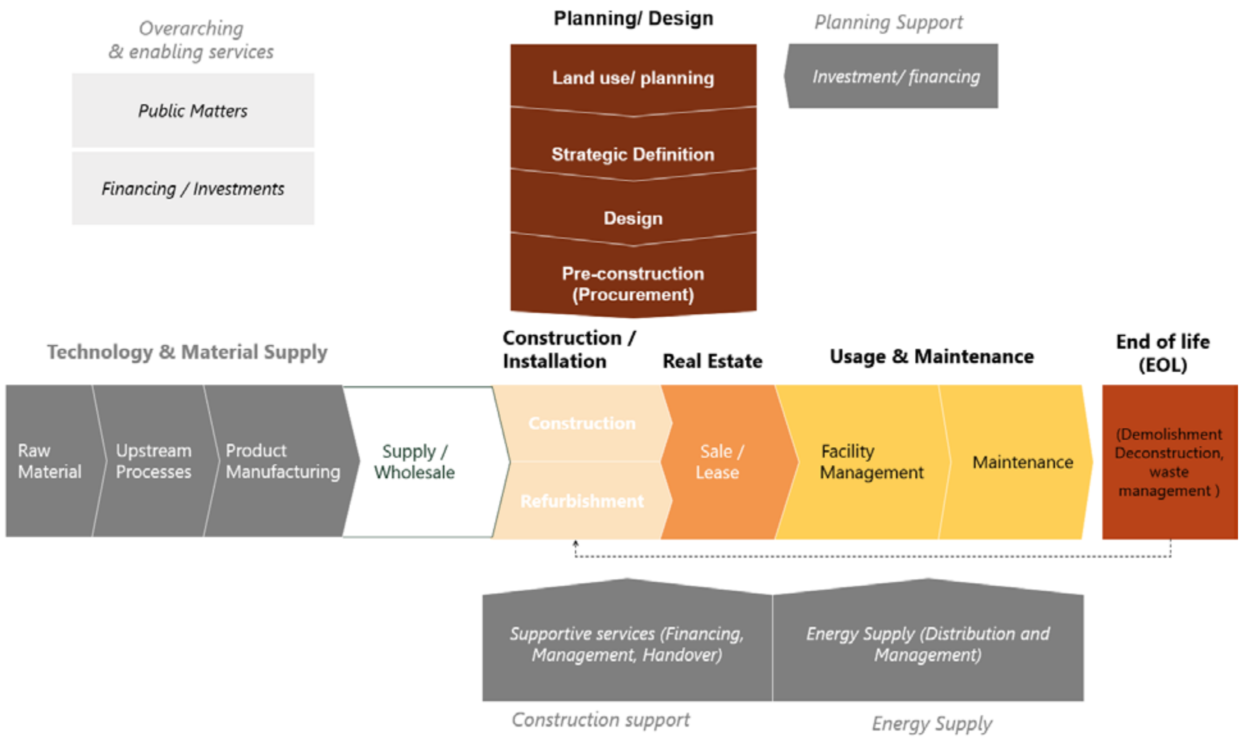


Figure 4.2: Simplified residential building value chain.

Table 4.1: Stakeholder groups and subgroups actively involved in the uptake of EET in residential buildings. Categorized based on their perspective within the project.

#	Stakeholder groups and subgroups	*Main presence in the building value chain*	*Perspective*	Professional/non-professional
1	**Conceiving, planning, and consulting services**	***Planning/Design, Construction/installation***	***Enablers***	***Professional***
1.1.	Architect			
1.2.	Engineer			
2	**Material and technology suppliers**	***Technology and Material supply***	***Supply-side actors***	***Professional***
2.1	Technology or material manufacturer or trader			
3	**Construction and installation**	***Construction/installation***	***Enablers***	***Professional***
3.1	Construction Company			
3.2	Installer			
4	**Enabling services**	***Overarching & enabling services***	***Enablers***	***Professional***
4.1	Local public authorities (e.g. construction permit authorities)			
4.2	Bank or other financial services (including local branch offices)			
5	**Operation and maintenance services**	***Usage & Maintenance***	***Enablers***	***Professional***
5.1	Facility manager (commercial, administrative)			
5.2	Facility manager (technical, maintenance etc.)			
5.3	Energy supply/utility and Energy service company (ESCO)			
6	**Institutional demand side**	***Real Estate, Usage & Maintenance***	***Demand-side actors***	***Professional***
6.1	Investor or Developer			
6.2	Housing company (for profit)			
6.3	Housing company or housing association, cooperative (public/ part governmental/ non-profit)			
7	**Private demand side**	***Real Estate, Usage & Maintenance***	***Demand-side actors***	***Non-professional***
7.1	Private house owner (private owner but flats rented out)			
7.2	Self-occupying private house owner (you live in your own house or flat)			

II. Building Typology

Building typologies are a set of model buildings with their own age of construction, geometrical, thermo-physical, equipment and energy performance properties [100]. The building composition and energy solutions vary substantially from one building typology to another. Characterizing and identifying the building typology is, hence, critical in the study of energy efficiency technology measures, as it provides essential information about the building composition and viable energy efficiency technical measures that can be implemented in each case.

One of the biggest EU initiatives to characterise building typologies across European countries is the IEE TABULA project ("Typology Approach for Building Stock Energy Assessment"). In the TABULA, each typology is well-defined by building types with specific parameters. Table 4.2 shows the names and definition of some of the identified building typologies.

Table 4.2: Building typologies: definitions and acronyms.

Acronym	Name	Definition
SFH	Single-family house or detached house	*A house for a single family or household that is not attached to any other building*
SDH	Semi-detached house, Twin house, or Duplex	*A twin house/duplex/semidetached house is a house, typically with two separate entry doors (sometimes with one) divided into two parts and housing two separate owners or tenants; this can be side-by-side, or one over the other.*
RH	Row house or Terrace house	*A row house/terrace house is one of a series of houses, often of similar or identical design, situated side by side and joined by common walls.*
SFH	Small multi-dwelling home or small apartment building	*A small multi family home/small apartment building is a building where multiple separate housing units (12 or less) for residential inhabitants are contained within one building or several buildings within one complex.*
LMF	Large multi-dwelling home or large apartment building	*A large multi family home/large apartment building is a building where multiple separate housing units (more than 12) for residential inhabitants are contained within one building or several buildings within one complex*

However, to simplify the classification for the survey, the building typologies were clustered into two main groups, based on their number of dwellings (i.e. single or multiple dwellings). Table 4.3 below shows the building typologies encompassed in each case:

Table 4.3: Building typology groups: building types encompassed and acronyms.

Acronym	Name	Definition (i.e. building types included)
SDB	Single-dwelling building	*Single family houses (SFH), Semi-detached house (SDH), terraced house (TH) or row houses (RH)*
SDB	Multi-dwelling building	*Small multi-dwelling houses (SMH), large multi-dwelling houses (LMH).*

III. Project type

The building life cycle refers to the prospect of a building over the course of its entire life - encompassing from the land use and planning to construction, operation, maintenance, modification and eventual demolition and waste treatment [101]. In Europe, residential buildings have an average life-span of 60 to 120 years, mostly depending on their constructive configuration [102]. The Standard ISO 15686 'Buildings and constructed assets-Service life planning' (ISO, 2000) can serve as a model or framework for the whole field of service life assessment. The main phases, interactions and project types in the life-cycle of a building are represented in figure 4.3.

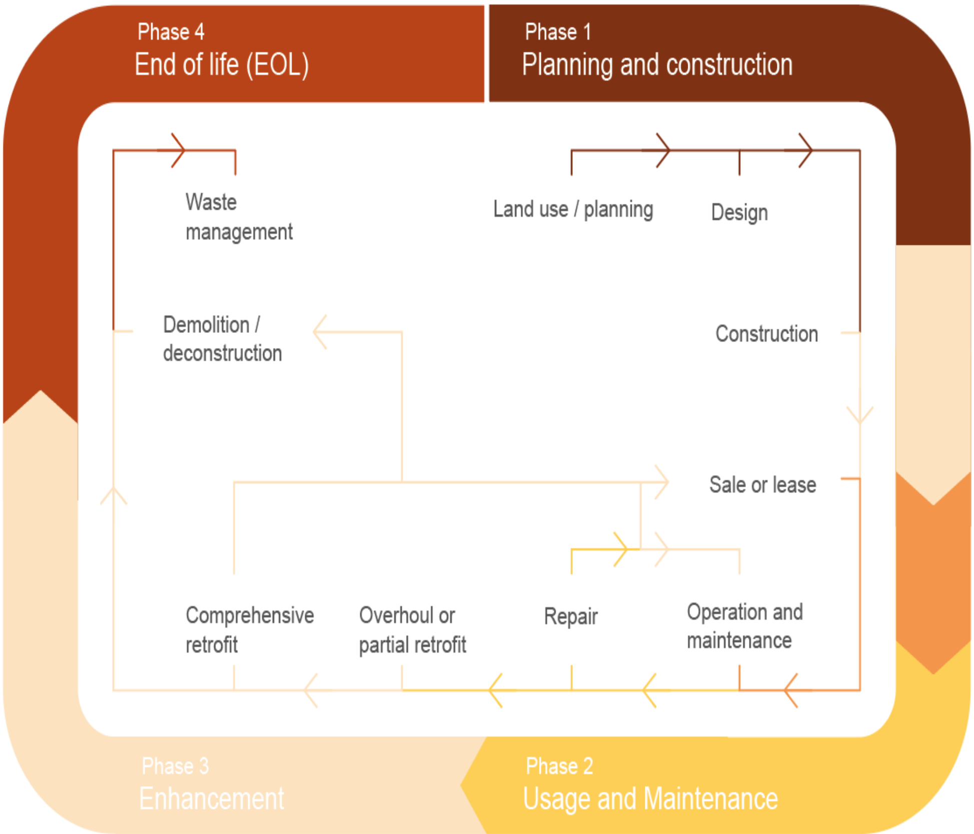


Figure 4.3: Life-cycle of a building: Main phases, project types and interactions.

The main phases, project types and interventions relevant in residential buildings, are described in table 4.4 below:

Table 4.4: Main phases, actions or project types in residential buildings.

Phase	Project types and interventions	Description
1	**Design**	Concept that focuses on the components or elements of a structure or system and unifies them into a coherent and functional whole, according to an approach in achieving the objective(s) under the given constraints or limitations.
1	**Construction**	According to the OECD, new construction refers to site preparation for, and construction of, entirely new structures and/or significant extensions to existing structures whether the site was previously occupied.

2	**Operation and maintenance**	Different standard systems offer different definitions for the term 'maintenance'. For this study the European standard EN13306 is used, (European Committee for Standardization, 2001), which gives a broad classification for this term in which most operation and daily repair activities are included in the definition of maintenance. In other words, 'the necessary routine works to keep the fabric and/or technical system of a place in good order'
2	**Repair**	Restore to a good or sound condition after decay or damage. When referred to a building, it defines any necessary action to restore any broken, damaged or failed device, equipment, part or property to an up-to-date usable state. The main difference between maintenance and repairs is that repairs are generally not planned, whereas maintenance works are.
2	**Reinstatement**	Replacement or modification of a component to with an identical one.
3	**Retrofit**	Upgrade the function of a component.
3	**Deep/comprehensive renovation**	Extra measures with the aim to upgrade the building to a higher standard (a better utility value from users' perspective). These actions can be for example: upgrading wall components, heating systems, plan design, etc.
3	**Energy renovation**	The implementation of energy efficiency measures. Such measures are for example: extra insulation for the walls, ground floor and attic, air-tightening of the building's envelope, new energy efficient windows, heat recovery, solar cells, etc. Therefore, costs related only to the energy- / renovation are considered as investment and those costs related to maintenance are considered only as costs."
3	**Renovation or refurbishment**	An overarching term used referred to modification and improvements to an existing building, in order to bring it up to an acceptable condition (SS-EN 15643-2:2011).

To simplify the number and types of projects within the survey, these have been classified following the work of [83]. In their investigation, Hecher, M. et al. distinguish between three main cases based on the trigger behind the decision to invest, these are: (1) New construction, (2) Problem-prompted, and (3) Opportunity-caused. Table 4.5 below shows grouped according to these three described triggers.

Table 4.5: Building typology groups: building types encompassed and acronyms.

Acronym	Trigger	Project type
NB	*Build new*	New construction
R	*Problem*	Repair or overhaul or partial retrofit
DR	*Opportunity*	Deep retrofit

When the two main building typology groups and the three project types stated above are then combined together, the following six clusters arise, herein referred to as ‘buckets’:

1. new construction of single-dwelling buildings (SDB)
2. new construction of multi-dwelling buildings (MDB)
3. repair, overhaul or partial retrofit of single-dwelling buildings (SDB)
4. repair, overhaul or partial retrofit of multi-dwelling building (MDB)
5. deep or comprehensive retrofit of single-dwelling buildings (SDB)
6. deep or comprehensive retrofit of multi-dwelling buildings (MDB)

4.2.3.3.Quota sampling

The quota refers to the number of responses required for each sample strata [96]. Within this study -due to the stratified approach- there is no maximum number of responses stipulated, but rather a minimum quota for different strata and sub-strata. This minimum number has been defined based on the estimate of some of the sample size calculation approaches defined by [96], and it has been defined for the three axes of stratification (i.e. stakeholder group, building typology and project type). One stratification axe is controlled ex-ante (stakeholder group) and two are controlled for during the survey or ex-post (building typology and project type).

I. Stakeholder group

A minimum number of stakeholders for each of the groups defined in table **X**. The goal is to have a minimum of 100 responses in most of the main groups 1 to 5 (i.e. at least about 550 on the supply side) and about 270 responses in each of main groups 6 and 7 (i.e. 500 on the demand side) and ideally 48 responses from each sub-group of the categories 1.1 through 5.3 and about 100 responses of the categories 6.1 through 7.2 respectively.

II. Project type

Answers should also equally cover the types of projects. As described in section **X**, the main project types relevant to the uptake of EET are: new construction, overhaul or partial retrofit, and refurbishment and deep retrofit. To have a minimum representation each one of these should contain 240 answers.

III. Building Typology

Out of each type of project above, it should also be ensured that the two main building typologies are discussed within minimum number of responses, these are:

- *Single-dwelling buildings (SDB): single family houses (SFH), Semi-detached house (SDH), terraced house (TH) or row houses (RH). Min: 600 answers*

- *Multi-dwelling buildings (MDB): small multi-dwelling houses (SMH), large multi-dwelling houses (LMH). Min: 600 answers*

The aspired number of responses are broken down into the three layers of stratification (stakeholder group, project type and building typology). The results are shown in table 4.6.

Table 4.6. Minimum quota broken down into the three axes of stratification

		Project type								
		New built		**Comprehensive Retrofit**		**Partial retrofit**				
	Bucket no.	*1*	*2*	*3*	*4*	*5*	*6*			
								SUB-TOTAL		**GRAND TOTAL**
Stakeholder group		**SDB**	**MDB**	**SDB**	**MDB**	**SDB**	**MDB**	**SDB**	**MDB**	
1.Conceiving, planning, and consulting services	1.1. Architect	4	4	4	4	4	4	14	14	**36**
	1.2. Engineer	4	4	4	4	4	4	14	14	**36**
Sub-total	**Main group 1**	**10**	**10**	**10**	**10**	**10**	**10**	**36**	**36**	**91**
2. Material and Technology supplier	2.1. Technology or material manufacturer or trader	***6***	***6***	***6***	***6***	***6***	***6***	***21***	***21***	**53**
Sub-total	**Main group 2**	***6***	***6***	***6***	***6***	***6***	***6***	***21***	***21***	**53**
3. Construction and installation	3.1. Construction company	4	4	4	4	4	4	14	14	**36**
	3.2. Installer	4	4	4	4	4	4	14	14	**36**
Sub-total	***Main group 3***	***10***	***10***	***10***	***10***	***10***	***10***	***36***	***36***	***91***
4. Enabling services	4.1. Local public authorities (e.g. construction permit authorities)	4	4	4	4	4	4	14	14	**36**
	4.2. Bank or other financial services (including local branch offices)	4	4	4	4	4	4	14	14	**36**
Sub-total	***Main group 4***	***10***	***10***	***10***	***10***	***10***	***10***	***36***	***36***	**91**
5. Operation and	5.1. Facility manager (commercial,	4	4	4	4	4	4	15	15	**38**

Maintenance services	administrative)									
	5.2. Facility manager (technical, maintenance etc.)	4	4	4	4	4	4	15	15	**38**
	5.3. Energy supply/utility and Energy service company (ESCO)	4	4	4	4	4	4	15	15	**38**
Sub-total	***Main group 5***	***15***	***15***	***15***	***15***	***15***	***15***	***57***	***57***	**143**
6. Institutional demand-side	6.1. Investor or developer	6		6		6		23		**29**
	6.2. Housing company (for profit)	8	8	8	8	8	8	29	29	**72**
	6.3. Housing company or housing association, cooperative (public/ part governmental/ non-profit)	8	8	8	8	8	8	29	29	**72**
Sub-total	***Main group 6***	***23***	***23***	***23***	***23***	***23***	***23***	***86***	***86***	**215**
7. Private demand side	7.1. Private house owner (private owner but flats rented out)	10		10		10		38		48
	7.2. Self-occupying private house owner (you live in your own house or flat)	29	10	29	10	29	10	107	36	179
Sub-total	***Main group 7***	***50***		***50***		***50***		***185***		**230**
Grand total	***Grand total***	***240***		***240***		***240***		***-***		***968***

Response rate

After defining the quota (and before tracing the number of people that the survey should be distributed to, in the distribution strategy), it is important to take into consideration the response rate. The response rate refers to the number of respondents who complete a questionnaire compared to the number of responses that have been assigned, usually expressed as a percentage [103]. An average response rate is usually assumed to be around 10-20%. With a presumption of a response ratio of 12% (hopefully 15%) to 20% an oversampling rate of a factor of 5 to 7 is needed (i.e. the number of addressees to which the survey is sent to needs higher by this factor. This means that, in total, roughly 8000 stakeholders need to be approached in each country.

4.2.3.4.Questionnaire: content and structure

Based on the study of the literature, discussions with market experts and input from stakeholder group representatives across the whole value chain, a quantitative questionnaire was developed. Within the questionnaire, the first step in the survey is the characterization of the stakeholder profile (Part I). The respondents are asked to identify what had been their latest project. Once they have, they are requested to select their building typology and type of project (Part II). The behavioural factors determining adoption decisions were measured in two ways: First, the respondents are asked to assess the perceived influence, interest and level of communication with actors involved in the decision affecting the selection of the technology (Part III). Afterwards, they are inquired about their level of familiarity with different building technologies. Based on their answer, they were requested to identify the main drivers and barriers in relation that technology (Part IV). Finally, questions about contextual factors, such as building, and socio-demographic characteristics were posed (Part V). These topics were pursued following the structure illustrated in figure 4.4. The questionnaire was profiled based on the stakeholder group they identified themselves in as well as the building typology and project type they selected. The complete questionnaire can be found in Annex 5. Survey Questionnaire.

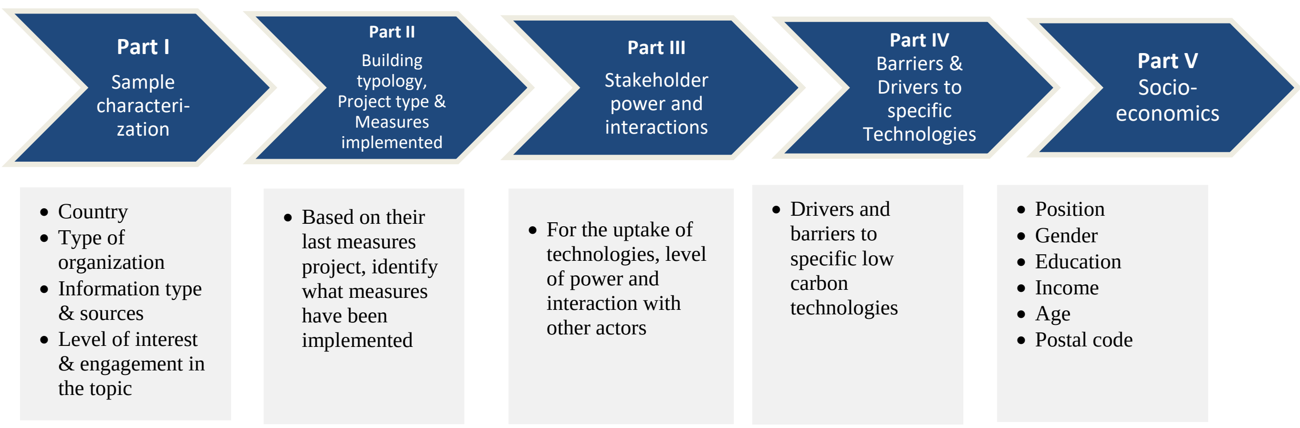


Figure 4.4: Content topic structure of the survey

4.2.3.5.Survey Intelligence

As seen in the previous section, the building value chain is complex and dynamic (i.e. multiple building typologies, project types, stakeholder groups involved, timings, etc.). Thus, to characterize the uptake of energy efficiency technologies and encompass this complexity (while attaining the high number of responses that were needed), the survey questionnaire ought to be dynamic and adaptive. This need for dynamism and adaptability requires back-end programming, hereafter referred to 'survey intelligence'. The survey intelligence, hence, refers to the latent architecture designed and coded within the survey. Its objective was two-fold:

I. Control that the questionnaire so it can adapt to every stakeholder profile within the value chain (i.e. questionnaire profiling).
II. Ensure that the minimum quota is met (i.e. minimum quota).

The design and implementation of the survey intelligence and how it effectively works in practice are explained hereafter.

i. Questionnaire profiling

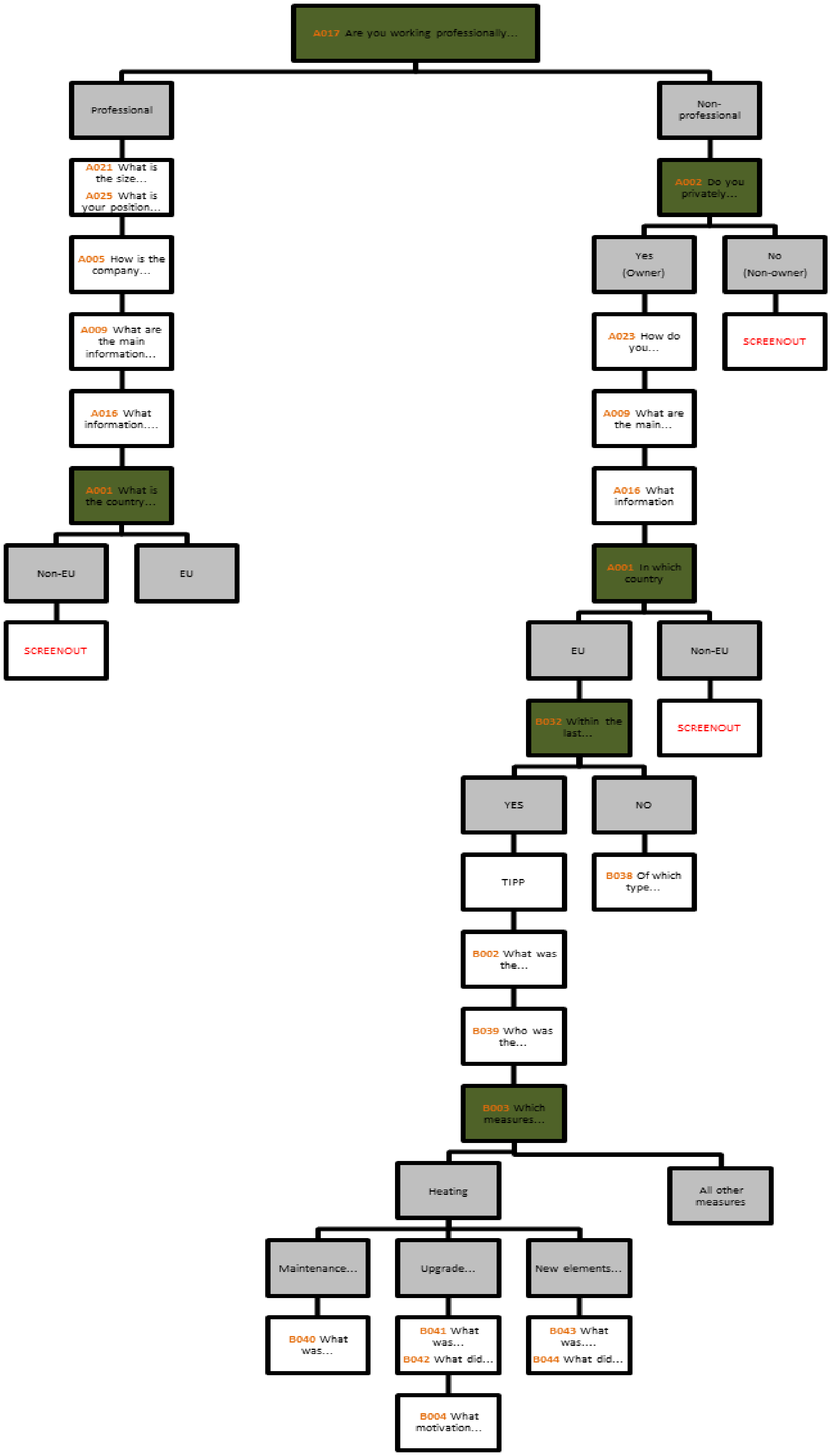
Given the high number of stakeholder groups, the study encompasses (n<21) -with distinct perspectives and level of knowledge in the topics addressed- the questionnaire needed to be programmed to dynamically adapt to each angle. This effort is labelled as 'questionnaire profiling' and has been implemented on two levels. First, on an overall questionnaire architecture, adapting it according to the stakeholder group and concrete response selected. For instance, technology providers do not necessarily have practical experience in building projects and might, therefore, need to skip any project-related questions (see figure 4.5). The second type of questionnaire profiling was on a more detailed level, related to the formulation of the specific questions. For example, once the respondent had identified their country or type of project and building typology, the upcoming questions were coded so that it referred to this information and the respondent could relate to the question better. Another example of this was questions B046-57 (see Annex 5. Survey Questionnaire), to identify the exact alias they had chosen for the different stakeholder groups.

ii. Minimum Quota

There are several ways in which the questionnaire controls the quotient. One of these is the quotient stop; if there are enough questionnaires for certain stratus, further participants of this group are requested to answer the survey for another stratum (e.g. deep retrofit instead of new built, large house instead of small house etc.). Second is to ask for a specific project type and building typology (i.e. bucket), when the current numbers are insufficient, and the quota of the other buckets has already been satisfied.

In order to enable the proper functioning of the survey intelligence both for the questionnaire profiling and minimum quota to ensure the validity and reliability of the results, the survey intelligence was evaluated and pre-tested. Further details on the evaluation and pre-testing phase are provided in the consequent section.

Figure 4.5. Simplified flow chart of the survey intelligence architecture based on stakeholder profile and concrete response selected.



4.2.4. Survey pre-testing

As depicted in figure 4.1, the survey design and operationalization (as well as the parameters within it) were pre-tested and validated along with the different phases of its development. Hereby a selection of the most relevant criterion and audit aspects.

i. Conceptual framework

As aforementioned, to test the validity of the survey design and examine any potential flaws in the research conception, a workshop was organized gathering stakeholder representatives from all relevant groups in the building value chain (i.e. supply-side actors, demand-side actors and enablers). More than 20 participants attended the workshop. The input received validated the survey design and served as a valuable basis for drafting the quantitative questionnaire.

ii. Content and structure

The final questionnaire layout was drafted and reviewed by market experts as well as pre-tested by market experts from 8 different European countries[*]. The pre-test phase helped to identify inconsistencies in the questionnaire structure, unclear questions, data gaps as well as coding errors.

iii. Language and jargon

The content and the exact formulation of the questions were adapted to fit the jargon of each of the stakeholder groups involved in the building value chain and actively involved in the uptake of EET (which the survey was addressed to). To this end, during the pre-test phase, the survey was distributed to stakeholder group representatives to ensure the proper understanding of each question. Two representatives from each stakeholder group were asked to go through the survey and identify any potential inconsistencies and errors. A total of 30 stakeholder representatives participated in this process. Finally, the questions were translated into the respective language for each of the countries. The translations were then revised by market experts in each country to ensure the correct understanding and interpretation of the questions within their context and, again, sent to stakeholder group representatives to validate the correct comprehension.

iv. Survey intelligence

The pre-testing phase was critical to ensure that the survey intelligence had a proper functioning and that the results were apt for the later analysis. Due to the goal and operationalization of the survey intelligence, the pre-testing was divided into three main phases. The first phase was dedicated to ensuring that the overall structure of the architecture was viable and that all stakeholders profiles could respond to all of the

[*] Due to the research project requirements, the scope of the original survey was larger than the one presented in this thesis. Further details on the aim and scope of the project can be found in Annex 3.

questions they were assigned. As described above, two representatives from each stakeholder group were asked to go through the survey and identify any potential inconsistencies and errors. In the second phase, the coding was revised and cleaned, in order to avoid any bugs or errors in the systems. Special attention was drawn to correct functioning ‘buckets’ as well as the correct storage of the completed questionnaires to ensure that they could be extracted later for the data analysis. The third and final phase was dedicated to ensuring that the translation of the questionnaire was properly functioning. To this end, instructions were elaborated creating ´personas´ for each of the stakeholder group profiles and ‘buckets’. Market experts in each country from each of the studied markets were asked to follow these instructions. They were also asked to report on any gap or bug in the system.

4.2.5. Survey distribution

Once the survey had been developed, an aligned and accurate execution of the survey distribution is crucial to ensure the coherence of results on a national level as well as across countries. Due to the high number of markets addressed in this study, the distribution of the survey was commissioned to research institutes in the respective country, hereafter referred to as ‘local partners’. To this end, detailed distribution instructions were elaborated. The progress of the dissemination was scrupulously guided and monitored by the author of this thesis in order to ensure it was strictly followed.

Step 1 : Preparation

i. Questionnaire : translation and interpretation

Translate the survey to the **language and jargon** of the country/market the survey is distributed in. The translation should make sure that the language is as simple as possible for an easy comprehension of the respondent. The correct translation should be validated by sharing the survey to 1-2 representatives from each stakeholder groups.

ii. Universe Characterization – Overview of the stakeholder structure in the building sector of your country

Before start collecting the list of addresses whom to send the survey to, there needs to be a proper understanding of the universe and of the market structure in the given country. This means, for the stakeholder groups defined in table 4.1 answering to the following questions:

- How does the market work? *(I.e. integrated companies delivering services along a large part of the value chain or fragmented structure)*
- How are stakeholder groups structured in terms of size and market shares? *(E.g. a certain segment of the value chain of a certain project type covered rather by small or by large companies).* To this effect, **each local partner will be provided with a universe characterization of the universe** (i.e. statistical information about the number of companies by the main group and by sub-group and by size class according to EUROSTAT).
- As the survey focusses mostly on operational aspects (and it is less about the company's goals and strategic levels), the target group is not aimed at high level executive. In this sense, project managers and other responsible personnel with contact with building projects. Within each stakeholder group, each profile varies. As for the non-professional stakeholders, these were not profiled. Any private demand-side actor was invited to participate in the survey if they had been involved in the residential building project within the EU. Further details on this profiling are provided in Annex 5, section 2.

iii. Finding the best channels & ways to reach the contacts

The local partner should decide what are the best ways to reach the target groups. Further instructions on how to execute this step are provided in Annex 5, section 2.

iv. Collecting Contacts

Based on the results of the earlier steps, the local partner should gather relevant contacts. The concrete procedure to collect these contacts is shown in Annex 5, section 2.2.

v. Preparing e-mails, Surface Mailing or anything documentation needed

As a last step of the preparation, the local partner shall assemble the email draft, letter, etc. needed to approach the contacts. Further instructions on how to execute this step are provided in Annex 5, section 2.5.1.

Step 2: Survey Launch

Once all the steps in the preparation phase have been completed, the local partner will proceed to send out the survey (channel: e-mails, letters, etc.) to all collected parties. It is up to the local partner to decide what the best way to ensure the minimum quota is and how to assure that the questions are sensibly answered. E.g. computer-assisted telephone interviews (CATI). A collection of methods and best practices (i.e. proved to be the most effective ones in other countries) is provided in Annex 5, section 2.5.2.

Step 3: Follow-up of the respondents

A month after the survey has been sent out, a follow-up meeting takes place. In this meeting, the following topics are addressed:

- Update on the survey response. In terms of:
    - Number of responses per stakeholder groups, building typologies and project types (i.e. quota per buckets)
    - Rate of response
- Based on survey responses
    - A second wave of distribution might be needed. This time focusing on those stakeholder groups with the lowest number of responses.
    - Worst case, if the response rate is in overall low and the minimum number of responses are not achieved, the current method of distribution will be revised.

Step 4: Closing the survey

The survey was opened uninterruptedly for a maximum of 3 months (the time might be extended if the response rate is too low). After these months are over, the survey closed, and the results were to be collected.

4.3. Introducing RQs in the survey questionnaire

Although the scope of the survey is broader*, the research questions were explicitly addressed in the questionnaire. The following section describes how the research questions have been conceived and formulated within the survey questionnaire. It is important to note that given the special constrains that an online survey hosts (as well as the level of understanding of different stakeholder groups), the research questions needed to be converted into an appropriate form to fit a survey format and stakeholder groups addressed. This affected both their language style and format. The exact formulation of the questions in relation to each research questions and sub-questions is described hereafter.

4.3.1. Research question I: Characterization of Energy Efficiency Technology Measures

As described in chapter 3, research question I (RQ I) stated:

I. *What energy efficiency technology measures are being implemented in residential building projects for different building typologies across EU country members?*

i. *Why didn't they implement (even) more efficient technologies?*
ii. *What are the motivations behind the projects?*
iii. *What are the preferred co-benefits of the energy efficiency technology measures, for the stakeholders actively involved in the technology selection?*

Characterizing the technological energy efficiency measures that have been implemented in their latest project (RQ I) is a core aspect of the study and, thereby, of the survey questionnaire. However, to optimize the time the respondents spend in answering what exact measures were undertaken, a table was developed. The table format allowed to address most of the possible measures in a compact unique question. When respondents selected heating system (T5) or ventilation system (T1), they were provided with follow-up questions, tailored to the type of measure they had identified (i.e. maintenance (A), upgrade of existing elements (B) or new element or systems (C)).

Which measures were implemented in your project?

	Element or system	*Maintenance (including repair)*	*Upgrade of existing elements or systems (incl. insulation and control)*	*New element or systems*
		A	*B*	*C*
E1	***Wall (outer)***	☐	☐	☐

* See Annex X for further details of the aim and scope of the survey.

E2	***Windows***	☐	☐	☐
E3	***Roof (pitched/flat) or attic***	☐	☐	☐
E4	***Basement/crawl space***	☐	☐	☐
T1	***Ventilation system***	☐	☐	☐
T2	***Energy generation (PV or solar collector)***	☐	☐	☐
T3	***Energy storage***	☐	☐	☐
T4	***Appliances*** *Please specify if possible:*	☐	☐	☐
T5	***Heating system***	☐	☐	☐
T6	***Cooling system***	☐	☐	☐
T7	***Combined system Electricity / Heat / Cool (CHP)***	☐	☐	☐

- *Other (e.g. kitchen, bathroom, installations):*
  Please describe
- *I don't know*

If the respondent selected that they had changed the heating system (maintenance), survey intelligence was programmed to follow-up with the question:

What was the energy carrier of the heating system, which has been maintained or repaired?

- *Biomass*
- *Geothermal energy*
- *Lignite*
- *Coal*
- *Natural gas*
- *Mineral oil*
- *Electricity*
- *Other: Please describe*

If the respondent selected that they had changed the heating system (upgrade), survey intelligence was programmed to follow-up with the question:

What was the heating system before the upgrade?

- *Oil heating system*
- *Gas heating system*
- *Electric direct or storage heating system*
- *Non-biomass heating system (such as coal/anthracite)*
- *Wood-based heating systems (such as pellet heating systems, stoves)*
- *Heat pumps (Geothermal, water or air heat source)*
- *District heating (normal or low temperature)*
- *Solar*
- *Co-generation (combined heat and power)*
- *Other: Please describe*

What did you upgrade this to?

- *Oil heating system*
- *Gas heating system*
- *Electric direct or storage heating system*
- *Non-biomass heating system (such as coal/anthracite)*
- *Wood-based heating systems (such as pellet heating systems, stoves)*
- *Heat pumps (Geothermal, water or air heat source)*
- *District heating (normal or low temperature)*
- *Solar*
- *Co-generation (combined heat and power)*
- *Other: Please describe*

If the respondent selected T5 (Heating system) - New element or systems), survey intelligence was programmed to follow-up with the question:

What was the system before the replacement?

- *Oil heating system*
- *Gas heating system*
- *Electric direct or storage heating system*
- *Non-biomass heating system (such as coal/anthracite)*
- *Wood-based heating systems (such as pellet heating systems, stoves)*
- *Heat pumps (Geothermal, water or air heat source)*
- *District heating (normal or low temperature)*
- *Solar*
- *Co-generation (combined heat and power)*

- *Other: Please describe*

What new heating system has been installed?

- *Oil heating system*
- *Gas heating system*
- *Electric direct or storage heating system*
- *Non-biomass heating system (such as coal/anthracite)*
- *Wood-based heating systems (such as pellet heating systems, stoves)*
- *Heat pumps (Geothermal, water or air heat source)*
- *District heating (normal or low temperature)*
- *Solar*
- *Co-generation (combined heat and power)*
- *Other: Please describe*

4.3.1.1. Definition of deep/comprehensive retrofit

Results from the literature review showed that there is not a unified definition of refurbishment nor refurbishment rates in the EU housings. Thus, there is also no aligned convention in the definition of deep refurbishment. To be able to identify and categorize what projects could be defined as deep refurbishment, the following definition was developed, based on the exact measures that the respondents had selected to have been implemented in their projects:

In order to categorize a project as deep refurbishment, there must be an upgrade (including insulation and control) or replacement of building elements or systems, including:

- Either 3 out of 4 elements of the envelope (out of options E1-E4)
- Or 3 out of 4 elements of the technology group (out of T1 -T4)
- Or at least 2 envelope measures (out of E1-E4) and 2 technologies (out of T1 -T4)

	Element or system
E1	***Wall (outer)***
E2	***Windows***
E3	***Roof (pitched/flat) or attic***
E4	***Basement/crawl space***
T1	***Ventilation system***
T2	***Heating system***

T3	***Energy generation (PV or solar collector)***
T4	***Energy storage***
T5	***Appliances*** *Please specify:*

4.3.1.2. Impacts in the adoption of EETM

The goal of sub-questions ii and iii was to identify what the motivation behind the projects and co-benefits of energy efficiency technologies, respectively. The questions were successive because the research conception was established to investigate if there was any correlation between motivation behind projects and potential co-benefits of energy efficiency measures. How this was operationalized within the research question was that, first, they were asked about the motivation behind their project. Then, in order to address the co-benefits, the answer options provided in this question were extracted from literature on co-benefits. The correlation between these two parameters will be then be assessed in the analysis of the data.

As a result, the question below was posed:

What were the main motivations for your project?

- *Environmental*
  - *Saving energy*
  - *Reducing CO2-emissions*
  - *Reducing other environmental adverse effects*
- *Technical*
  - *Building's update or future-proof*
  - *Part of the building / technology reached end of lifetime*
  - *A damage needed to be repaired*
- *Economic*
  - *It was a work assignment*
  - *Capital Investment*
  - *Maintenance of the value of the building (or respective part)*
  - *Increase of the value of the building (or respective part)*
  - *A subsidy scheme made the project attractive*
  - *Lower energy and/or operating costs*
  - *Prevent increasing maintenance costs in the future*
- *Social*
  - *The wish / need to build a new building*
  - *Fulfil tenants' / owner's wishes / requirements*

    - *Marketing reasons (e.g. prestige project)*
    - *Social peer pressure (the last not-refurbished house in the street/advice from friends)*
- *Aesthetic reasons*
    - *A change of tenants / residents offered the opportunity to do the work now*
    - *The function, program or plan of the building was modified*
- *Legal, standards and labels*
    - *Compliance with legal standards*
    - *Meeting appealing voluntary standards or labels*
- *Other: Please describe*

- *I do not know*

4.3.2. Research question II: Decision-making processes in the technology selection

As described in chapter 3, research question II (RQ II) stated:

I. ***What is the stakeholder setup in the process leading to the selection of the energy efficiency technology measures in refurbishment of different residential building typologies across EU country members?***

i. *Which stakeholders are involved?*
ii. *What is their level of interest and influence in the selection of EET?*
iii. *What is the level of communication among each other in the selection of EET process?*

To typify what stakeholders are involved in the decision leading to the technology selection (RQ I.i), what was the level of power of each one and how they interact with each other, the following questions were asked:

With the following questions, we want to find out more about the 4 most important actors for the technology selection ((*|of the technologies that were implemented as part of your project)) of your project (whether through personal conversations, letters, e-mail, online or phone).

Who were the four most important actors you were in contact with for the technology selection *((*|of the technologies that were implemented as part of your project))?*

For your own reference, please note the first name or alias of the names of the four people in the order of importance (first most relevant actor).

- *Actor A: alias + role (dropdown list – %B048%)*
- *Actor B: alias + role (dropdown list – %B049%)*
- *Actor C: alias + role (dropdown list – %B050%)*
- *Actor D: alias + role (dropdown list – %B051%)*

- *I don't know*
- *I had no contact with anyone*

Dropdown list

- *Material or technology trader*
- *Architect*
- *Engineer*
- *Consultant*
- *Installer*
- *Constructor*
- *Public authority*
- *Bank / other financial service company*
- *Facility manager – administrative*
- *Facility manager - technical*
- *Energy supplier / utility or Energy service company*
- *Business association, agency agent*
- *Investment or developing agent*

- *Housing company agent (for profit)*
- *Housing company or association agent (public / non-profit)*
- *Building owner*
- *OTHER company or organisation type in the building sector*

Survey intelligence was developed to place the name of the Alias from the four main stakeholders identified in the previous question. The use of an alias has been found to be a successful tool in investigations when asking about more than three people in relation to a past action. This tool ensures that they 'anchor' their memory and revisit their thought in a more accurate manner.

In order to be able to draft a network of stakeholders involved in the technology selection, we needed to know the relationship between the respondent and the other stakeholders involved in the process. This information was gathered through the following question:

With the following questions, we want to learn more about the relationship between you and the people you just mentioned, in your project.

How often were you in contact with each actor in the technology selection?
(whether face-to-face, by letter, e-mail, online or by phone)

	0 Never	*1*	*2*	*3*	*4*	*5 Daily*	*I do not know*
Alias actor A	o	o	o	o	o	o	o
Alias actor B	o	o	o	o	o	o	o
Alias actor B	o	o	o	o	o	o	o
Alias actor D	o	o	o	o	o	o	o

In order to know what their level of interest and influence was (RQ II.ii), the following two questions were posed. Again, survey intelligence was developed to place the name of the alias from the four main stakeholders identified in the first question.

What was the level of influence of each actor in the technology selection?

	0 None	*1*	*2*	*3*	*4*	*5 Very high*	*Not involved*	*I do not know*
Alias actor A	o	o	o	o	o	o	o	o
Alias actor B	o	o	o	o	o	o	o	o
Alias actor B	o	o	o	o	o	o	o	o
Alias actor D	o	o	o	o	o	o	o	o
Yourself	o	o	o	o	o	o	o	o

What was the level of interest of each actor in the technology selection?

	0 None	1	2	3	4	5 Very high	Not involved	I do not know
Alias actor A	o	o	o	o	o	o	o	o
Alias actor B	o	o	o	o	o	o	o	o
Alias actor B	o	o	o	o	o	o	o	o
Alias actor D	o	o	o	o	o	o	o	o
Yourself	o	o	o	o	o	o	o	o

Finally, to know what the level of communication among stakeholders was (RQ II.iii), respondents were asked about the level of communication between actors involved along the process leading to the technology selection. In order to make this level of communication more tangible, the answer options varied from never to daily. One more time, survey intelligence was developed to place the name of the two respective aliases from the four main stakeholders identified in the first question.

The resulting formulation was:

With the following questions, we want to learn more about the relationship between the actors you just mentioned in your project.

How often did you assume the actors communicated with each other for the technology selection *((*|of the technologies that were implemented as part of your project))* ***?***

	0 Never	1	2	3	4	5 Daily	I do not know
Actor A and B	o	o	o	o	o	o	o
Actor A and C	o	o	o	o	o	o	o
Actor B and C	o	o	o	o	o	o	o
Actor A and D	o	o	o	o	o	o	o
Actor B and D	o	o	o	o	o	o	o
Actor C and D	o	o	o	o	o	o	o

4.4.3. Research question III: Drivers and Barriers to specific building technologies

As described in chapter 3, research question III (RQ III) stated:

> ***III. What are the perceived barriers and drivers for specific energy efficiency technologies in refurbishment projects for different building typologies across EU country members?***
>
> i. *What are considered as the most promising technologies?*
> ii. *What would be needed to upscale these technologies?*
> iii. *How does this vary across stakeholder groups?*

To identify drivers and barriers to specific building technologies (RQ III), it is important to first make sure that the person responding to the query knows about the technology at issue. Therefore, the first thing that the respondent was asked, was on their level of practical experience in the different technologies. Then, the survey was programmed (as part of the survey intelligence) to select the or those technologies the respondent had identified as high or very high experience, asking them about the drivers and barriers in relation to those technologies. The exact formulation of the questions and answer options are listed below. Given that the question was asked in overall for their country, survey intelligence was again programmed to tailor it to the concrete country and technology they have selected.

What is your general level of practical experience regarding the following energy-efficiency and low-carbon technologies in %country%?

If you feel an important technology is missing, please enter it in the last line.

	No experience	*Worked with it once*	*Worked with it several times*	*Part of day-to-day business*
Ventilation (with heat recovery)	o	o	o	o
Energy generation (for self-consumption or feed-in) (such as PV, solar thermal, combined heat and power)	o	o	o	o
Electric direct or storage heating system	o	o	o	o
Wood-based heating systems (such as pellet heating systems, stoves)	o	o	o	o
Heat pumps	o	o	o	o

District heating (normal or low temperature)	o	o	o	o
Electrical cooling systems	o	o	o	o
Geothermal energy systems	o	o	o	o
Energy monitoring, building automation, regulation and control, smart metering	o	o	o	o
High-performance windows	o	o	o	o
Insulation of walls, roofs, floors, etc.	o	o	o	o
Low-carbon materials (such as wood, low-carbon concrete, recycled materials)	o	o	o	o
Please describe	o	o	o	o

For the follow-up question, survey intelligence was developed. If they had selected ‘Part of day-to-day business’ in any of the listed technologies, this technology was selected for the next question asking for barriers and drivers for the technology. If they didn’t select any technology as part of their day-to-day business, they were randomly assigned a technology.

A randomly selected technology was assigned in each questionnaire. The reason for this was that the list of energy efficiency technologies was quite extensive and asking on this question for each of the technologies would have made the question too long, increasing the risk of drop-out from the survey. Survey intelligence needed to be coded to implement the random selection of the technology as well as to include the country the respondent belonged to in the formulation of the question.

What are the key barriers for %technology% in the current %country% market?

The technology is randomly selected and assigned to you.

- *Environmental*
    - o *Lack of ambitious and clear political environmental targets*
    - o *Lack of environmental awareness*
- *Technical*
    - o *Lack of reliable technologies*
    - o *Lack of high-performance technologies*
    - o *Lack of simple production process*

- *Lack of comprehensive information about alternatives and advantages/disadvantages*
- *Economic*
    - *Lack of affordable products*
    - *Low energy prices*
    - *Lack of subsidies*
    - *Lack of tax incentives*
    - *Lack of trust / awareness of lower life cycle / running costs*
    - *Lack of comprehensive financing models*
    - *Lack of qualified organizations/ employees (e.g. for installation, construction)*
- *Social*
    - *Lack of trust / awareness in higher acoustic comfort*
    - *Lack of trust / awareness in heat comfort*
    - *Lack of interest in attractive design*
    - *Lack of short or easy installation or maintenance*
    - *Lack of education*
- *Legal*
    - *Lack of a comprehensive legal framework*
    - *Lack of a comprehensive building standards*
    - *Lack of implementation of legal standards*

Other: Please describe

- *I do not think this technology should scale up*
- *I do not know*

Results from the piloting phase of the survey showed that the word ‘driver’ was difficult to understand for some of the stakeholder groups, that is why the exact formulation of the question was adapted to ‘what should happen to scale the technology’, as can be seen in the question below.

Again, a randomly selected technology was assigned in each questionnaire. The reason for this was that the list of energy efficiency technologies was quite extensive and asking on this question for each of the technologies would have made the question too long, increasing the risk of drop-out from the survey. Survey intelligence needed to be coded to implement the random selection of the technology as well as to include the country the respondent belonged to in the formulation of the question.

What should happen to scale %technology% in %country%?
The technology is randomly selected and assigned to you.

- *Environmental*
    - *Improvement of the technology’s environmental performance (e.g. less energy consumption or carbon emissions)*
    - *Energy input such as electricity, district heat, gas, oil should be produced more from renewable energy sources*
- *Technical*
    - *Improvement of the reliability and functionality*
    - *Easier installation process*
    - *Application comfort improvement*
    - *Better design*
    - *Improved advertising*

- *Economic*
    - *Price decrease and shorter payback time*
    - *Energy cost saving and low running costs*
- *Social*
    - *Better marketing of technology*
    - *Improved consideration of demands by tenants and building owners*
    - *Improved communication in project teams*
    -
- *Legal, standards and labels*
    - *Enforcement of building codes or by other legal requirements*
    - *Promotion of energy-efficiency, low-carbon or sustainability labels for buildings*
    - *Information campaign of authorities*
- *Other: Please describe*

- *I do not think this technology should scale up*
- *I do not know*

To answer to RQ III.ii (i.e. What are considered as the most promising technologies?), the following question was posed?

Which four measures have the highest potential to contribute to reaching ambitious climate-protection goals in %country%?

Please mark two answers each for refurbishment and new buildings, respectively.

	Refurbishment	***New Building***
The heating system		
The centralized energy production		
The decentralized energy production		
The ventilation system		
The building envelope		
The user		
Monitoring, regulation and controls		
Efficient household appliances		
Other: Please describe		
I don't know / can't judge:		

To answer to RQ III.iii (i.e. What would be needed to upscale these technologies?), the following question was posed. One more time, a randomly selected technology was assigned in each questionnaire. The reason for this was that the list of energy efficiency technologies was quite extensive and asking on this question for each of the technologies would have made the question too long, increasing the risk of drop-out from the survey. Survey intelligence needed to be coded to implement the random selection of the technology as well as to include the country the respondent belonged to in the formulation of the question.

What should happen to scale %tech% in %country%?
The technology is randomly selected and assigned to you.

- *Environmental*
  - *Improvement of the technology's environmental performance (e.g. less energy consumption or carbon emissions)*
  - *Energy input such as electricity, district heat, gas, oil should be produced more from renewable energy sources*
- *Technical*
  - *Improvement of the reliability and functionality*
  - *Easier installation process*
  - *Application comfort improvement*
  - *Better design*
  - *Improved advertising*
- *Economic*
  - *Price decrease and shorter payback time*
  - *Energy cost saving and low running costs*
- *Social*
  - *Better marketing of technology*
  - *Improved consideration of demands by tenants and building owners*
  - *Improved communication in project teams*
- *Legal, standards and labels*
  - *Enforcement of building codes or by other legal requirements*
  - *Promotion of energy-efficiency, low-carbon or sustainability labels for buildings*
  - *Information campaign of authorities*
- *Other: Please describe*

- *I do not think this technology should scale up*
- *I do not know*

Given that responses are provided per stakeholder group, responses will be analysed in order to categorize the drivers and barriers for specific technologies based on the stakeholder perspective. Hence answering to RQ III.iii i.e. i. (I.e. How does this vary across stakeholder groups?).

4. STATUS OF THE SURVEY

This chapter shows the status of the roll-out of the survey (as of April 2019) in Poland, Italy, Spain, Germany, United Kingdom and the Netherlands. To this end, the overall quota is presented, as well as a breakdown of the number of responses per country.

5.1. Quota

As described in the previous chapter, the final step in the survey development is the survey distribution. In order to ensure the coherence of results on a national level as well as across countries, detailed distribution instructions were elaborated, and the progress of the dissemination was scrupulously guided and monitored by the author of this thesis. The current number of responses, however, varies across countries (see table 5.1). There are two main reasons for this: (i) although the methodology is designed and implemented homogeneously across the selected countries, the effect can be different due to different national, regional and local contexts. (ii) The starting date for the distribution varies across countries, and Poland, Germany, the U.K., France and the Netherlands, the survey distribution is still ongoing.

It is important to note that, given the scope of the survey was larger than the one defined by the research questions, there is a divergence between the total number of responses to the survey and the total number of responses from the analysed set per country.

Table 5.1 Number of survey responses per country

Acronym	**Country Name**	**Full set (N)** *(total number of responses obtained in the survey)*	**Analysed set (N)** *(total number of responses that can be used for the analysis of this thesis)*
PL	Poland*	310	306
IT	Italy	673	661
SP	Spain	907	546
DE	Germany*	201	200
UK	United Kingdom*	17	13
FR	France*	81	72
NL	The Netherlands*	12	9

**: distribution of the survey is ongoing*

5.2. Poland

The breakdown of the responses in Poland, based on the defined stratified sample is shown in table 5.2 below. Currently, the stakeholder group that has provided the highest number of responses are architects and engineers within the group ‘1. Conceiving, planning, and consulting services’. The survey distribution is, however, still ongoing. A minimum number of responses from all stakeholder groups is expected (as well as project types and building typologies) once the distribution process of the survey is finalized in this country.

Table 5.2. Breakdown of survey number of responses in Poland.

		Project type								
		New built		**Comprehensive Retrofit**		**Partial Retrofit**		**Sub-Total**		**Grand total**
		SDH	**MDH**	**SDH**	**MDH**	**SDH**	**MDH**	**SDH**	**MDH**	
	Bucket no.	*1*	*2*	*3*	*4*	*5*	*6*			
1. Conceiving, planning, and consulting services	1.1. Architect	7	10	5	1	4	4	16	15	**31**
	1.2. Engineer	7	4	5	10	2	12	14	22	**36**
Sub-total	***Main Group 1***	**14**	**14**	**10**	**11**	**6**	**16**	**30**	**37**	**67**
2. Material and technology suppliers	2.1. Technology or material manufacturer or trader	3	2	1	0	5	4	9	6	**15**
3. Construction and installation	3.1. Construction Company	3	2	0	1	3	1	6	4	**10**
	3.2. Installer	1	1	0	0	2	1	3	1	**4**
Sub-total	***Main Group 3***	**4**	**3**	**0**	**1**	**5**	**2**	**9**	**5**	**14**
4. Enabling services	4.1. Local public authorities	0	0	0	2	1	0	1	2	**3**
	4.2. Bank or other financial services	0	0	1	0	1	2	2	2	**4**

Sub-total	***Main Group 4***	**0**	**0**	**1**	**2**	**2**	**2**	**3**	**4**	**7**
5. Operation and maintenance services	5.1. Facility manager (commercial, administrative)	1	0	0	1	0	5	1	6	**7**
	5.2. Facility manager (technical, maintenance etc.)	0	0	0	1	0	0	0	1	**1**
	5.3. Energy supply/utility and Energy service company (ESCO)	0	0	1	1	0	0	1	1	**2**
Sub-total	***Main Group 5***	**1**	**0**	**1**	**3**	**0**	**5**	**2**	**8**	**10**
6. Institutional demand side	**6.1. Investor or Developer**	2	6	2	4	1	3	5	13	**18**
	6.2. Housing company (for profit)	8	1	4	1	8	2	20	3	**23**
	6.3. Housing company or housing association, cooperative (public/ part Governmental/ non-profit)	2	2	0	7	3	5	5	12	**17**
Sub-total	***Main Group 6***	**12**	**9**	**6**	**12**	**12**	**10**	**30**	**28**	**58**
7.Private demand side	7.1. Private house owner	6	0	1	2	0	1	7	3	**10**
	7.2. Self-occupying private house owner	3	2	5	3	11	3	19	6	**25**
Sub-total	***Main Group 7***	9	2	6	5	11	4	26	9	**35**
	Other	13	0	10	16	22	22	45	38	**83**
Grand total	***Grand total***	**56**	**30**	**35**	**50**	**63**	**65**	**159**	**147**	**306**

5.3 Italy

The breakdown of the responses in Italy, based on the defined stratified sample is shown in table 5.3 below. The survey closed with 673 completed questionnaires out of which a total of 661 responses are eligible for the analysis. The stakeholder group that has provided the highest number of responses are ‘6. Institutional demand side’ (n=173) and the least ‘7. Private demand side’ (n=28). The most often selected project is partial retrofit and building typology is single-dwelling house (SDH), being partial retrofit of SDH the most often selected bucket.

Table 5.3. Breakdown of survey number of responses in Italy

		Project type								
		New built		Comprehensive Retrofit		Partial Retrofit		Sub-Total		Grand total
		SDH	MDH	SDH	MDH	SDH	MDH	SDH	MDH	
	Bucket no.	*1*	*2*	*3*	*4*	*5*	*6*			
1. Conceiving, planning, and consulting services	1.1. Architect	6	3	5	4	7	6	18	13	31
	1.2. Engineer	5	2	3	3	8	1	16	6	22
Sub-total	***Main Group 1***	***11***	***5***	***8***	***7***	***15***	***7***	***34***	***19***	***53***
2. Material and technology suppliers	2.1. Technology or material manufacturer or trader	8	6	9	7	21	14	38	27	65
3. Construction and installation	3.1. Construction Company	13	5	9	8	10	11	32	24	56
	3.2. Installer	6	3	11	3	20	2	37	8	45
Sub-total	***Main Group 3***	***19***	***8***	***20***	***11***	***30***	***13***	***69***	***32***	***101***
4. Enabling services	4.1. Local public authorities	3	1	3	2	2	2	8	5	13

	4.2. Bank or other financial services	19	2	21	1	9	7	49	10	59
Sub-total	***Main Group 4***	***22***	***3***	***24***	***3***	***11***	***9***	***57***	***15***	***72***
5. Operation and maintenance services	5.1. Facility manager (commercial, administrative)	2	2	1	0	1	1	4	3	7
	5.2. Facility manager (technical, maintenance etc.)	5	2	7	2	9	0	21	4	25
	5.3. Energy supply/utility and Energy service company (ESCO)	10	2	6	6	17	13	33	21	54
Sub-total	***Main Group 5***	***17***	***6***	***14***	***8***	***27***	***14***	***58***	***28***	***86***
6. Institutional demand side	**6.1. Investor or Developer**	15	4	5	2	10	3	30	9	39
	6.2. Housing company (for profit)	17	11	14	8	27	10	58	29	87
	6.3. Housing company or housing association, cooperative (public/ part Governmental/ non-profit)	15	7	11	4	7	3	33	14	47
Sub-total	***Main Group 6***	***47***	***22***	***30***	***14***	***44***	***16***	***121***	***52***	***173***
7.Private demand side	7.1. Private house owner	1	1	1	0	1	1	3	2	5
	7.2. Self-occupying private house owner	2	0	8	1	7	5	17	6	23
Sub-total	***Main Group 7***	3	1	9	1	8	6	20	8	28
	Other	5	1	10	3	10	7	25	11	36
Grand total	***Grand total***	***132***	***52***	***124***	***54***	***166***	***86***	***455***	***206***	***661***

5.4. Spain

The breakdown of the responses in Spain, based on the defined stratified sample is shown in table 5.4 below. The survey closed with 907 completed questionnaires, out of which a total of 546 responses are eligible for the analysis. The stakeholder group that has provided the highest number of responses are ‘7. Private demand side’ (n=270) and the least ‘3. Construction and installation’ (n=71). The most often selected project is partial retrofit and building typology is single-dwelling house (SDH), (n=455). However, deep retrofit of MDH is the most often selected ‘bucket’ (n=72).

Table 5.4. Breakdown of survey number of responses in Spain

		Project type								
		New built		**Comprehensive Retrofit**		**Partial Retrofit**		**Sub-Total**		**Grand total**
		SDH	**MDH**	**SDH**	**MDH**	**SDH**	**MDH**	**SDH**	**MDH**	
	Bucket no.	*1*	*2*	*3*	*4*	*5*	*6*			
1. Conceiving, planning, and consulting services	1.1. Architect	2	6	4	4	9	5	15	15	30
	1.2. Engineer	0	8	0	13	3	0	3	21	24
Sub-total	***Main Group 1***	***2***	***14***	***4***	***17***	***12***	***5***	***18***	***36***	***54***
2. Material and technology suppliers	2.1. Technology or material manufacturer or trader	1	3	3	1	4	1	8	5	13
3. Construction and installation	3.1. Construction Company	6	0	0	1	0	0	6	1	7
	3.2. Installer	5	2	2	7	8	4	15	13	28
Sub-total	***Main Group 3***	***11***	***2***	***2***	***8***	***8***	***4***	***21***	***14***	***35***
4. Enabling services	4.1. Local public authorities	2	2	0	2	2	4	4	8	12

	4.2. Bank or other financial services	1	0	1	2	0	1	2	3	5
Sub-total	***Main Group 4***	***3***	***2***	***1***	***4***	***2***	***5***	***6***	***11***	***17***
5. Operation and maintenance services	5.1. Facility manager (commercial, administrative)	1	1	2	5	6	23	9	29	38
	5.2. Facility manager (technical, maintenance etc.)	0	0	1	0	2	2	3	2	5
	5.3. Energy supply/utility and Energy service company (ESCO)	3	2	1	2	1	3	5	7	12
Sub-total	***Main Group 5***	***4***	***3***	***4***	***7***	***9***	***28***	***17***	***38***	***55***
6. Institutional demand side	**6.1. Investor or Developer**	4	22	1	11	0	0	5	33	38
	6.2. Housing company (for profit)	4	5	7	1	11	5	22	11	33
	6.3. Housing company or housing association, cooperative (public/ part Governmental/ non-profit)	4	7	3	4	1	4	8	15	23
Sub-total	***Main Group 6***	***12***	***34***	***11***	***16***	***12***	***9***	***35***	***59***	***94***
7.Private demand side	7.1. Private house owner	1	2	4	3	5	1	10	6	16
	7.2. Self-occupying private house owner	7	7	7	16	15	9	29	32	61
Sub-total	***Main Group 7***	8	9	11	19	20	10	39	38	77
	Other	1	10	5	12	11	4	17	26	43
Grand total	***Grand total***	***41***	***67***	***36***	***72***	***67***	***62***	***345***	***201***	***546***

5.5. Germany

The breakdown of the responses in Germany, based on the defined stratified sample is shown in table 5.5 below. Currently, the stakeholder group that has provided the highest number of responses are architects and engineers within ‘1. Conceiving, planning, and consulting services’. The survey distribution is, however, still ongoing. A minimum number of responses from all stakeholder groups is expected (as well as project types and building typologies) once the distribution process of the survey is finalized in this country.

Table 5.5. Breakdown of survey number of responses in Germany.

		Project type								
		New built		**Comprehensive Retrofit**		**Partial Retrofit**		**Sub-Total**		**Grand total**
		SDH	**MDH**	**SDH**	**MDH**	**SDH**	**MDH**	**SDH**	**MDH**	
	Bucket no.	*1*	*2*	*3*	*4*	*5*	*6*			
1. Conceiving, planning, and consulting services	1.1. Architect	5	3	5	5	3	1	13	9	22
	1.2. Engineer	7	7	4	5	8	4	19	16	35
Sub-total	***Main Group 1***	***12***	***10***	***9***	***10***	***11***	***5***	***32***	***25***	***57***
2. Material and technology suppliers	2.1. Technology or material manufacturer or trader	2	1	3	1	4	1	9	3	12
3. Construction and installation	3.1. Construction Company	2	2	1	0	1	0	4	2	6
	3.2. Installer	1	1	3	2	3	2	7	5	12
Sub-total	***Main Group 3***	***3***	***3***	***4***	***2***	***4***	***2***	***11***	***7***	***18***
4. Enabling services	4.1. Local public authorities	1	3	4	4	1	5	6	12	18
	4.2. Bank or other financial services	0	0	0	0	1	0	1	0	1

Sub-total	***Main Group 4***	***1***	***3***	***4***	***4***	***2***	***5***	***7***	***12***	***19***
5. Operation and maintenance services	5.1. Facility manager (commercial, administrative)	0	0	0	1	0	0	0	1	1
	5.2. Facility manager (technical, maintenance etc.)	0	0	0	0	0	0	0	0	0
	5.3. Energy supply/utility and Energy service company (ESCO)	0	1	0	0	1	0	1	1	2
Sub-total	***Main Group 5***	***0***	***1***	***0***	***1***	***1***	***0***	***1***	***2***	***3***
6. Institutional demand side	**6.1. Investor or Developer**	0	0	0	0	0	0	0	0	0
	6.2. Housing company (for profit)	0	2	0	0	1	1	1	3	4
	6.3. Housing company or housing association, cooperative (public/ part Governmental/ non-profit)	0	5	0	8	0	2	0	15	15
Sub-total	***Main Group 6***	***0***	***7***	***0***	***8***	***1***	***3***	***1***	***18***	***19***
7.Private demand side	7.1. Private house owner	0	0	3	2	2	1	5	3	8
	7.2. Self-occupying private house owner	1	1	2	0	5	1	8	2	10
Sub-total	***Main Group 7***	1	1	5	2	7	2	13	5	18
	Other	4	5	9	4	7	10	20	19	39
Grand total	***Grand total***	***23***	***31***	***34***	***32***	***37***	***28***	***94***	***106***	***200***

5.6. The United Kingdom

The breakdown of the responses in the United Kingdom, based on the defined stratified sample is shown in table 5.6 below. However, the survey distribution is still ongoing in this market, so no further conclusions can be derived. A minimum number of responses from all stakeholder groups is expected (as well as project types and building typologies) once the distribution process of the survey is finalized in this country.

Table 5.6. Breakdown of survey number of responses in the United Kingdom.

		Project type								
		New built		**Comprehensive Retrofit**		**Partial Retrofit**		**Sub-Total**		**Grand total**
		SDH	**MDH**	**SDH**	**MDH**	**SDH**	**MDH**	**SDH**	**MDH**	
	Bucket no.	*1*	*2*	*3*	*4*	*5*	*6*			
1. Conceiving, planning, and consulting services	1.1. Architect	0	0	0	1	0	0	0	1	1
	1.2. Engineer	0	0	1	0	0	0	1	0	1
Sub-total	***Main Group 1***	***0***	***0***	***1***	***1***	***0***	***0***	***1***	***1***	***2***
2. Material and technology suppliers	2.1. Technology or material manufacturer or trader	0	0	0	0	1	1	1	1	2
3. Construction and installation	3.1. Construction Company	0	0	0	0	0	0	0	0	0
	3.2. Installer	0	2	0	0	0	0	0	2	2
Sub-total	***Main Group 3***	***0***	***2***	***0***	***0***	***0***	***0***	***0***	***2***	***2***
4. Enabling services	4.1. Local public authorities	0	0	0	0	0	0	0	0	0
	4.2. Bank or other financial services	0	0	0	0	0	0	0	0	0
Sub-total	***Main Group 4***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***

5. Operation and maintenance services	5.1. Facility manager (commercial, administrative)	0	0	0	0	0	0	0	0	0
	5.2. Facility manager (technical, maintenance etc.)	0	0	0	1	0	0	0	1	1
	5.3. Energy supply/utility and Energy service company (ESCO)	0	0	0	0	0	0	0	0	0
Sub-total	***Main Group 5***	***0***	***0***	***0***	***1***	***0***	***0***	***0***	***1***	***1***
6. Institutional demand side	**6.1.Investor or Developer**	0	0	0	0	0	0	0	0	0
	6.2. Housing company (for profit)	0	0	0	0	0	0	0	0	0
	6.3. Housing company or housing association, cooperative (public/ part Governmental/ non-profit)	0	0	0	0	0	0	0	0	0
Sub-total	***Main Group 6***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
7.Private demand side	7.1. Private house owner	0	0	0	0	0	0	0	0	0
	7.2. Self-occupying private house owner	0	0	0	0	0	0	0	0	0
Sub-total	***Main Group 7***	***0***	***0***	***0***	***1***	***0***	***0***	***0***	***1***	***1***
	Other	0	1	1	2	0	2	1	5	6
Grand total	***Grand total***	***0***	***3***	***2***	***4***	***1***	***3***	***3***	***10***	***13***

5.7. The Netherlands

The breakdown of the responses in the Netherlands, based on the defined stratified sample is shown in table 5.7 below. The survey distribution is, however, still ongoing. A minimum number of responses from all stakeholder groups is expected (as well as project types and building typologies) once the distribution process of the survey is finalized in this country.

Table 5.7: Breakdown of survey number of responses in the Netherlands.

		Project type								
		New built		**Comprehensive Retrofit**		**Partial Retrofit**		**Sub-Total**		**Grand total**
		SDH	**MDH**	**SDH**	**MDH**	**SDH**	**MDH**	**SDH**	**MDH**	
	Bucket no.	*1*	*2*	*3*	*4*	*5*	*6*			
1. Conceiving, planning, and consulting services	1.1. Architect	0	1	0	0	0	0	0	1	1
	1.2. Engineer	0	0	0	0	0	0	0	0	0
Sub-total	***Main Group 1***	***0***	***1***	***0***	***0***	***0***	***0***	***0***	***1***	***1***
2. Material and technology suppliers	2.1. Technology or material manufacturer or trader	0	0	0	0	0	0	0	0	0
3. Construction and installation	3.1. Construction Company	0	0	0	1	0	0	0	1	1
	3.2. Installer	1	0	0	0	0	0	1	0	1
Sub-total	***Main Group 3***	***1***	***0***	***0***	***1***	***0***	***0***	***1***	***1***	***2***
4. Enabling services	4.1. Local public authorities	0	0	0	0	1	0	1	0	1
	4.2. Bank or other financial services	0	0	0	0	1	0	1	0	1
Sub-total	***Main Group 4***	***0***	***0***	***0***	***0***	***2***	***0***	***2***	***0***	***2***

5. Operation and maintenance services	5.1. Facility manager (commercial, administrative)	0	0	0	0	0	0	0	0	0
	5.2. Facility manager (technical, maintenance etc.)	0	0	0	0	0	0	0	0	0
	5.3. Energy supply/utility and Energy service company (ESCO)	0	0	0	0	0	0	0	0	0
Sub-total	***Main Group 5***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
6. Institutional demand side	**6.1. Investor or Developer**	0	0	0	0	0	0	0	0	0
	6.2. Housing company (for profit)	0	0	0	0	0	0	0	0	0
	6.3. Housing company or housing association, cooperative (public/ part Governmental/ non-profit)	0	0	0	0	0	1	0	1	1
Sub-total	***Main Group 6***	***0***	***0***	***0***	***0***	***0***	***1***	***0***	***1***	***1***
7.Private demand side	7.1. Private house owner	0	0	0	0	0	0	0	0	0
	7.2. Self-occupying private house owner	0	0	0	0	0	0	0	0	0
Sub-total	***Main Group 7***	0	0	0	0	0	0	0	0	0
	Other	0	2	0	0	2	1	2	3	5
Grand total	***Grand total***	***1***	***3***	***0***	***1***	***4***	***2***	***5***	***7***	***12***

6. DISCUSSION AND CONCLUSIONS

This chapter lists some of the deductions obtained from work developed in this licentiate thesis. Accordingly, the two key parts of the thesis are critically discussed, the literature study and the survey development and subsequent database generation. Conclusions are drawn thereafter.

6.1. Literature review

The purpose of the first part of this thesis was to define the state-of-the-art (SOTA) in relation to the uptake of EET in residential building projects in Europe. To this end, a deductive research approach was followed, consisting of preliminary theory study, formulating hypotheses, observation of existing knowledge and testing the hypotheses. The selection and mapping of the article titles was conducted through a bibliometric analysis, a quantitative research tool to explore knowledge networks based on published literature.

The bibliometric analysis proved to be a useful method for the defined goal. The co-citation network analysis allowed an accurate mapping of the scientific basis, based on co-citations, identifying key research topics and niches. Results from the bibliometric analysis suggest that (1) the characterization of EETM, (2) decision-making behind the uptake or diffusion of energy efficiency technologies and (3) multiple impacts (MI) of their uptake, are key topic areas within this research field. Moreover, it demonstrates that this field has gained considerable momentum in the past decade, but it still lacks a comprehensive understanding, especially on a cross-country level. Hence, further research and data generation is needed. The identified lack of cross-country comprehensive understanding lies in accordance with the preliminary sources and hypotheses traced. It also partially explains the energy efficiency gap, as this lack of evidence can hinder the path of decision-makers in taking effective actions.

Results from the bibliometric analysis can contribute to the scientific knowledge, as they provide a comprehensive quantitative and qualitative overview of the SOTA in relation to the uptake of EET in residential building projects in Europe. It also offers a network visualization of the publications in this field. This can support peer researchers in the visualization of the field, relevant topics and key papers. However, in order to advance in this sphere of knowledge, further research will be needed. This scientific effort should ideally be conducted in an orchestrated and collaborative manner. It should also ensure the information gathered is useful for the society by guaranteeing its suitability of application in the path towards the decarbonization of the residential building stock in Europe.

6.2. Survey and database generation

In the second part of the work, an online survey was developed. The goal of the survey was to gather empirical evidence and be able to answer the research questions. Given the complex and fragmented nature of the residential building market (i.e. the various stakeholders groups, building typologies, project types, etc.), a stratified sample approach and survey intelligence are developed. The survey has been distributed in Germany, the United Kingdom, France, Spain, Italy, the Netherlands and Poland.

The development and operationalization of the survey, through its distribution in Spain and Italy, successfully demonstrated that factual documentation in the uptake of energy efficiency technologies can be gathered, both on a national and cross-national scale. Furthermore, this information can address the different stakeholder perspectives, building typologies and project types present in the building value chain. The online format of the survey showed that it is a suitable research tool to address for this purpose, as it could adapt to tackle many different variables and combinations of these variables needed to gather all of this information.

However, for a decisive achievement of results from the survey, a minimum number of responses is required (i.e. quota). Given the three axes of stratification and multiple variables entailed in each of these axes, the minimum quota that is needed for a comprehensive database is relatively high. The experience of distributing the survey in the first seven countries has shown that acquiring the minimum number of responses can be a very demanding task in three main ways: (1) budget required, (2) management and coordination of the partners in each country, and (3) efforts and dedication needed from the local partners to achieve the minimum number of responses from each stakeholder group. This high level of demand in the distribution of the survey to achieve a minim quota can introduce challenges in the upscaling of the survey (i.e. roll-out into other countries). Most of these challenges can be overcome through the experience acquired from the first seven countries. However, contextual factors vary from country to country that can affect the favourable distribution of the survey. These cannot be and will need to be solved *ad hoc*.

The responses gathered from the survey (if statistically valid) can provide a comprehensive database to characterize relevant aspects in the uptake of energy efficiency technologies. This information will be represented for different building typologies and across countries. It can, therefore, address the existing knowledge gaps defined by [44,104]. This can be a contribution to the scientific community by defining an aligned methodology that can be applied to any country to create a cross-country understanding. Furthermore, the information gathered can be linked to other models, such as BSM, as described in the next section.

7. FUTURE RESEARCH

Research to be covered until the end of the Ph.D. project and respective planned publications are introduced below. This is complemented with the link to other research fields.

7.1. National-scale statistical validity

Attaining a well-rounded stratified sample of the survey is a key aspect of this study due to its goal and the stratiform sample approach that has been adopted. Within the remaining phase of this Ph.D. project, efforts will be allocated to ensuring that a sufficient quota is reached in every market. Once the minimum quota has been fulfilled for all stated countries, descriptive statistics will be conducted to evaluate if statistical validity of the results can be attained (e.g. Chi squared tests).

7.2. Further data analysis and upcoming journal papers

Once the statistical validity of the results has been assessed, further analysis methods will be applied to the data in order to be able to answer to the research questions. Each of the research questions points out at a specific aspect in the uptake of EET and, therefore, requires of a specific type of analysis. Hereunder a brief description of the planned analyses for each topic (i.e. research questions) and respective publication.

7.2.1. Characterization of energy efficiency technology measures (Planned paper #1)

In order to characterize what EETM are taking place in the different building typologies, contexts and countries analysed in this study, planned paper #1 will cluster EETM into building typologies and project types. A regression analysis will be then conducted in order to discern if the motivation behind each type of project affects the type of energy efficiency measure or ambition level that is implemented in each case. This paper will also compare this information across the EU Member States.

7.2.2. Stakeholder setup in the selection of EETM (Planned paper #2)

As previously described, in the process leading to the technology selection stakeholder groups involved, the level of interaction, interest and influence varies for different project types and market contexts. Upcoming paper #2 will make use of Social Network Analysis (SNA) methods to quantitative and qualitative characterise the stakeholder structure and roles of the specific stakeholders in relation to the technology selection in residential building projects. This paper will also compare this information across the EU Member States.

7.2.3. Perceived barriers and drivers for specific energy efficiency technologies (Planned paper #2)

As described in scientific sources, perceived barriers and drivers for energy efficiency technologies vary across stakeholder groups and market contexts. Understanding drivers and barriers for specific technologies are key in order to develop tailored bottom-up instruments to foster their implementation. The final paper planned within the scope of this Ph.D. project (paper #3), will characterise the drivers and barriers to specific energy efficiency technologies. A regression analysis will be conducted in order to detect if these vary across stakeholder groups and/or across the EU Member States.

7.3. Connection to other research fields

There are a number of possible connection points to other research fields in the vicinity of the Ph.D. within the research group, the department and the research network in which the Ph.D. project is embedded in. The most relevant ones are listed below:

7.3.1. Development of a model to feed into multinomial logit models (MNL) and BSMs

The final results from the survey, if statistically valid, can provide empirical evidence in the uptake of EET on a national and cross-national scale. This information can have many applications. One of its uses lies within the field of BSM. Statistically valid results from the survey could support the validation and/or calibration of some of the assumptions made by many of the BSMs that are currently being used in the European context to calculate energy demand and CO_2 emissions. Especially those models in which the selection of the technology is primarily based on the technology costs (e.g. multinomial logit model, MNL). For BSM based on MNL, statistically valid results of the aspects addressed in this survey could provide insights of exogenous factors affecting the selection of a specific technology, such as stakeholders involved, level of influence, drivers and barriers in relation to a specific technology, etc. Hence, provide a more comprehensive understanding of the actual process behind the uptake of EET. In this line, further research within the scope of this project will seek to develop a framework to enable the implementation of these findings within the multinomial logit model (MNL).

7.3.2. Multiple impacts (MI) of energy efficiency technology measures (EETM)

There is a strong consensus that EETM can offer a wide range of positive side-effects beyond the potential energy cost savings and that these can, oftentimes, even outweigh the direct costs of the potential energy savings. However, these positive side effects are seldom quantified or taken into consideration by decision-makers. Further research within this project will focus on assessing some of these positive effects. More particularly in classifying what are the benefits that have been identified as most appealing by key decision-makers directly involved in the technology selection and how this information could be used to support the development of policy instruments. The methodology should enable a cross-country comparison of the results among the EU member countries.

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ANNEXES

This licentiate thesis comprises the following annexes:

- Annex 1: Uptake of energy efficiency technologies in European residential buildings: A bibliometric analysis
- Annex 2: Specific Barriers to Massive Scale Energetic Refurbishment for Sample Markets in Europe
- Annex 3: BMB Project Description
- Annex 4: Survey Methodology & Instructions for Local Partners
- Annex 5: Survey Questionnaire