Deep REnovation roadmaps to decrease households VulnERability to Energy poveRty

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Disclaimer

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Executive Summary

REVERTER aims to develop 9 roadmaps in four different European areas (Brezovo-Bulgaria, Athens Urban area-Greece, Riga-Latvia and Coimbra-Portugal) in order to effectively alleviate EP through deep renovation of houses of vulnerable households. The roadmaps will target the worst-performing homes first ("worst first" principle), will cope with split-incentive dilemmas and will address market, information and behavioural failures through the creation of "one-stop shops'' (OSS) as defaults for the enrolment of vulnerable households in subsidised energy efficiency improvement programmes. The overall aim is to improve the quality of life for vulnerable citizens across Europe through providing energy advice which leads to energy efficiency improvements. The four REVERTER pilots will engage with vulnerable citizens and local, national and EU stakeholder groups and experts to create long-term sustainable impacts at local, national and regional levels.

In such a context, it is important to review the existing knowledge from EU-supported projects and scientific and grey literature, to establish an up-to-date scientific and technical baseline and fill existing gaps in the fields of (a) energy poverty (EP) definitions, drivers and indicators (b) deep renovation measures (such as building envelope insulation, replacement/improvement of the technical building systems, and window replacement, etc.); and (c) EP and building renovation roadmaps. It is also important to review of market, information (such as energy-financial illiteracy) and behavioural barriers and biases and the role that scarcity conditions have on decision-making, with the aim to (a) identify certain cognitive biases that might arise in EP contexts, and (b) devise strategies to unlock individuals' potential to make decisions that result in better outcomes for themselves and their surroundings.

Deliverable 2.1 presents a state-of-the-art review and assessment of several aspects related to EP, being the result of T.2.1-2.4, namely:

- T.2.1. Review and assessment of the state-of-the-art knowledge in EP, energy retrofits and road mapping
- T.2.2. Assessment and prioritisation of alternative energy-saving measures
- T.2.3. Review and assessment of renovation barriers and multiple benefits
- T.2.4. Assessment of policies, initiatives, strategies, etc. for the alleviation of EP and the promotion of deep renovation at national, regional and local levels

Drivers, Definitions, and Indicators for EP

The drivers, definitions and indicators for EP were reviewed. A plethora of scientific publications, studies, and technical reports providing insights into specific indicators for EP and strategies to combat this issue are readily accessible. The magnitude of events cantered on EP is substantial, and governments are actively formulating policies to ensure inclusivity. Nevertheless, the predicament persists and is exacerbated by the pressing demand for a transition to clean energy, placing more households in precarious situations.

Measuring the number of households grappling with EP proves challenging due to its multidimensional nature, temporal and spatial variability, and private characteristics. The literature reveals a divergence among experts regarding the optimal indicators and metrics for measuring EP, given its complexity — a multifaceted, socially sensitive matter affecting various sectors such as energy, infrastructure, health, and mobility. Despite this divergence, experts unanimously acknowledge the importance of measurement in devising effective solutions to address the problem. Key gaps in indicators have been identified, encompassing issues like summer EP, housing deficiencies or well-being, energy illiteracy, digital literacy, gender sensitivity (particularly gender bias in policy-making), resilience to climate change (evaluated in terms of environmental sustainability and technological advancement), resilience to vulnerabilities (measuring the ability to cope with adversity), transport poverty, and health-related impacts.

The main indicator gaps identified include summer energy poverty, housing faults or well-being, energy and digital illiteracy, gender sensitivity, resilience to climate change (assessing how green and digital solutions are), resilience to vulnerabilities (measuring ability to cope with adversity), transport poverty, and health-related impacts. Additionally, not all parameters related to energy poverty are integrated into the current definition. Therefore, ongoing research is crucial to determine all relevant parameters and gather the necessary data. A significant challenge in calculating energy poverty indicators is the lack of appropriate data. Existing data is limited, and efforts to develop a universally applicable Energy Poverty Indicator remain a contentious and unresolved issue.

EP and Building Renovation Roadmaps

The Long-Term Renovation Strategies (LTRS) of 10 EU Member States were analysed to identify the most essential aspects of the renovation roadmaps. All of the LTRS incorporate a monitoring scheme to ensure the effective implementation of renovation policies and measures, with the exception of Greece. Within the LTRS framework, comprehensive mapping and reporting of the main market and non-market barriers affecting building stock renovation have been conducted.

The main market and non-market barriers affecting building renovation have been mapped within the LTRS framework. The significant barriers include high renovation costs with long payback periods, limited access to financing and reluctance of banks to lend, lack of awareness about effective energy efficiency interventions, insufficient skills and training among involved actors, uncertainty about future technology, energy prices, and regulations, high bureaucracy in existing renovation programs, a complex regulatory framework for building renovation, complicated building ownership structures, and split-incentive dilemmas.

The analysis of existing roadmaps led to several policy recommendations for effective renovation roadmaps. These include explicitly defining renovation targets in absolute values and percentages of the building stock, determining the trajectory and milestones for achieving these targets, identifying cost-effective energy efficiency intervention packages, and estimating the required investments for achieving the specified targets. It is also important to map and assess potential barriers and propose suitable solutions, identify effective policies and measures to mobilise investments and address barriers, establish a monitoring mechanism for assessing target achievement, consult with relevant stakeholders to reach a consensus on the roadmap, and design and implement early actions to initiate the renovation roadmap.

Assessment of Deep Renovation Measures

Various energy efficiency measures were assessed to identify the most appropriate set for reference buildings in each pilot region, considering both Multi-Family Buildings (MFB) and Single-Family Buildings (SFB). A methodology was then formulated to evaluate and prioritise alternative deep renovation packages (DRPs) for each reference building in every pilot area. This evaluation considered financial, technical, social, and environmental criteria, with a specific focus on utilising Life Cycle Assessment (LCA) to pinpoint measures that decrease overall energy consumption and environmental impacts throughout the entire life cycle of the buildings.

In Bulgaria, the evaluation of the SFB and MFB reveals that none of the DRPs exhibit a discernible advantage over the current building scenario, despite the positive environmental impacts. In contrast, for the public reference building the proposed solutions present similar financial life cycle costs to the existing building but present a higher-level social impact. In Greece, for the SFB and the MFB, the best NPV is achieved with DRP1. However, from a societal viewpoint, DRP3 for the SBF and DRP2 for the MFB present the best results, and DRP3 for the MFB present the best results from an environmental point of view. In Latvia, the best NPV is ensured with the baseline scenario. Hence, from both a private and societal perspective the economic performance of all DRPs is lagging behind the existing building situation. In Portugal for the SFB, DRP1 achieves the minimum NPV, and the best results from a societal viewpoint, but from an environmental perspective the most desirable alternative is DRP3. For the MFB, DRP1 achieves not only the lowest NPV, but also the best societal and environmental results. In Latvia, the financial and social NPV of life cycle costs minimises for the baseline scenario. Hence, from both a private and societal perspective the economic performance of all DRPs is lagging behind the existing building situation. This is related to the long payback periods of all DPRs (minimum 19 years). However, from an environmental perspective, it's apparent that all DPRs outperform compared to the baseline scenario, as the life cycle GHG emissions (for a 20-year lifetime) decrease by more than 55%.

From a policy-making point of view, the primary finding across the analysed reference buildings in the four REVERTER pilots is that undertaking deep renovations for residences is not economically advantageous for the majority of households. Therefore, the objectives of the EU's Renovation wave will not be achieved without appropriate financial incentives, predominantly in the form of subsidies targeting renovation investment costs. This imperative is particularly pronounced for vulnerable and low-income households, as highlighted in the relevant section, where substantial barriers arise due to their financial incapacity to cover investment costs and limited access to loan capital.

Renovation Barriers and Multiple Benefits

The barriers to energy renovation as well as the benefits were identified and analysed. These barriers can be categorised into six general groups: Behavioral/Social barriers, such as demographic factors and disruptions during construction works; Financial barriers, including limited access to capital and diseconomies of scale; Knowledge/Informative barriers, like asymmetric information and lack of awareness of benefits; Organizational and Decision-Making barriers, such as split incentives between investors and society and lack of coordination; Regulatory barriers, including inconsistent policies and institutional complexities; and Technical barriers, like the absence of codes and standards and lack of technical capacity.

Beyond the reduction in consumption and energy bills, energy renovations yield various other advantages. These include indirect economic effects (e.g., job creation, macroeconomic impacts, enhanced energy security, etc.), social benefits (e.g., improvements in health and well-being, especially for vulnerable groups, elderly and children), and environmental benefits (e.g., reduced greenhouse gas emissions and harmful pollutants) associated with building renovations. Similar to barriers, these benefits can manifest at different levels (individual, societal, etc.) and may vary based on factors such as country, building type, renovation measure, and ownership status. Identifying, quantifying, and monetizing these benefits are crucial to attracting more private and public funds for energy retrofit initiatives.

The main barriers identified in the four REVERTER pilots are summarised hereinafter.

In Bulgaria, alignment with EU energy efficiency goals and well-structured renovation packages in the National Strategy for Energy Renovation in Buildings are positive political factors. However, limited local finance mechanisms, political instability, and a lack of long-term planning pose challenges. Economically, the development of energy-efficient technologies and potential job creation are benefits, but high inflation, rising energy prices, and a shortage of skilled professionals hinder progress. Socially, municipal policies that support regional strategies and build administrative and professional capacity in energy planning and social inclusion are beneficial, but there is a lack of socio-economic studies assessing the broader benefits and engaging citizens. Technologically, there is potential for renewable energy utilization and improving thermal conditions in buildings, but local authorities often lack technical capacity, social aid for heating is inefficiently spent, and smart metering adoption is slow. Environmentally, municipal programs for energy efficiency and renewable energy are positive, but there is limited knowledge about climate change mitigation and adaptation for buildings.

In Greece, national and European policy developments are key drivers for energy renovation of residential buildings. Ambitious targets in Greece's National Energy and Climate Plan for 2030 and the Long-Term strategy will enable targeted measures, despite missed targets in 2021 and 2022 requiring additional policies. The Exoikonomo programme supports energy efficiency, while centralized policies ensure coordinated implementation. Promoting PV systems will boost RES penetration. Sufficient lending funds and realistic bank requirements are crucial, though high interest rates, limited loan access, and rising living costs pose barriers. Interest in renovation has grown due to the energy crisis. Social issues like energy poverty and low awareness of energy efficiency highlight the need for a better understanding of prosumerism. Smart meters and RES technologies are essential. The building sector's high RES and energy efficiency potential contribute to targets, despite barriers like limited environmental restrictions. Legislative frameworks will help achieve renovation targets, and an action plan for alleviating energy poverty will drive renovations in energy-poor households. Updating the legislative framework is crucial for ongoing renovation efforts.

Latvia aims to renovate at least 2000 MFBs by 2030 as part of a strategy targeting 4860 MFBs. Typological renovation packages and financial incentives, including a national investment bank program and municipal tax reductions, will support this effort. Legislative changes align with the LTRS and the EU's Fit-for-55 package. Renovation subsidies and banking funds are available, particularly in regions lacking private funding, but construction capacity challenges, high energy costs, inflation, and interest rates pose economic difficulties. Increased demand faces financing issues and household skepticism. Economic recession, energy crises, low awareness of renewable energy, an aging population, energy poverty, and tenant issues complicate matters. There is a lack of frameworks for new technologies and digitalization, and challenges in smart city concepts and smart meter deployment. Revising laws and addressing energy efficiency in MFBs are essential.

In Portugal, the analysis highlights several factors affecting renovation roadmaps. Politically, alignment with European Directives and targets for carbon neutrality by 2045 drive renovation efforts, supported by the National Energy and Climate Plan and the National Strategy for Energy Poverty. However, local regulations and bureaucracy delay progress. Financially, incentives like IFRRU, 1º Direito, energy efficiency vouchers, and VAT reductions benefit low-income families, and the government promotes RES and ambitious energy-saving targets. Bureaucratic delays and a lack of stakeholders for quality renovations hinder progress. Cultural habits, skepticism toward ESCOs, mild climate, low income, high electricity costs, and low literacy exacerbate energy poverty, limiting the impact of Portugal's renewable energy policies.

As far as the renovation benefits are concerned, the analysis for the pilots was based on the monetised results of the COMBI project online tool. One of the main benefits of using COMBI's estimates is the ability to express the benefits per-energy saved values, i.e., in €/kWh.

Policies, Initiatives, and Strategies at National, Regional and Local Levels

To comprehensively identify and categorise diverse policies and practices across European countries, an Excel tool was created to collect and further analyse various policy aspects, including size, scale, scope, objectives, budget, and more. A total of 68 policies were identified by the partners, not only from the pilot countries but also from other EU countries. Specifically, the identified policies spanned across the following countries: Bulgaria, Greece, Latvia, Portugal, Spain, the UK, France, Denmark, Poland, Ireland, Austria, and Italy. This approach was adopted to enable the analysis and potential replication of more good practices, thereby enhancing the extent of implementation in the roadmaps in T3.5.

The Bulgarian, Greek, Latvian and Portuguese governments, mainly driven by the EU legislation, are currently developing national strategies for energy poverty mitigation, aiming to address these challenges and ensure access to affordable, reliable, and clean energy services for all citizens. Even though there are specific national particularities, the measures that are being considered are common to all countries (improving the energy efficiency of the building envelop and energy systems, expanding the use of renewable energy sources, promoting behavioural changes and awareness campaigns, and strengthening the social protection and support schemes for low-income and vulnerable households, such as social tariffs and financial assistance programs for vulnerable households). However, these are not widely known or used. There is no official concept or definition of EP and there is also a substantial lack of reliable and appropriate data and indicators to monitor and measure the extent and impact of energy poverty in the most affected countries. Harmonised collection of household data, through a dedicated survey on energy poverty and a harmonised household budget survey, is essential to collect robust and adequate data. To advance the measurement of EP at all levels: the European scale, national and local levels, the collection of quantitative and qualitative data must improve to help the implementation of policies that are able to deliver to the ground. Furthermore, there is a need to set a proper legal framework to ensure a multilevel approach to EP, including legislation, adequate financing and cooperation between local governments and entities.

List of Acronyms

AFCP	After-Fuel Cost Poverty
AHP	Analytic Hierarchy Process
CDD	Cooling Degree Days
CoM	Covenant of Mayors
DEL	Disturbance for building occupants
DHW	Domestic Hot Water
DRP	Deep Renovation Package
EC	Embodied Carbon
EED	Energy Efficiency Directive
EEOs	Energy Efficiency Obligation scheme
EIB	European Investment Bank
EP	Energy Poverty
EPAH	Energy Poverty Advisory Hub
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Contracting
EPD	Environmental Product Declaration
EPEE	European Fuel Poverty and Energy Efficiency
EPOV	EU Energy Poverty Observatory
EPTA	Energy Performance Tenancy Agreement
ESCO	Energy Service Companies
EU	European Union
EVALUATE	Energy Vulnerability and Urban Transitions in Europe
FPEER	Fuel Poverty Energy Efficiency Rating
GHG	Greenhouse Gas
HEP	Hidden Energy Poverty
HBS	Household Budget Survey
HDD	Heating Degree Days
HP	Heat Pumps
HVAC	Heating Ventilation and Air Conditioning
IHC	Improved comfort and health
IRC	Initial Renovation Cost
ITRE	European Parliament's Committee on Industry, Research and Energy
LCA	Life Cycle Assessment
LCP	Life-cycle economic performance
LHR	Local emission reductions
LIHC	Low Income High Cost
LILEE	Low-Income Low Energy Efficiency
LTRP	Long Term Renovation Plans
LTRS	Long Term Renovation Strategies
MFB	Multi-Family Building
MIS	Minimum Income Standard

MOD	Modularity
MS	Member States
NECP	National Energy and Climate Plans
NPV	Net Present Value
nZEB	near Zero Emissions Building
OM	Operating and Maintenance cost
OSS	One Stop Shop
PEP	Perceived Energy Poverty
PV	Photovoltaics
RA	REVERTER Ambassadors
REA	Rapid Evidence Assessment
RES	Renewable Energy Sources
RRP	Recovery and Resilience Plan
SFB	Single-Family Building
SILC	Statistics on Income and Living Conditions
SV	Salvage Value
VAT	Value Added Tax
VCWG	Vulnerable Consumers Working Group
WHO	World Health Organisation
WTP	Willingness to pay

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1 Introduction

1.1 Motivation

Energy poverty (EP) is a crucial social-economic problem of the current society, as it deprives people of a basic standard of living and quality of life. European Union (EU) action towards Energy Poverty mitigation is active: the Social Climate Fund was recently updated, European-wide Energy Poverty Indicators requested, and practices evolving in countries with recognised "on-the-ground" experience. However, the problem is far from solved, since according to the latest available data for EP across Europe, in 2022, 9.3% of people in the EU could not afford to keep their homes adequately warm, up from 6.9% in 2021. As presented in Figure 1, among the EU Member States, this share ranged from 1.4% in Finland to 22.5 % in Bulgaria. In 21 of the EU Member States, the share of people who could not afford to keep their homes adequately warm increased between 2021 and 2022 (Eurostat, 2023).

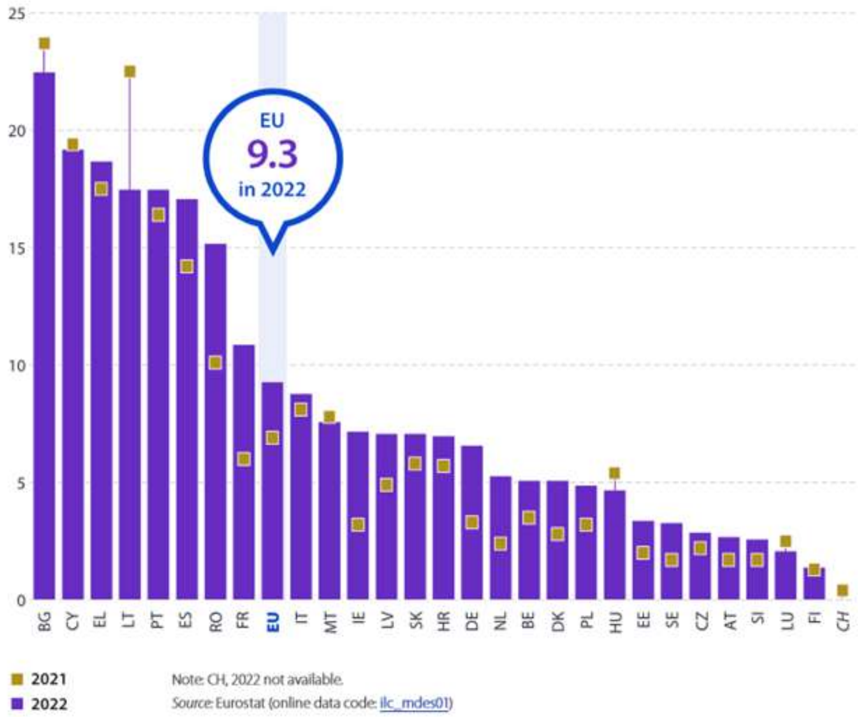

Figure 1: Share of people living in households unable to keep their home adequately warm (%, 2021 and 2022) (Eurostat, 2023)

Overall, there are several factors associated with EP, such as housing conditions (e.g. dwelling type and type of heating systems used); household characteristics (e.g. size of household); building characteristics (e.g. building size and energy efficiency); and demographic characteristics (e.g. employment status, education, nationality, gender) (Bouzarovski, 2014; Papada et al., 2019; Thomson & Snell, 2013). However, EP is mainly connected with three causes: high energy costs, low household income and energy-inefficient buildings (Atanasiu et al., 2014; International Energy

Agency, 2011; Palmer et al., 2008). Due to the recent energy crisis in Europe, the importance of these factors has escalated.

Under the Clean Energy for All Europeans package, MS, through their National Energy and Climate Plans (NECPs) and Long-Term Renovation Strategies (LTRS), must identify dwellings of people at risk of EP and develop effective strategies for renovating these as a matter of priority. Further, the Energy Efficiency Directive (2012/27/EU) (EED), as amended by Directive 2018/2002/EU, requires MS to take into account the need to reduce EP, and the revised Energy Performance of Buildings Directive (2018/844/EU) (EPBD) requires MS to address split-incentive dilemmas and market failures as part of the national LTRS, and to target the least efficient building stock first ("worst first" principle). In this direction, the EPBD recast (COM(2021) 802 final) seeks to boost the renovation of the 15% worst performing buildings, aiming to prioritise the most cost-effective renovations while fighting EP.

Bearing in mind the above remarks, REVERTER will develop 9 roadmaps to alleviate EP by addressing the poor energy efficiency of dwellings. The roadmaps will be tailor-made to the characteristics of the building stock, the characteristics of the vulnerable households and the climate conditions, to cover a sufficiently cohesive group of cases that will allow for a larger-scale rollout and replication of the proposed actions for the effective analysis and tackling of the problem. The roadmaps will target the worst-performing homes first ("worst first" principle), will cope with split-incentive dilemmas and will address market, information and behavioural failures through the creation of "one-stop shops'' (OSS) as defaults for the enrolment of vulnerable households in subsidised energy efficiency improvement programmes. The project will test the roadmaps by setting up a network of pilots in four European countries (Brezovo-Bulgaria, Athens Urban area-Greece, Riga-Latvia and Coimbra-Portugal) that cover four different climate regions (Southern Dry: Portugal; Mediterranean: Greece; Southern Continental: Bulgaria; Northern Continental: Latvia) and different socioeconomic conditions regarding age and size of buildings, owner-occupancy rates, percentage of Multi-Family Houses and Single Family Houses, income, values and beliefs of the inhabitants etc. Furthermore, engagement with local, national and EU stakeholder groups and experts will embed the roadmaps to be developed in defining future policies for the reduction of EP. For more details, see the Annex in section 10.

1.2 Objectives

Current definitions of Energy Poverty and Deep Renovation embrace years of research, practice, policies, specific frameworks, and challenges. Understanding the concepts, limitations, and opportunities of jargon like Energy Poverty indicators and indexes, and Deep Renovation and underlying reasons is crucial to understanding the role health, comfort and digitisation play in this process.

In such a context it is important to review the existing knowledge from EU-supported projects and scientific and grey literature, to establish an up-to-date scientific and technical baseline and fill existing gaps in the fields of (a) EP definitions, drivers and indicators (b) deep renovation measures (such as building envelope insulation, replacement/improvement of the technical building systems, and window replacement, etc.); and (c) EP and building renovation roadmaps. It is also important to review of market, information (such as energy-financial illiteracy) and behavioural barriers and biases and the role that scarcity conditions have on decision-making, with the aim to (a) identify certain cognitive biases that might arise in EP contexts, and (b) devise strategies to unlock individuals' potential to make decisions that result in better outcomes for themselves and their surroundings.

Deliverable 2.1 presents a state-of-the-art review and assessment of several aspects related to EP, being the result of T.2.1-2.4, namely:

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- T.2.2. Assessment and prioritisation of alternative energy-saving measures
- T.2.3. Review and assessment of renovation barriers and multiple benefits
- T.2.4. Assessment of policies, initiatives, strategies, etc. for the alleviation of EP and the promotion of deep renovation at national, regional and local levels

1.3 Structure

The remainder of this document is organized as follows:

- Section 2 presents the contextualization of the work, namely the policy framework, research and innovation projects, as well as the methodological approach.
- Section 3 presents the results of task 2.1 regarding the EP drivers, definitions and indicators.
- Section 4 presents the results of the assessment of EP and building renovation roadmaps (from task 2.1).
- Section 5 concentrates the information about deep renovation measures, including the review of deep renovation measures (from task 2.1) and the assessment and prioritisation of alternative energy-saving measures (from task 2.2).
- Section 6 presents the review and assessment of renovation barriers and multiple benefits (from task 2.3).
- Section 7 presents the results of the assessment of policies, initiatives, and strategies, for the alleviation of EP and the promotion of deep renovation at national, regional and local levels (from task 2.4).
- Section 8 presents the concluding remarks.

2 Contextualizing the Work

Energy poverty is considered a distinct form of poverty that is associated with a range of adverse consequences in relation to individuals' health and well-being, such as respiratory, cardiac, and mental health problems due to poor housing and low income, such as not being able to maintain an adequate temperature in the home, and stress resulting from the uncertainty of being able to afford basic goods. Energy poverty can have significant impacts on children, especially in developing countries where access to modern, reliable, and affordable energy services is often limited. Additionally, women are particularly vulnerable to EP because, as a cultural heritage, in the vast majority of households, they are still responsible for housekeeping, and the impacts of humidity and low temperatures in female skeletal muscle diseases are particularly severe. The main impacts of energy poverty include:

- **Health impacts:** Energy poverty is often associated with a lack of access to clean cooking fuels and lighting, which can lead to indoor air pollution and respiratory illnesses. Children are particularly vulnerable to the impacts of indoor air pollution, which can affect their health and cognitive development.
- **Education impacts:** Energy poverty can impact children's education, as limited access to electricity can limit their ability to study after dark or use modern educational technologies. This can have a negative impact on their academic performance, compromising and limiting their future opportunities.
- **Social impacts:** Energy poverty promotes social exclusion because people living in energy poverty feel embarrassment and tend to isolate avoiding social contact with peers, worsening their life.
- **Safety impacts**: Safety impacts are not widely indicated in this context, but energy poverty can also have safety implications, particularly for women and children in rural areas, who must collect fuelwood or kerosene in dangerous or isolated areas. This can expose them to physical and sexual violence and increase their vulnerability to exploitation and abuse. Moreover, safety impacts are also relevant when using gas or coal indoors. The number of accidents, explosions, and fires are common in many countries.
- **Environmental impacts**: Energy poverty can also contribute to environmental degradation and natural resource depletion, as reliance on traditional fuels can result in deforestation and soil erosion.

The following section presents the policy framework for energy poverty at the European level, as well as an overview of recent research and innovation projects and initiatives addressing this issue. It also presents the global methodology used to collect the information and data for the different reviews and assessments presented in the next chapters.

2.1 EP Policy Framework

Over the past decade, the EU has been committed to tackling energy poverty and protecting vulnerable consumers. In the Clean Energy for All Europeans package, adopted in 2019, the EU increased its efforts and made energy poverty a key concept. The reduction and mitigation of energy poverty has also been increasingly targeted in energy efficiency, decarbonisation and clean energy policies to support a just energy transition for all (EC, 2019b).

As part of their obligation to assess energy poverty in their National Energy and Climate Plans (NECPs) (EC, 2023i), several EU countries have integrated targeted measures in their national strategies and are developing their own definitions, measurement and monitoring methods and solutions to tackle energy poverty.

In 2020, to support EU countries' efforts to tackle energy poverty, the Commission published a Recommendation on energy poverty (EC, 2020a), issued as part of the Renovation wave strategy. The recommendation provides guidance on adequate indicators to measure energy poverty, promotes sharing best practices between EU countries and identifies the potential to access EU funding programmes that prioritise measures targeting vulnerable groups.

Building on this recommendation, the Fit for 55 package (EC, 2021a), adopted in July 2021, proposed specific measures to identify key drivers of energy-poverty risks for consumers, such as too high energy prices, low household income and poor energy-efficient buildings and appliances, taking into account structural solutions to vulnerabilities and underlying inequalities. The Fit for 55 package includes a proposal for a revision of the Energy Efficiency Directive (EC, 2023g) to put a stronger focus on alleviating energy poverty and empowering consumers.

In the Autumn of 2021, the Commission published the Communication “Tackling rising energy prices: a toolbox for action and support” (EC, 2021b), which lists a range of short and medium-term initiatives that can be taken at the national level to support and help the most vulnerable consumers. The proposal for a recast of the Energy Performance of Buildings Directive (EC, 2023a) and the hydrogen and decarbonised gas market package (EC, 2023h) is expected to further stress the importance of the mitigation of energy poverty in EU policies.

The Commission Decision 2022/589 established in April 2022 the Commission Energy Poverty and Vulnerable Consumers Coordination Group (EC, 2022), which aims to provide EU countries with a space to exchange best practices and increase coordination of policy measures to support vulnerable and energy-poor households.

If the EP was already a major concern being tackled by different policies, 2022 brought an unprecedented challenge for European citizens when it comes to access to energy and energy bills. During the EPAH lunch talk #3 organized early in 2023 (EPAH, 2023), the developments regarding energy poverty during the past year as well as a debate of what is the roadmap ahead for local governments that wish to address energy poverty, has been on the focus. Nonetheless, until recently, there was no uniform definition of Energy Poverty at the EU level, and the indicators being used are diverse.

Bouzarovski (EPAH, 2023) highlighted that “energy poverty is not only just about poverty: it is about infrastructure, it is about how you provide energy and how you organise your housing sector. So, it has to do with the system and the chains through energy services are demanded by households”. He explained that with the energy crisis of the past year, energy poverty became a major news item while worsening significantly. To address this rising challenge, more policy developments emerged at different levels (at the European level, but also national and local). Moreover, it was underlined that the finalisation of the Social Climate Fund is a great step forward, with the entry of social consideration in the EU mandate, as some years ago it was for Energy Security.

Energy poverty (and poverty in a broader sense) is a serious reality, which needs local, flexible and "tailor-made" public policies, adapted to the local context and involving the various players and stakeholders. In the pilot countries the most relevant initiatives at the national level to deal with this problem, so far, are as follows:

- **Bulgaria:** Currently Bulgaria is in the process of starting the full liberalisation of electricity supply for households, leading to higher electricity prices, with an upward impact on household electricity costs, where the most affected will be the most vulnerable, namely the "energy poor" unless they start to invest in energy efficiency and start forming citizen RES energy communities. A long-term national strategy to support the renewal of the residential and non-residential buildings stock - 2021-2050 has been designed to increase the refurbishment rates of the inefficient building stock. The emphasis in the renovation process is given to deep renovation and the transformation of buildings into nearly zero-energy buildings, where this is financially viable. According to the National Plan for Recovery and Resilience, a National Decarbonisation Fund will be established, which aims to support investing in low-carbon development through sustainable and targeted financing to a wide group of beneficiaries. The plan sets out the development of a definition and criteria for "energy poverty" in the Energy Act to serve as an instrument during the electricity market liberalisation and financing of energy efficiency projects. One-stop-shops will be established within 6 pilot municipalities, but only within the large cities and on a territorial basis. Mechanism for financing energy projects efficiency and RES along with energy bills will be established and the Single funding program with a budget of 140 M€ aiming to increase the use of RES in final energy consumption in the household sector by financing the purchase of new solar systems, both seen as instruments to alleviate EP. It is also foreseen a large investment program for improving the energy efficiency in the building stock with a budget of 767 M€.
- **Greece:** The implementation of the foreseen policies and measures within the Action Plan for the Alleviation of Energy Poverty has already started. The planned policies and measures are classified into three categories (A. Protection of consumers, B. Development dimension and C. Awareness raising and information). The foreseen policies and measures are presented for each category separately: A. Protection of consumers: M1. Improvement of the Social Tariff, M2. Provision of energy cards to energy-poor households and M3. Regulatory measures for the protection of energy-poor households; B. Development dimension: M4. Energy upgrade of the energy-poor households' building including the installation of RES systems, M5. Provision of incentives to energy-poor households within the framework of the Just Transition Plan, M6. Provision of incentives to energy-poor households within the framework of the Energy Efficiency Obligation scheme (EEOs) and M7. Provision of incentives to energy-poor households within the framework of the Energy Communities; C. Awareness raising and information: M8. Conduction of measures within the framework of the EEOs and M9. Conduction of targeted measures centrally by the Ministry of Environment and Energy. The policies and measures, which are integrated into the Development dimension, will contribute to the increase of the renovation rate. The "Exoikonomo 2021" program was launched officially by the end of 2021 and for the first time, a separate budget of up to €100 million has been earmarked specifically to support vulnerable households. Priority is given to households with lower incomes, people with disabilities, single-parent families, long-term unemployed, large families and households with increased energy needs. The " Exoikonomo 2023" programme is the new energy upgrade programme for residential buildings, which is a continuation of the " Exoikonomo

2021" programme, with a total budget of €300 million. It also foresees a separate budget of up to €60 million specifically to support vulnerable households Another financial support scheme is the Heating oil allowance. The policy measure will continue to be implemented under the National Recovery and Resilience Plan through programmes financed by the NSRF 2021-2027 aiming at the radical eradication of the energy poverty phenomenon. The policy measure for the energy upgrade of the energy-poor households' buildings is considered the most significant within the framework of the Action Plan for combating EP on an annual basis. Furthermore, the Energy Efficiency Obligation scheme for the period 2021-2030 started in 2022 facilitating the promotion of energy efficiency and the energy renovation of the buildings. The obligated parties will be incentivised through the increase of the reported energy savings by a factor equal to 40% for the case of technical measures targeted at energy-poor households by the obligated parties. Finally, the energy communities can also foster the energy renovation of buildings even though the emphasis is given to the installation of RES stations.

- **Latvia:** Currently there is a national initiative to support the renovation of multi-family buildings. The programme is aimed at reducing energy consumption of MFBs by providing a grant for deep renovation measures. The available funding is up to 49% excl. VAT of the total MFB renovation costs, if at least 30% reduction of primary energy consumption is achieved. There are also local initiatives where local authorities are providing long-term financial support for vulnerable households turned to the local authority for help such as providing a specific amount from utility bills. However, the type of initiative/financial mechanisms and provided amount depends on the requirements of the specific local authority. In addition, due to the recent increase in electricity prices, the Latvian government has provided short-term financial support for large families, people with disabilities and low-income families. The available support for heating depends on the local authority in case it is ensured by the local district heating company. Currently, it is provided in several local authorities, where the heat is mainly produced from natural gas, as a significant increase in prices of natural gas has been observed in recent months. This support is temporary and for all types of households.
- **Portugal:** According to the most recent Portuguese strategic view for 2030, the NECP recently identified energy efficiency as being crucial for the decarbonisation of society and as a response to the need for a competitive economy and a resilient, secure and self-sufficient energy system. In this context, Portugal commits to the principle of 'Energy Efficiency Priority' when deciding on investment projects in the energy sector, with a view to sustainability and cost-effectiveness. This logic has been reflected in the available financing mechanisms, for the domestic and services sector, through the Environmental Fund or the Recovery and Resilience Plan. The energy renovation of the national building stock and the decarbonisation of energy consumption, including through enhanced electrification, are key measures to meet national energy and climate objectives, as well as to meet other policy objectives, such as tackling energy poverty and supporting vulnerable consumers, in line with the aim of ensuring a just and cohesive transition. In the residential sector, the aim is to increase the thermal comfort of households (heating and cooling), focusing on passive insulation, sun protection and ventilation solutions, and continuing with the trend towards electrification of the sector and the use of renewable energy sources. A

continued focus on urban regeneration will provide an opportunity to incorporate energy and water efficiency improvements, the incorporation of low-carbon materials and renewable energy sources, contributing to the fight against energy poverty. In the scope of LTRS and RRP, the Portuguese Government has prepared an Energy Poverty Plan that was under public consultation twice, in 2019 and 2023, yet it is not published. The expectation was high, but it has not yet been discussed in the Council. The existing National support schemes to alleviate EP, such as social tariffs and financial vouchers, are not addressing deep renovation. More recently, the Climate Fund launched an incentive programme to support the replacement of old windows by efficient ones, in the residential sector, but the scheme was not designed to address energy poverty as there was a need to advance the payment. Vulnerable consumers are struggling to pay the bills and cannot afford to pay the upfront costs. However, according to National experts, only a structured strategy based on robust and consolidated information can tackle the EP in Portugal**.** Single measures, like the 1300€ once financial vouchers that were distributed among lower-income families, in the scope of the Recovery and Resilience Plan, have a low impact on mitigating EP or improving their quality of life. Recently (November 2023), this programme was launched again with some interesting improvements. In this new call, one household can apply for three vouchers, amounting to 3900+VAT. Even though it is not possible to deeply renovate a dwelling, the eligible amount allows some improvements to be carried out. There are other interesting National initiatives financed by the climate fund, aiming to promote actions at the local level, to improve the quality of life in the neighbours of the cities, which are inspiring and are also a lever for REVERTER activities: Healthy Neighbourhoods 2020 | Programa Bairros Saudáveis, República Portuguesa [23/07/2021 – Current].

An overview of the EU legislation related to energy poverty and deep renovation is presented in the Annex in section 11.

2.2 Research and Innovation Projects

The European Commission supports many projects and initiatives to accelerate the clean energy transition, aligned to transform inefficient housing stock in vulnerable districts and reduce the negative effects on energy-poor residents. The EU has also several facilities to finance legal, technical and financial support for large-scale projects, e.g. the Sustainable Energy Investment Forum (EC, 2023l), the Affordable Housing Initiative (EC, 2023d) and the Covenant of Mayors Investment Forum: Energy Efficiency Finance Market Place (EC, 2023f). After 2015 all municipalities who have signed the Covenant of Mayors have committed to also take action on alleviating EP in their geographical area. This adds up to more than 4120 municipalities with the political will to act on EP at a local level. Many public or private investors such as cities, municipalities, parish councils, individuals, businesses, etc., need assistance to take their energy efficiency projects from idea to implementation.

REVERTER builds on and/or up-scale results of previous and ongoing projects in the fields of EP, energy retrofitting, energy road-mapping and energy-related behavioural change. Table 1 provides an overview of such projects.

Table 1: Previous and ongoing projects in the fields of EP, energy retrofitting and energy road-mapping

Project	Website	Years	Outputs
4RinEU - Robust and Reliable technology concepts and business models for triggering deep Renovation of Residential buildings in EU	www.4rineu.eu	2016 - 2021	The Cost-effectiveness Rating System, which is a reliable energy/economic model exploring the level of risks and failures in the renovation chain.
ASSIST - Support Network for Household Energy Saving	www.assist2gether.eu	2017 - 2020	The HEA (Home Energy Advisor) training support material and the in-depth analysis on vulnerability and EP in Europe.
CEES - Community Energy for Energy Solidarity	www.energysolidarity.eu	2021 - 2024	Toolkit for EU replication of most successful cases of community energy initiatives to tackle energy poverty through the European federation of citizen energy cooperative.
ComAct - Community Tailored Actions for Energy Poverty Mitigation	comact-project.eu	2020 - 2024	The ComAct Knowledge Exchange platform, the educational materials for Energy Advisors and the Toolbox of financing models
COMBI - Calculating and Operationalising the Multiple Benefits of Energy Efficiency Improvements in Europe	combi-project.eu	2015 - 2018	Quantify the energy poverty related health impacts of energy efficiency.
EMPOWERMED - Empowering women to take action against energy poverty in the Mediterranean	www.empowermed.eu	2019 - 2023	Awareness pilot programmes to reduce energy poverty, assess its impact on health, and share knowledge for policy building at local- and EU-wide level.
ENERFUND - An ENErgy Retrofit FUNDing rating tool	enerfund.eu	2016 - 2019	The ENERFUND tool that rates and scores deep renovation opportunities.
EnergyMEASURES – Tailored measures supporting energy vulnerable households	energymeasures.eu	2020 - 2024	The results from working with energy-poor households to improve their energy efficiency through a combination of low-cost measures, and changes in their energy-related behaviours and practices
EnerSHIFT - Energy Social Housing Innovative Financing Tender	enershift.eu	2016 - 2020	The innovative financing models developed to facilitate the energy renovation of public housing in Liguria.

ENPOR - Energy poor households in the private rented sector	www.enpor.eu	2020 - 2023	The Energy Poverty Dashboard and the 10 energy efficiency policies and measures for EP in the private rented sector in 7 Member States.
EuroPACE - Developing, piloting and standardising on-tax financing for residential energy efficiency retrofits in European cities	www.europace2020.eu	2018 - 2021	The repayment collection mechanism as 'safe conduit', so that municipalities can have an active role in remitting the loan repayments for retrofitting homes from homeowners to private investors and the integrated home renovation program (which is used instead of the OSS term).
EVALUATE - Energy Vulnerability and Urban Transitions in Europe	urban-energy.org/evaluate	2013 - 2018	Comparative study of eight urban districts within Gdańsk (Poland), Prague (Czech Republic), Budapest (Hungary) and Skopje (FYR Macedonia).
Happen - Holistic AProach and Platform for the deep renovation of the med residential built ENvironment	medzeb-happen.eu	2018 - 2021	Comprehensive and integrated framework of conditions for enhancing the overall appeal, convenience and reliability of deep renovations market
HIROSS4all - Home integrated renovation one-stop-shop for vulnerable districts (Opengela)	opengela.eus	2019 - 2023	The experience gained from the test in two OSS in Otxarkoaga (Bilbao) and Txonta (Eibar), in the Basque Country (Spain).
iBROAD - Individual Building Renovation Roadmaps	ibroad-project.eu	2017 - 2020	The roadmaps for single-family houses, the iBRoad Handbook and training toolkit for Energy Auditors, and the field test experience for the roadmaps.
iBROAD2EPC - Integrating Building Renovation Passports into Energy Performance Certification schemes for a decarbonised building stock	https://ibroad2epc.eu	2021 - 2024	Explores energy performance assessment schemes and certification practices with the aim of promoting and showcasing the integration of Building Renovation Passport elements into EPC schemes.
INNOVATE - Integrated solutioNs for ambitiOus energy refurbishment of priVATE housing	financingbuildingrenovation.eu	2017 - 2020	The overall methodology and experience from setting up and operating OSSs for energy retrofits (though not for vulnerable households).
LEMON - Less Energy More OpportuNities	www.lemon-project.eu	2016 - 2020	The manuals and training materials for tenants and policy makers and tools for energy refurbishments, such as the EPTA and EPC.

NUDGE - NUDging consumers towards enerGy Efficiency through behavioral science	www.nudgeproject.eu	2020 - 2023	The behavioural interventions that will be designed to achieve long lasting energy efficiency behaviour.
PowerPoor - Empowering Energy Poor Citizens through Joint Energy Initiatives	powerpoor.eu	2020 - 2023	Output: The Energy Poverty Mitigation Toolkit and the 8 National Roadmaps to alleviate EP.
POWERTY - Renewable energies for vulnerable groups	https://projects2014-2020.interregeurope.eu/powerty/	2019 - 2023	50 innovative best practises in tackling energy poverty through innovate RES, new financial models, citizens empowerment
R4E - Roadmaps for Energy	roadmapsforenergy.eu	2015 - 2018	The roadmap for smart buildings.
REACH - Reduce energy needs and change habits	reachenergy.door.hr	2014 - 2017	The materials for working with households, local actors and energy advisors.
RENOVERTY - Home Renovation Roadmaps to Address Energy Poverty in Vulnerable Rural Districts	ieecp.org/projects/renoverty	2022 - 2025	Tools and resources to support local actors to build and implement financially viable roadmaps with the participation of all actors involved to be then
SHEERenov - Seamless services for Housing Energy Efficiency Renovation	www.sheerenov.eu	2020 - 2022	The results from the operation of the OSS in Sophia and the sustainable financial mechanisms to facilitate loans access, conditional subsidy receipt and targeted support to insolvents in Bulgaria.
STEP - Solutions to Tackle Energy Poverty	www.stepenergy.eu	2019 - 2022	The online training modules for frontline workers, who are used to advising people on a range of issues such as financial or health issues.
STEP-IN - Using Living Labs to roll out Sustainable Strategies for Energy Poor Individuals	www.step-in-project.eu	2018 - 2021	The methodology to set up and organise community engagement activities, namely energy cafés, and train energy advisors
StepUP - Solutions and Technologies for deep Energy renovation Processes UPtake	www.stepup-project.eu	2019 - 2024	The new process for deep energy renovation that will introduce plug and play technologies to maximise effects on energy, costs, indoor environmental quality and user comfort.

2.3 Methodological Approach

To achieve its objectives, REVERTER will build on best practices and knowledge from past and ongoing projects in the field of EP. Therefore, WP2 (T2.1-T2.4) was implemented to provide a coherent conceptual basis and strong evidence-based framework for the project. The main focus of the in-depth assessment was the review of:

- The existing knowledge from EU-supported projects and scientific and grey literature, to establish an up-to-date scientific and technical baseline and fill existing gaps
- Market, information (such as energy-financial illiteracy), behavioural barriers and biases and the role that scarcity conditions have on decision-making, with the aim to (a) identify certain cognitive biases that might arise in EP contexts, and (b) devise strategies to unlock individuals' potential to make decisions that result in better outcomes for themselves and their surroundings.
- The prioritisation of alternative energy-saving measures from an economic perspective, a technical perspective and an environmental and social using Life Cycle Assessment (LCA) models.
- Analysis of social and environmental benefits from the alleviation of EP and energy efficiency
- Assessment of national, regional and local policies, initiatives, targets, etc.

A rapid evidence assessment (REA) methodology was established to conduct the in-depth literature review covering all MS, because REAs provide a balanced assessment of what is already known about an issue, by using systematic review methods to search and critically appraise existing information. They aim to be rigorous and explicit in method and thus systematic but make concessions to the breadth or depth of the process by limiting particular aspects of the systematic review process. REA methods include stages of reflection and going back to repeat earlier steps as necessary, facilitating the collection of different types of information.

The literature review explores these concepts to look for innovative approaches to identify vulnerable households and include multiple benefits in energy renovation projects to trigger investment funds and improve their frequency of uptake, towards alleviating energy poverty. Moreover, a specialised template (an xls file) was prepared to facilitate the collection of homogeneous information for all the topics of interest.

To conceptualise a decision-making framework and identify a range of relevant renovation measures, the following REVERTER research questions were envisaged at the beginning of the project:

1. How has a renovation approach to energy efficiency been used? What are the main energy efficiency renovation measures more likely to be adopted? Why?
2. What were the drivers behind the investment decisions? How can energy efficiency policies be improved to address Energy Poverty?

3. How could a renovation approach to energy efficiency investments be designed to successfully target Energy Poverty? How could a renovation approach to energy efficiency investments in vulnerable households be operationalised?
4. Were there any side benefits of energy efficiency specifically recognised? What examples of good practice or innovative use of multiple benefits in renovation approaches exist?

In research like REVERTER, defining search terms and research questions are two complementary things to do. In theory, the first thing to settle is the "search terms", which are the terms to be used in the search engines to find the relevant publications. Although the search terms are the first ones to start searching, these have to be defined according to the research questions we are addressing. Therefore, in practice, the "research questions", which are the information we want to extract from the publications, need to be defined in advance and turn the research questions into a search strategy (in terms of keywords and combinations, etc.). When the research questions were defined, the key terms and definitions were agreed upon by the Consortium Members as the basis to define the scope of the literature search, as several of these questions are closely related. The used search terms and topics were the following:

- Energy Poverty;
- Energy Efficiency;
- Energy vulnerability;
- Building retrofitting;
- Home renovations;
- Energy services;
- Integrating RES;
- Consumption baseline;
- Thermal insulation;
- Circular economy;
- Baseline consumption;
- Perceived comfort level;
- Energy equity and justice.

A systematic desktop search was carried out to investigate the development within this field of work during recent years. To narrow the desktop search, most research published after 2015 was initially gathered and the search was not restricted to specific journals, but used different routes:

- Databases searching – mainly including academic papers in peer-reviewed journals, but also including conference papers, grey literature, technical reports, etc. (Google Scholar, Scopus; Research Gate, Odysee-Mure, ….)
- Conference proceedings – where the full proceedings of relevant conferences are not indexed in research databases, search on conference websites instead.
- Screening official documents from EU and Member States (e.g. NECPs, LTRPs, …).

- Analysing recent and ongoing related projects and deliverables, as well as related high-level conferences and events.
- Expert identification - asking team members and members of the advisory board to identify important and relevant literature.
- Looking for papers which have cited key contributions.

Through this methodology, more than 300 publications were found. The abstracts and summaries were reviewed, which narrowed it down to almost 100 publications. If an article in the review gave references to other research, which were related to the impact of REVERTER, these were also included. Overall, almost 150 papers, reports and official documents and legislative acts were reviewed.

3 Drivers, Definitions, and Indicators for EP

This section discusses the drivers, definitions and indicators associated with Energy Poverty, namely:

- Drivers – what factors are leading to energy poverty?
- Definitions – what can be considered energy poverty?
- Indicators – what parameters can be used to assess energy poverty?

3.1 Energy Poverty Drivers

Energy Poverty is a 'symptom', an expression of a 'precondition' that affects our livelihoods, namely through the lack of access to essential energy services. In such a context, the meaning of 'symptom' will be useful:

Meaning of symptom *(noun)*
1. any feeling of illness or physical or mental change that is caused by a particular disease
2. any single problem that is caused by and shows a more serious and general problem
(Cambridge U.P., 2023e)

A 'disease' is defined by an aggregate of 'symptoms', and is often known as a 'condition':

Meaning of condition *(noun)*
1. the particular state that something or someone is in: (…)
3. any of different types of diseases (…) *(Cambridge U.P., 2023a)*

The impact of a given temporary 'condition' on a citizen, whether in acute (short) or chronic (long) duration, is influenced by genetics, behaviour, environment and other factors. A close word, 'precondition', helps in the analogy:

Meaning of precondition *(noun)*
1. something that must happen or be true before it is possible for something else to happen
(Cambridge U.P., 2023d)

Infrastructural 'preconditions', 'drivers', will have a significant influence on the severity and duration of the 'condition', and on its' long-term direct and indirect effects. 'Driver is defined as:

Meaning of driver *(noun)*
something that makes other things progress, develop, or grow stronger (Cambridge U.P., 2023c)

Just like in any flu or COVID-19 outbreak, a large number of professionals will be engaged in the response process, implying "bridge-making" tools. Like in health care, energy poverty mitigation is an iterative process, justifying the "interdependent and mutually supporting" approach REVERTER relies on (see the Annex in section 10).

Energy poverty typically stems from a combination of factors, including high energy costs, limited income, and homes that are inefficient in terms of energy use, which can be affected by factors such as the age, condition, and construction materials of the building envelope, as well as the energy efficiency of appliances. Additionally, factors like one's residential status (whether they own or rent their home) and the type of heating/cooling system in place also play a role in determining the ability to make energy-related improvements. Individuals with lower incomes often reside in dwellings with subpar insulation and frequently rely on second-hand or outdated appliances that are not energy efficient. Moreover, they often have to manage their electricity and gas expenses through pre-payment systems, which can result in them incurring higher unit costs compared to those using monthly billing systems (Clancy et al., 2017).

Rademaekers et al. (2016) developed a conceptual map, presented in Figure 2, illustrating various drivers and elements that may contribute to an individual or household experiencing energy poverty.

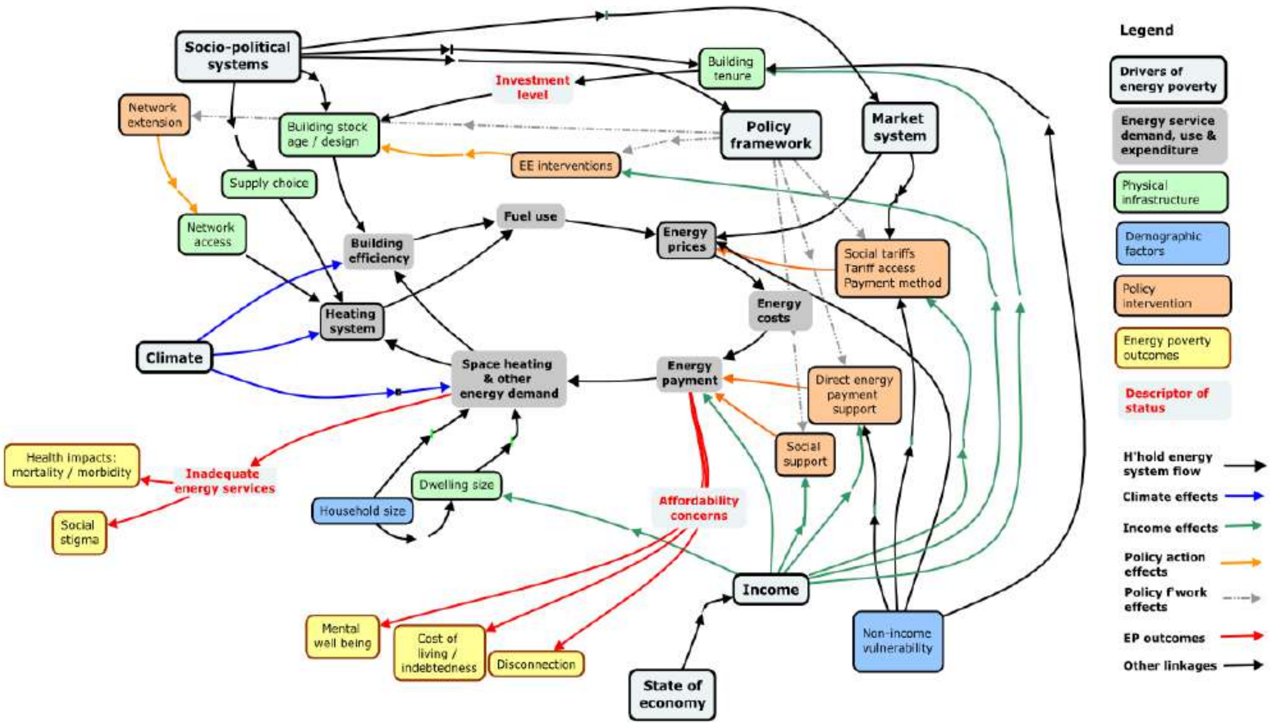

Figure 2: Conceptual map of the drivers, causes and effects of Energy Poverty (Rademaekers et al., 2016)

The drivers impacting the affordability of household energy services and potentially leading to energy poverty can be categorized as both direct and indirect drivers. The prior and existing political and economic systems have an impact on the development of energy markets, institutional arrangements, the infrastructure for heating and cooling, the housing stock and tenure, as well as energy supply. The nature of the energy market, including the level of deregulation and the degree of competition, influences the range of energy service rates and products available, as well as the types of measures implemented to enhance energy affordability. Climate patterns also affect energy demand, especially for heating and cooling, which, in turn, is influenced by the energy efficiency of buildings. Economic conditions have a direct influence on income, which subsequently shapes the type of housing, including tenure and physical structure, that an individual or family can afford. The physical structure of housing has a direct impact on energy efficiency and the affordability of energy services. The policy framework plays a pivotal role in determining whether energy poverty is acknowledged as a political priority and, consequently, whether support measures are established to address this issue (Clancy et al., 2017).

The key drivers of energy poverty are frequently assigned to factors like access/availability, affordability/income inequality/capacity of investment, energy efficiency of the envelope and appliances, needs and expectations of families and practices/awareness relating knowledge about household good use, financing support schemes and low-cost passive measures (Ben Cheikh et al., 2023; Bouzarovski & Petrova, 2015). Figure 3 presents the dimensions influencing the delivery of energy services to the home, and the emergence of domestic energy deprivation. However, energy poverty drivers go beyond these factors and are connected to structural political, economic, and natural circumstances.

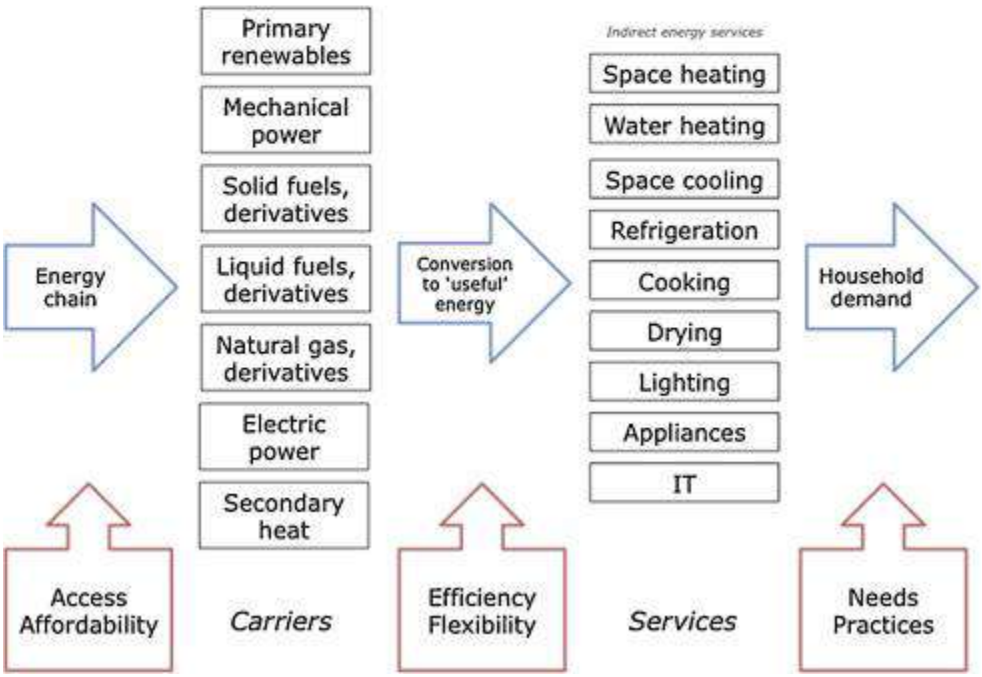

Figure 3: Dimensions influencing the delivery of energy services to the home, and the emergence of domestic energy deprivation. (Bouzarovski & Petrova, 2015)

The socio-political system is a structural driver for energy poverty representing previous and current political and economic systems of MS and is important for understanding some of the underlying causes of energy poverty. It is an important influencing factor in energy market development, institutional structures, heating infrastructure, dwelling stock and tenure, as well as energy supply. Bouzarovski et al. (2012), particularly cite the example of Bulgaria –

and the legacies of communist-era centrally planned economies. This is a strong determinant of building efficiency, energy systems, policy framework, etc.

Another important driver for energy poverty, shortage of income and high energy prices is related to the type of energy market, and the extent of liberalisation and level of competition, within different MS, which can have an important bearing on the choice of energy service tariffs/products, and the type of interventions for assisting those in need with energy affordability. Pye et al. (2015) highlight the difference in types of interventions depending on the market system, notably concerning consumer protection. There is also a clear link between market competitiveness, tariff choice, and type of specific tariffs under different regimes e.g. regulated prices versus social tariffs.

The climate zone naturally determines the energy demand, particularly for heating and cooling. It also influences the level of investment that is needed for ensuring the necessary building envelop measures and adequate climatization systems (both for heating and cooling). Bouzarovski et al. (2014) underscore the trend for higher levels of self-reported inability to keep the home warm in Southern Europe. This points to inadequate heating systems and inefficient housing for shorter, less severe cold months – but also recent recessionary effects. Conversely, highly efficient housing in colder Scandinavia is observed. Other key references include (Healy & Clinch, 2002) and (Thomson & Snell, 2013).

The economic structure of MS besides influencing the average incomes, significantly influences the level of energy services that are provided, depending on energy costs as a share of income. It also may determine the tenure of a household, the dwelling size, and any additional support that might be available through policy interventions. Bouzarovski et al. (2014) point out the link between increasing rates of energy poverty due to economic downturns, austerity measures and rising energy prices in different regions of the EU. Level of income is a key feature of energy poverty and is incorporated into different metrics e.g. LIHC (Hills, 2012), 10% expenditure, etc. This links to many important factors and therefore is one of the most important drivers.

The policy framework in place in MS strongly determines the type of interventions that are put in place. If a social-political system is in place, national policies explicitly target supporting vulnerable consumers and/or addressing energy poverty and the measures being implemented are aligned with energy security but also social stability. Recognition of the energy poverty challenge is a key driver of related policies, whether that be how social or energy policy is formulated – and resulting interventions. Pye et al. (2015) made some preliminary efforts to consider the types of policy approaches and measures in different countries across the EU.

The various drivers of energy poverty are also associated with contextual factors, as presented in Table 2 (Jiglau et al., 2023).

Table 2: Energy poverty drivers and context factors (Jiglau et al., 2023)

Low incomes	Poor energy efficiency of homes and equipment	High energy prices and poor energy supply conditions
Individual drivers • Material deprivation • Age, gender • Household composition • Employments status, vulnerable employment • Level of education • Health status • Ethnicity **Both individual and contextual** • Feeling poor • Past and expected income evolutions • Trust in institutions • Dependency on remittances • Importance of the Shadow Economy • Population dynamics (emigration, ageing) **Context factors** • Income inequalities (between income groups, inequalities related to age, gender, education level) • Social policy • Economic crises • Regions in economic decline • Post-war country • Quality of institutions	**Individual drivers** • Financial capacity to invest • Heating equipment (age and quality) **Both individual and contextual** • Age and type of buildings (for example panel buildings) • Energy management inside buildings (case of district heating) • Individual/collective housing • Homeownership • Urban/peri-urban/rural • General quality and condition of building (renovated or not) • Exposure to cold or warm temperatures in different locations • Trust in renovation policies and programs • Trust in neighbours (for the renovation of co-owned buildings) **Context factors** • Ease to renovate buildings • Regulations of building quality • Regulations of heating equipment • Past and present refurbishment policies • Population dynamics (local and national) including emigration influence the desirability of renovations locally • Local climate	**Individual drivers** • Ability and financial capacity to choose sources of heating used for energy **Both individual and contextual** • Interdependencies between energy consumers, in cities and in buildings (use of district heating) **Context factors** • Existence and availability of various and affordable energy sources • Access to networks supplying affordable energy sources • Quality of energy supply infrastructures • Right to opt out of certain types of energy supply (for example district heating) • Protection of vulnerable energy customers • Energy price regulation Subsidised household energy prices • Energy sector reforms (competition) and quality of regulation • Share of households vs. business or industry electricity customers in the country • Regulations on the use of coal or waste to limit air pollution • Evolution of local energy markets (for

		example wood) in terms of price and availability • Energy security and independence considerations of the country

3.2 Energy Poverty Definitions

This section discusses the definitions of Energy Poverty, regarding the evolution of the definition, as well as the definitions in force in the EU.

3.2.1 Evolution of the Definition

Although established above as a portion of a wider problem, Energy Poverty and Fuel Poverty are often used without distinction to refer to the whole area of knowledge (Bouzarovski, 2018). This simplification results probably due to the "Energy Poverty" term capacity to quickly portray the concept and its consequences in two very visual words.

Energy Poverty definitions attempt to frame a concept that is socially relevant (EC, 2020a) and for which urgent targeted solutions are required. In the next paragraphs, a comparative analysis of the definitions of Energy Poverty in the relevant literature, policies and practices will help to illustrate the evolution of the concept and the framing contexts.

Observing Energy Poverty definitions can inform the evolution of the concept and intrinsic logic. The reference to the topic of Energy Poverty is relatively recent in Europe[1]:

> *"The existence of energy poverty in the 'developed' countries of the Global North was traditionally interpreted within a relatively narrow thematic and geographic register: for a long time, public recognition of the problem was limited to the UK and the Republic of Ireland. The last decade has seen as expansion of scientific and policy debates to a much wider range of countries and regions, particularly in Europe (…)"* *(Bouzarovski, 2018)*

The need for a definition was identified by British civil servants in 1979 (Petrova, 2016; Thomson, 2017). This small and often missed reference is key to mitigating Energy Poverty, as this health-affecting condition (Thomson, Snell, et al., 2017) is rarely acknowledged by those who suffer from it. As "*Many participants did not know what 'energy poverty' was and did not talk about it with friends (…) [and] 'Struggling' considered a private, and perhaps shameful, issue*" (Thomson, 2017), the role of "civil servants"—currently local communities stakeholders—must be recognized in identification and solutions optimization.

[1] In (Bouzarovski, 2018, p. 2) a list of "scientific and policy debates" across the "Global North" is provided.

Revisiting the meaning of the definition:

> *Definition (noun)*
> *- a statement that explains the meaning of a word or phrase*
> *- a description of the features and limits of something*
> *- how clear an image or sound is* *(Cambridge U.P., 2023b)*

Identifying "the issue" implied some sort of unwritten definitions, linking to the need to empower communities and stakeholders in the recognition, action, and optimization of Energy Poverty mitigation measures. This approach is already practised in UK procedures, where chapters such as "Enhancing and improving understanding of fuel poverty" (Sustainable Warmth: Protecting Vulnerable Households in England, 2021)

In 1991, the *definition by* Boardman (1991) *was* characterized as "a pioneering achievement (…) [that] has proven remarkably resilient despite being challenged in various fora" (Bouzarovski, 2018, p. 10). EP is defined as:

> *"when a household cannot afford domestic heating – and other energy services – in cases where it needed to spend more than 10 per cent of its income in a satisfactory condition " (Boardman, 1991)*

For those in the field directly contacting vulnerable families this definition is of great use to "de-prejudice" the term of Energy Poverty in itself. As clarified by (Boardman, 2010; Bouzarovski, 2018) the expression "needed to spend" refers not to the actually spent energy, but to a level of expenditure necessary to guarantee basic levels of comfort like those recommended by the World Health Organization (WHO)—18 °C for bedrooms and 20–21 °C for living rooms (Boardman, 2010).

A more recent definition, principally used in England, sees households as fuel poor if required energy costs are higher than those of the nation-wide median, while pushing them below the 'official poverty line (Bouzarovski & Petrova, 2015).

In Bouzarovski & Petrova (2015), a comparison between the definition and framework in developing and developed world is developed, as presented in Table 3.

Table 3: Principal elements of 'energy poverty' and 'fuel poverty' frameworks in traditional understandings of the two concepts (Bouzarovski & Petrova, 2015).

Element	Developing world 'energy poverty'	Developed-world 'fuel poverty'
Recognition	Explicitly acknowledged in isolated documents during the early 1970s . Subsequent debates mainly focused on technological expansion. More recent research addresses participation and governance challenges.	First mentions date back to the late 1970s and 1980s, principally referring to rising energy costs and 'the right to fuel' in countries like the UK. Later research allowed for a wider understanding of the problem .
Driving forces	Primarily low levels of electrification and other forms of networked energy provision due to economic under-development and non-functional institutions.	High or rising energy prices vs. low household incomes. Inefficient housing, heating systems and appliance stocks.
Expression	Lack of access to adequate facilities for cooking, lighting and electric appliances, but also other services such as space cooling and heating.	Mainly inadequate heating in the home; importance of other services (particularly space cooling, lighting, appliances, IT) is increasingly recognized in recent years.
Consequences	Detrimental impacts on health, gender inequality, education and economic development more generally.	Long and short-term mental and physical health, inadequate participation in society.
Principal policies	Support for transitions to 'modern' energy fuels, investment in power grid expansion or micro-scale renewables; income support.	Combination of income support, provision of energy at lower costs, and energy efficiency investment.

3.2.2 Definitions in Force in the EU

The concept of energy poverty was introduced in the EU energy policy in 2009 by the Directive concerning common rules for the internal market in electricity (EC, 2009).

> *'energy poverty is a growing problem in the Community. Member States which are affected and which have not yet done so should therefore develop national action plans or other appropriate frameworks to tackle energy poverty, aiming at decreasing the number of people suffering such situation. In any event, Member States should ensure the necessary energy supply for vulnerable customers. In doing so, an integrated approach, such as in the framework of social policy, could be used and measures could include social policies or energy efficiency improvements for housing. At the very least, this Directive should allow national policies in favour of vulnerable customers. (EC, 2009).*

However, it was only defined in 2012, in the Energy Efficiency Directive (EC, 2012):

> *'a household's lack of access to essential energy services that underpin a decent standard of living and health, including adequate warmth, cooling, lighting, and energy to power appliances, in the relevant national context, existing social policy and other relevant policies' (EC, 2012)*

The way Energy Poverty is addressed through regulatory requirements has been significantly strengthened through the ‘Fit for 55’ package and in 2023, in the Energy Efficiency Directive (Recast) (EC, 2023c), the Energy Poverty definition was updated to:

> *“Article 2*
> *‘energy poverty’ means a household’s lack of access to essential energy services, where such services provide basic levels and decent standards of living and health, including adequate heating, hot water, cooling, lighting, and energy to power appliances, in the relevant national context, existing national social policy and other relevant national policies, caused by a combination of factors, including at least non-affordability, insufficient disposable income, high energy expenditure and poor energy efficiency of homes;”* *(EC, 2023c),*

With the definition of EP included in the new legislation (EC, 2023c), EU countries are compelled to prioritise energy efficiency improvements for vulnerable customers, low-income households, and individuals in social housing, including within the scope of the energy savings obligation schemes and or alternative policy measures (article 8 and article 9, EED 2023), take appropriate measures to promote and facilitate an efficient use of energy by final customers and final users. The EU legal framework requires that energy poverty in Member States is identified and tackled in their NECPs. Energy poor households should be prioritised for public investments or energy efficiency measures and other packages in the legislative process. Specific provisions and funding have been introduced in the Social Climate Fund Regulation and some Member States are addressing energy poverty in their Recovery and Resilience Plans (RRP), notably through measures supported by the REPowerEU chapters (EC, 2023b).

Defining the concept of energy poverty at the national level and making it publicly available is the first step in a structured approach to embedding energy poverty in the national legal framework, as proposed in the Energy Poverty Recommendation 2020 and further in the EED recast 2023/1791. The lack of a definition of energy poverty at the European level has so far led to different approaches at the Member State level, which has made it difficult to coordinate and compare data at the EU level. Nevertheless, some Member States have made progress and developed their own definitions. An energy definition should lead to a more comprehensive and coherent approach to tackling energy poverty. In some Member States, it has led to a coordinated approach between national authorities and stakeholders. In some Member States, there is still no official definition of energy poverty, but at the same time, it is clear that awareness of the problem and measures to tackle it have been in place for years. However, the existence of a definition of energy poverty improves the ability to identify the problem and to adapt or propose measures and programmes to better tackle it, both in the EU context and at the national level (EC, 2023b).

Table 4 presents an overview of the official and unofficial definitions of Energy Poverty at the national level.

Table 4: Official and unofficial definitions of Energy Poverty at the national level

Country	Status	Definition
Austria	Official	A household is considered energy poor if its income is below the at-risk-of-poverty threshold and, at the same time, it has to cover above-average energy costs.
Belgium	Unofficial	Energy poor: Households spend too high proportion of their disposable income on expenditure for energy In Flemish region, the inability to pay energy bills is considered to be an element of material deprivation (the usual standard of living in terms of rent, water, electricity, etc.). Walloon: Energy poverty is not clearly defined in law. It is generally accepted that energy poverty means a situation in which a person or a household faces particular difficulties in meeting their basic energy needs at home.
Bulgaria	Unofficial	Vulnerable users and consumers are at risk of Energy Poverty: due to a combination of low income, high energy costs and low energy efficiency of the homes they live in.
Croatia	Unofficial	Households with income levels below a certain level are considered energy poor (in principle, socially disadvantaged households).
Cyprus	Official	EP may relate to the situation of customers who may be in a difficult position because of their low income as indicated by their tax statements in conjunction with their professional status, marital status and specific health conditions and therefore, are unable to respond to the costs for the reasonable needs of the supply of electricity, as these costs represent a significant proportion of their disposable income.
Czech	Unofficial	Considering the definition from the w Energy Efficiency Directive,
Denmark		Not Defined
Estonia	Unofficial	In the transposition of the Directive, a person affected by energy poverty was linked to maintenance support, which means that the number of beneficiaries of subsistence support is equal to the number of persons affected by energy poverty.
England	Official	Fuel poor: Households whose energy expenditure are above the national average, and after paying that expenditure their income results below the official poverty line (60% of median income).
Finland		Not Defined
France	Official	A person in a fuel poverty situation is a person who has particular difficulties in his/her home in obtaining the energy supply necessary to meet basic needs because of the inadequacy of his/her resources or living conditions.
Germany		Not Defined
Greece	Official	In Greece, the National Strategy for Energy Poverty Alleviation proposes that a household is considered to fall into energy poverty, when both the following conditions are met: total annual energy costs represent less than 60% of the cost of minimum energy

		requirements and, net annual income is less than 60% of the national median
Hungary		Not Defined
Ireland	Official	EP can be described as a situation whereby a household is unable to attain an acceptable level of energy services (including heating, lighting, etc.) in the home due to an inability to meet these requirements at an affordable cost.
Italy	Official	EP difficulty for buying a minimum basket of energy goods and services, or condition where access to energy services implies a diversion of resources (in terms of expenditure or income) higher than socially acceptable
Latvia	Official	Inability of a household user to maintain an appropriate temperature in the dwelling or to use the services provided by energy supplier, or to pay for them due to low energy efficiency or because the payment for such services has a high share in household income
Lithuania	Unofficial	Persons living in households who cannot afford sufficient heating due to lack of money. Households that spend too little and do not provide services.
Luxembourg	Unofficial	Vulnerable people who are at risk of energy poverty because their income is low and their energy consumption is relatively high. Households that are unable to heat adequately or have to rely on state aid to pay their energy bills.
Northern Ireland	Official	A household is in fuel poverty if, in order to maintain an acceptable level of temperature throughout the home, the occupants would have to spend more than 10% of their income on all household fuel use.
Malta		Not Defined
Netherlands	Unofficial	TNO uses a lack of access to affordable modern forms of energy at home as a definition of energy poverty.
Poland		Not Defined
Portugal	Unofficial	EP inability to maintain housing with an adequate level of essential energy services, due to a combination of low income, low energy performance of dwellings and energy costs.
Romania	Official	EP impossibility of the vulnerable consumer to meet their minimum energy needs for the optimal heating of the home during the cold season
Scotland	Official	Fuel poor: A household, in order to maintain a satisfactory heating regime, it would be required to spend more than 10% of its income (including Housing Benefit or Income Support for Mortgage Interest) on all household fuel use.
Slovakia	Official	Energy poverty: Inability of a household to secure a socially- and materially- necessitated level of energy services in the home.
Spain	Official	Energy poverty is the situation in which a household finds itself in a situation in which its basic energy supply needs cannot be met as a result of an insufficient level of income and which, where appropriate, may be aggravated by having an inefficient energy house.

Sweden		Not Defined (Sweden does not distinguish energy poverty from poverty in general. Thus, the term 'energy poverty' is not used in Sweden and there are no specific objectives)
Wales	Official	Fuel poverty is defined as having to spend more than 10% of income (including housing benefit) on all household fuel use to maintain a satisfactory heating regime. Where expenditure on all household fuel exceeds 20% of income, households are defined as being in severe fuel poverty.

Considering the different approaches to define EP, the REVERTER project is based on a broad definition of Energy Poverty that accommodates the various needs of vulnerable households, in all countries: a condition in which a household is unable to secure a socially and materially needed level of energy services to ensure a minimum living comfort level, with a particular focus on worst performing buildings, aligned with the new EED 2023 (article22, §4 (b)).

3.3 Energy Poverty Indicators

3.3.1 Indicators in Force in the EU (and UK)

In March 2023, the Commission, the European Parliament, and the Council reached a provisional agreement to reform and strengthen the EU Energy Efficiency Directive. Besides the legal strength given to the energy efficiency first principle, the agreement includes the first-ever EU definition of energy poverty. Member States will now have to implement energy efficiency improvement measures as a priority among people affected by energy poverty, vulnerable customers, low-income households, and where applicable, people living in social housing. The revised rules put a stronger focus on alleviating energy poverty and empowering consumers, including the creation of one-stop shops for technical and financial assistance and out-of-court mechanisms for the settlement of disputes. Besides providing the first official definition of Energy Poverty, the Directive also provides a list of the minimum indicators MS should use to measure Energy Poverty:

> *"Member States shall, in their assessment of the share of energy poverty in their national energy and climate plans, consider the following indicators:*
> *(a) the inability to keep the home adequately warm (Eurostat, SILC [ilc_mdes01]);*
> *(b) the arrears on utility bills (Eurostat, SILC [ilc_mdes07]);*
> *(c) the total population living in a dwelling with a leaking roof, damp walls, floors or foundation, or rot in window frames or floor (Eurostat, SILC [ilc_mdho01]);*
> *(d) at-risk-of-poverty rate (Eurostat, SILC and ECHP surveys [ilc_li02]) (cutoff point: 60 % of median equivalised income after social transfers)."*
>
> *(EC, 2023c)*

Even though the UK is no longer a formal European Union Member State, their pioneering efforts, active Energy Poverty mitigation strategies, bold renovation targets/experimentation and pragmatic integrated practices are very relevant for this assessment and an excellent inspiration for REVERTER.

In 2021 (GOV.UK, 2021), the evolution of the Low Income High Cost (LIHC) indicator, namely the Low Income Low Energy Efficiency (LILEE), tracks simultaneously low/insufficient income and housing energy efficiency parameters close to REVERTER's needs:

> *"Following consultation in 2019, Government is updating the way we measure fuel poverty. Our aim is to better track progress toward the statutory fuel poverty target whilst still reflecting the three key drivers of fuel poverty (low income, energy efficiency and prices). The updated measure, Low Income Low Energy Efficiency (LILEE), finds a household to be fuel poor if it:*
> *• Has a residual income below the poverty line (after accounting for required fuel costs)*
> *and*
> *• Lives in a home that has an energy efficiency rating below Band C.*
> *The new measure will continue to show both the extent and severity of fuel poverty through the fuel poverty gap.*
> *The key change is that LILEE considers whether a household has reached Band C or above (Bands A and B) in energy efficiency7. Where such households struggle with their energy bills, it is unlikely to be because their home needs more insulation. Whilst we recognise that there are households living in energy efficiency Band A, B or C homes who are unable to afford sufficient energy to keep warm, due to a very low income, most will not significantly benefit from energy efficiency measures.*
> *As such, households in homes that have been improved to Band C or above, will not be considered as being in our measure of fuel poverty.*
> *We will, however, continue to consider the needs of low income vulnerable households living in Band A to C homes under our vulnerability principle, as well as the needs of fuel poor households living in Bands D to G."*
>
> *(GOV.UK, 2021)*

The LILEE indicator detailed in the (LILEE (DESNZ, UK.GOV), 2023) and requires the following data:

> *"• Household income (after housing costs);*
> *• Fuel Poverty Energy Efficiency Rating (FPEER) (in addition to building energy performance factors this is adjusted for direct energy cost interventions e.g. Warm Home Discount); and*
> *• Fuel costs."* *(LILEE (DESNZ, UK.GOV), 2023, p. 2)*

The LILEE delivers estimates on:

- Households with low income/ affordability (grey shaded area in Figure 4)
- Fuel poverty gap, the virtual distance to the nearest basic threshold

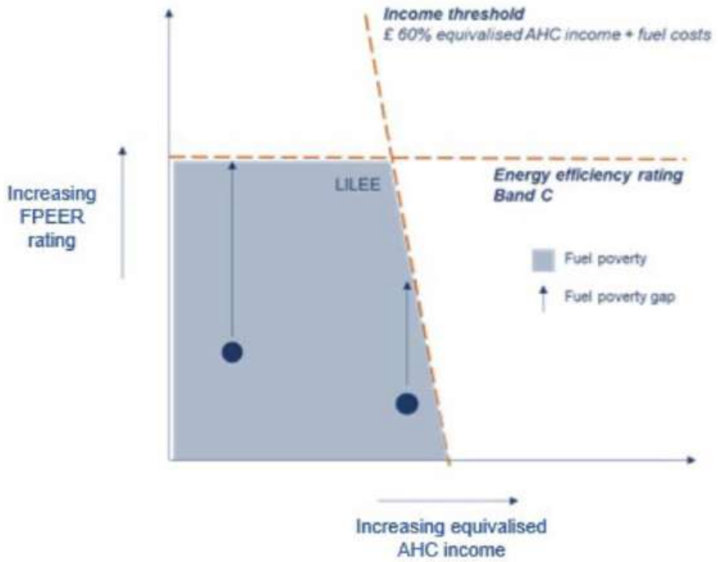

Figure 4: Fuel poverty under the Low Income Low Energy Efficiency Indicator (LILEE (DESNZ, UK.GOV), 2023, p. 2)

3.3.2 Options of Indicators

Even though there has been significant progress in the development of Energy Poverty indicators at the EU level and UK, there is no consensus about the best indicator and most literature on the subject claim that energy poverty cannot be measured by a single indicator, due to its multidimensional aspects, pointing to the need of using composite indicators or indexes that consider economic dimensions but also many others - for example, the decentralization of energy infrastructures and the improvement of renewable energy access can help to identify territorial disparities in household vulnerability. This multiple-measure approach is suggested by EPOV (Manchester Urban Institute, 2016) and later by EPAH (DG Energy, 2023), but also many experts working on the field who frame Energy Poverty within the following relevant factors: access to energy, affordability, flexibility, energy efficiency, needs and practices. Tackling energy poverty requires a multi-faceted approach that addresses several factors and addresses the needs of affected communities/consumers.

A foundational EU report carried out under the Framework Contract ENER/A4/516-2014, on Energy Poverty – Assessment of the Impact of the Crisis and Review of Existing and Possible New Measures in the Member States, entitled "Selecting indicators to measure energy poverty" (Rademaekers et al., 2016), after analysing a huge amount of factors, come up with four main indicators as the most suitable to assess primary energy poverty. The four selected indicators (Rademaekers et al., 2016) define a household as energy-poor if :

- Its share of income spent on energy services is larger than twice the national median.
- Its income after energy costs falls below the poverty line and the share of its income spent on energy is above the national median.
- Its energy expenditure is lower than half the national median energy spending.
- It declares not to be able to warm the house during the cold season.

In addition to identifying the indicators, the study also provided some reflections about the inappropriate use of energy poverty indicators as a basis for design on the ground-interventions:

> *"an energy poverty metric is an indicator that allows for the measuring and monitoring of energy poverty. (…). **It is not a basis for focusing on-the-ground interventions** but rather an indicator that provides policy makers with an understanding of the severity of the problem at Member State level, and allows for cross-comparison across the EU Member States."*
>
> *(Rademaekers et al., 2016).*

More recently, as part of the Covenant of Mayors - Europe movement, signatories committed to tackling energy poverty as one key action to ensure a just transition. To support signatories in their planning and implementation efforts on energy poverty, the Covenant of Mayors Europe Office, in cooperation with the European Commission's Join Research Centre (JRC) and the Energy Poverty Advisory Hub (EPAH), and through the engagement of a wide pool of practitioners, developed the energy poverty pillar of the CoM – Europe reporting and monitoring framework. The framework has been consulted with a group of city practitioners working on energy poverty. The pillar is also aligned with the recommendations of the Global Covenant of Mayors. A guideline to address Energy Poverty was published in 2022, including a list of potential EP indicators to be used (Covenant of Mayors, 2022).

This framework is flexible in order to cater to the different needs and local circumstances of signatories. The CoM-Europe energy poverty pillar consists of: (i) goal; (ii) assessment; (iii) actions, and to allow sufficient time for planning, there will be a transition period until the end of 2024, during which there will be no mandatory data reporting requirements for signatories. The assessment contains a list of over 20 indicators, grouped in five macro-areas: climate, facilities/housing, mobility, socio-economic aspects, policy and regulatory framework, participation and awareness raising. In Table 5, a generic definition and units are included for each indicator.

Table 5: Overview of the main indicators, descriptions and units (Covenant of Mayors, 2022)

Area	Indicator	Description	Unit
Climate	Frequency of heat waves	Frequency of heat waves per month in a year	Average per monthly/year
	Frequency of cold waves	Frequency of cold waves per month in a year	Average per monthly/year
	Number of heating degree days per year	Heating degree day is a measurement designed to quantify the demand for energy needed to heat a building, it is based on the outside temperature where heating is needed	Number of HDD and CDD /year
	Number of cooling degree days per year	Cooling degree day is a measurement designed to quantify the demand for energy needed to cool a building, it is based on the outside temperature where cooling is needed	Number of HDD and CDD /year
Facilities / housing	F+G + H band (EPC) dwelling / total number of dwelling	Percentage of buildings with Energy Performance Certifications bands F, G and H in the municipality	[%]

	Energy consumption (electricity + heating) per capita / national energy consumption (electricity + heating) per capita	Share of municipal energy consumption per capita out of national energy consumption per capita	[%]
	Share of buildings renovated per year	Share of buildings renovated per year out of total buildings	[%]
	Share of households / population with presence of leak, damp, rot in their dwelling / total households or population	Share of population / households with leak, damp or rot in their dwelling, based on question "Do you have any of the following problems with your dwelling / accommodation? a leaking roof; damp walls/floors/foundation; rot in window frames or floor.	[%]
	Percentage of households / persons within the municipality experiencing heating discomfort	Share of household / persons experiencing heating discomfort out of total households	[%]
	Percentage of households / persons within the municipality experiencing cooling discomfort	Share of household / persons experiencing and cooling discomfort out of total households	[%]
	Households / persons connected to the electricity grid / total households or persons	Share of households /persons connected to the electricity grid out of total households	[%]
	Households / persons connected to the gas grid / total households or persons	Share of households / persons connected to the gas grid out of total households	[%]
	EPC bands of dwelling higher than B	Percentage of dwellings with EPC higher than B out of total dwellings with certificate	[%]
	Households with centralised heating system / total households	Share of households with a centralised heating system out of total households	[%]
	Ownership of heating and cooling systems	Share of households with heating and cooling systems out of total households	[%]
	Number of social housing apartments/total number of apartments	Percentage of social housing apartments in total number of apartments	[%]
	Average energy demand of social housing buildings / sq.m.	Share of energy demand of social housing of median national demand	[kWh/sqm]
	Low absolute energy expenditure (M/2)	The M/2 indicator presents the share of households whose absolute energy expenditure is below half the national median, or in other words abnormally low. This could be due to high energy efficiency standards, but	[%]

		may also be indicative of households dangerously under-consuming energy. M/2 is a relatively new indicator that has been used in Belgian to complement other expenditure and self-reported indicators. Note: this indicator is influenced by the underlying distribution of absolute energy expenses in the lower half of households. If the median is relatively high and the distribution below very unequal, the M/2 indicator is high	
	Number of households with only oil boilers, wood calefactions, conventional gas boilers	Share of households with oil boilers, wood calefactions, conventional gas boilers out of total households	[%]
	Households with centralised cooling system / total households	Share of households with a centralised cooling system out of total households	[%]
	Households with centralised cooling system older than 10 y / total households with cooling system	Share of households with a centralised cooling system older than 10 years old out of total households with centralised cooling system	[%]
	Average age of the buildings	Average age of buildings per period of construction	Years
	Dwelling ownership	Percentage of households that own the dwelling out of total households	[%]
	Over and under occupation of dwellings	Percentage of households according to number of occupants	[%]
	Percentage of households / persons within the municipality with access to clean cooking fuels and technologies	Proportion of households / persons with primary reliance on clean fuels and technology is calculated as the number of people using clean fuels and technologies for cooking, heating and lighting divided by total population reporting that any cooking, heating or lighting, expressed as percentage. “Clean” is defined by the emission rate targets and specific fuel recommendations (i.e. against unprocessed coal and kerosene) included in the normative guidance WHO guidelines for indoor air quality: household fuel combustion.	[%]
Mobility	Population / households not having access to essential services within 1 hour by walking, cycling or public transport / total population	Percentage of population / households not having access to essential services (pharmacies, food stores, health facilities) within 1h by walking, cycling or public transport out of total population	[%]
	People / households living more than one 1 km from nearest public transport station / number of population	Percentage of people / households living more than one 1 km from nearest public transport station out of total population	[%]

	The local public transport travel frequently enough, covering the essential necessities for the population	Yes or no answer to the question: "do the local public transport travel frequently enough, covering the essential necessities for the population"?	Yes / No
	Social housing apartments not having easy access to public transport (*)/ all social housing apartments	Percentage of social housing households not having easy access to public transport out of total number of social housing	[%]
	Inhabitants / households receiving support to pay public transport services/public transport users	Percentage of inhabitants / households receiving support to pay public transport services out of total public transport users	[%]
Socio-economic aspects	Percentage of persons / households spending up to XX % their income on energy services	Share of persons / households spending more than an specific percentage of their incomes on energy services putting them in an situation of energy poverty	[%]
	Vulnerable households or persons / total households or persons	[This description is an example only; municipalities can define on their own] Households with lone parents, parents with more than three children, families with low income, households receiving social support, families with low level of education.	[%]
	Arrears on utility bills / total population or households	Share of (sub-) population / households having arrears on utility bills, based on question "In the last twelve months, has the household been in arrears, i.e. has been unable to pay on time due to financial difficulties for utility bills (heating, electricity, gas, water, etc.) for the main dwelling?"	[%]
	Inability to keep home adequately warm	Share of population / households not able to keep their home adequately warm.	[%]
	Inability to keep home adequately cool	Share of population / households not able to keep their home adequately cool.	[%]
	High share of energy expenditure in income (2M)	The 2M indicator presents the proportion of households whose share of energy expenditure in income is more than twice the national median share. Note: where income distributions are more equal, variance in energy expenditure translates to higher 2M shares. High variance in energy/income shares can occur due to structural differences in energy expenditure between household groups, as well as in situations where energy is often, but not exclusively, included in rent.	[%]
	Average price of electricity	Average price in [€] of the consumed electricity kwh in the municipal households	[€]
	Average price of gas	Average price in [€] of the consumed gas (m3/kwh) in the municipal households	[€]

	Energy related expenditure / local GDP	Relationship between the yearly energy cost the households and the local GDP, percentage average of the local GDP designated to the energy cost	[%]
	Citizens / households under poverty threshold / number of citizens / households	Percentage of the local population / households suffering from poverty, persons / households and families under the limit of incomes considering the family size	[%]
	At-risk-of-poverty rate	People / households at risk of poverty or social exclusion (% of population). The at-risk-of-poverty rate is the share of people with an equalized disposable income (after social transfer) below the at-risk-of-poverty threshold, which is set at 60 % of the national median equalized disposable income after social transfers.	[%]
	Citizens / households with social support	Number of citizens / households receiving financial assistance from administrative institutions	[%]
	Money spent to support energy poor households or persons / in relation to local GDP	Percentage of public funds spent in support programs out of total local GDP	[%]
	Energy poor households / persons supported / total energy poor households asking for support	Percentage of energy poor households / persons that benefit from some kind of support program out of total number of households asking for support	[%]
	Energy poor households / persons supported / total energy poor households detected	Percentage of energy poor households / persons that benefit from some kind of support program out of total number of energy poor households	[%]
	Unemployment rate	The unemployment rate is a measure of the prevalence of unemployment and it is calculated as a percentage by dividing the number of unemployed individuals by all individuals currently in the labour force	[%]
	Persons aged under 12	Persons aged under 12 / total population	[%]
	Persons aged over 65	Persons aged over 65 / total population	[%]
	Persons with respiratory and circulatory problems	Persons with respiratory and circulatory problems / total population	[%]
	Persons with an education level under lower secondary school	Taking in account the International Standard Classification of education (ISCED from the UNESCO) a lower education level refers to an education level under lower secondary school	[%]
Policy and regulatory framework	Existence of energy poverty strategy	Yes or no answer to the question: "Is there a energy poverty strategy"?	Yes / No
	Existing rent regulation	Yes or no answer to the question: "Are there rent regulation"?	Yes / No
	Specific measures related energy poverty	Yes or no answer to the question: "Are there energy poverty specific measures"?	Yes / No

	Existing incentives for landlord's programs	Yes or no answer to the question: "are there incentives/programs for landlords"?	Yes / No
Participation / awareness-raising	Awareness-raising campaigns targeting vulnerable households	Preventing rent increases due to energy retrofits, balancing the PRS with interest in homeownership and social housing	Yes / No
	Engagement and cooperation with local stakeholders on energy poverty	Yes or no answer to the question: "Is there engagement and cooperation with local stakeholders for energy poverty reduction"?	Yes / No

The many different indicators available in the literature usually address different aspects of the human condition, consider different approaches for the qualification of energy poverty, try to capture different conditions, and are grouped into different categories. The two main groups of indicators for measuring energy poverty can be divided into two main types of indicators: objective and subjective indicators.

Objective indicators are generally based on the share of the energy costs in the total household income that is used for keeping the dwelling at an adequate temperature (Atsalis et al., 2016). These indicators can be easily compared in different Member States, ensuring that climate correction and purchase power are taken into consideration. However, this data usually refers to the household expenditure for the provision of electricity and fuel, and therefore it does not reflect the cost to ensure thermal comfort in the dwelling (Atsalis et al., 2016). Lack of data, particularly data with adequate granularity, is reported as an important barrier to tackling EP (you cannot fight what you cannot measure; as stated in the "EPAH lunch talk - Indicators importance for local scale assessments of energy poverty" on 14 December 2022).

Subjective indicators assess basic parameters or characteristics of a dwelling and are therefore understood under a social dimension (Atsalis et al., 2016; Healy, 2003). These indicators are related to questions about the ability to maintain the appropriate temperature and pay bills before the deadline, as well as other questions about housing conditions (Waddams et al., 2012)

There is a vast list of other indicators which cannot immediately be included in the two categories. Indicators that are based on measuring the indoor temperature of dwellings (Thomson & Snell, 2013), indicators relating to the assumed consequences associated with energy poverty, such as debts on electricity or natural gas bills (arrears on energy bills), which may result in supply being cut off (Romero et al., 2018)), and excess mortality in winter and summer (Rademaekers et al., 2016). Studies on the influence of other indicators on energy poverty are also being considered, such as the carbon footprint, gentrification phenomena, and social energy services bonus (Bouzarovski et al., 2018), but consensus on how to measure energy poverty is not met either easy to reach and the debate around the energy poverty concept definition is large in the literature (Gouveia et al., 2018). Some experts propose an Index to measure energy poverty: a composite energy poverty index for each MS (Bouzarovski & Tirado Herrero, 2017), while the EU statistics use proxy indicators (Pye et al., 2015).

Some examples of objective and subjective indicators are presented hereinafter.

Objective Indicators (Expenditure Based): capture affordability of access to energy services

- % energy expenditures - 10% energy cost Ratio, high share of available energy costs;
- Low Income High Costs (LIHC), low available income (share of energy cost in low-income household revenue; insufficient energy spending;
- Hidden Energy Poverty (HEP) extent – households whose energy bills are abnormally low
- % of households unable to afford to keep their home adequately warm;
- % of households in arrears on utility bills;
- MIS (Minimum income standard).

Objective Indicators (Outcome Based): based on real data (utility data) and on health data.

Subjective Indicators (Consensual Based): capture self-perception, and understanding of subjective indicators that give an indication about comfort settings, habits, behaviour, and cultural aspects; more explicit insights than quantitative metrics.

- Perceived Energy Poverty (PEP) – number of households that report having financial difficulties in heating their homes sufficiently.

Based on the vast literature assessment carried out in WP2 and additional desk research, the most popular indicators can be identified as:

- The 10 % indicator or high-expenditure households– this indicator introduced for the First time in 1991 (Boardman, 1991) classifies a household as energy-poor if 10 per cent or more income is spent on energy services. This indicator is very pragmatic and easy to calculate, yet it does not ensure the real identification of households that are in EP (the 10% energy burden expenses of a low-income household who lives in a modest house cannot be compared with a 10% energy burden expenses of those that have large households and so require more energy for heating, lighting, etc., but can afford to spend a higher percentage of their income on energy bill).
- Low Income High Cost (LIHC) – The LIHC indicator (Hills, 2012) classifies a household based on the status of EP, that is when a household's income after energy services expenditure falls below the official poverty threshold and energy expenditure is higher than the median cost of the population.
- Minimum Income Standard Indicator (MIS) – The MIS indicator identifies a household in a situation of EP if its income after energy services expenditure is below the minimum income standard.
- After-Fuel-Cost Poverty Indicator (AFCP) – The AFCP indicator defines a household as energy-poor, when it does not have enough income to pay for essential energy services, after covering housing and other basic needs.
- EU-SILC – the house has a leaking roof, damp walls/floors/foundations, rot in window frames – The percentage of houses presenting leaking roofs, damp walls/floors/foundations, rot in the windows frames.

The Energy Poverty Advisory Hub (Directorate-General for Energy, 2023) was put forward in Clean Energy for All European packages in 2018 to monitor EP through data collected from several databases, such as the European Union Statistics on Income and Living Conditions (EU-SILC) and Household Budget Survey (HBS). Several EP indicators are provided by EPOV, including four primary indicators, two of which are based on self-reported, and subjective, experiences of limited access to energy services, namely:

- European Union Statistics on Income and Living Conditions (EU-SILC) – Inability to keep the home adequately warm (or cool) – the percentage of the population which is unable to keep the home adequately warm (or cool), based on EU SILC data.
- EU-SILC - Arrears on utility bills based on EU SILC data – the percentage of households with arrears on utility bills. Even though this indicator provides some information about households struggling to pay the energy bills, it is not a good indicator for energy poverty evaluation nor for comparing households' well-being, because having no arrears on utility bills does not give a real indication of the effort's households do to pay for the energy bills). It also does not give any indication about the comfort levels they are living in. Most people make an effort to pay the electricity bill on time, because they fear being disconnected, but live with high restrictions on the consumption of goods with a strong impact on comfort and health.
- Low absolute energy expenditure or hidden energy poverty is the share of the population whose absolute energy expenditure is below half the national median and, therefore, is abnormally low. This parameter indicates hidden energy poverty because it focuses on the percentage of households whose absolute energy expenditure is lower than half of the national median (M/2).
- Twice the National Median Indicators (2M) - classify a household based on the status of EP, that is, when a household's income after energy services expenditure falls below the official poverty threshold and energy expenditure is higher than the median cost of the population. 2M indicator, which translates the percentage of households in which the energy expenditure in income is more than twice the national median share (based on HBS).

The other two indicators are estimated. The 2M indicator (EPAH, 2022) includes four similar indicators: double the median, double the mean, double the median share, and double the mean share of household expenditure on energy. These indicators classify a household as energy-poor when a household pays more than double the median, double the mean, double the median share, and double the mean share of its income on energy services. However, these indicators require data that is not always available.

The most often reported advantages of the single EP indicators include their ability to be adapted to national standards and their objective nature. Single indicators are easy to calculate and apply but the information they provide is quite narrow and usually fails to reflect the full extent of the problem (Siksnelyte-Butkiene et al., 2021), (Mafalda Matos et al., 2022). Although these single indicators are used quite widely, they have been recently criticised for lack of empirical justification (Fizaine & Kahouli, 2019), lack of comprehensiveness or a too narrow approach towards the problem (Bouzarovski & Tirado Herrero, 2017). For instance, the 10% indicator is criticized for its overly narrow assessment and excessive dependence on energy prices (Legendre & Ricci, 2015) (Champagne et al., 2023). The LIHC fails to take into account the increasing energy prices and complicates the monitoring of political interventions

(Heindl & Schuessler, 2015), (März, 2018). The 2M indicator is criticized for the underlying difficulties in determining the minimum income on an objective basis (Castaño-Rosa et al., 2019). The EU-SILC indicators are also denounced for being subjective, dependent on culture, and not universal due to differences in climatic conditions (Castaño-Rosa et al., 2019), (Bouzarovski & Tirado Herrero, 2017).

Within this context, to further analyze the EP situation and help governments to design better strategies to mitigate the problem, researchers have been developing and using various composite indicators and sets of indicators. Some of them are more universal, while others are focused on specific aspects of EP.

The Multifaceted nature of EP

Energy poverty is an important societal issue, with economic impacts and implications for solidarity. Although its main drivers (e.g. insufficient income, poor quality housing, high energy prices) are widely recognised, until recently there was no common definition of energy poverty at the European level, let alone a common way of measuring the phenomenon (EC, 2023c). In this scenario, several countries have developed their own mechanisms to address the problem. In Belgium, an energy poverty barometer has been developed drawing on a set of complementary indicators with the aim of grasping the multifaceted nature of energy poverty: excessive energy bills compared to available income (measured energy poverty), restriction in energy consumption below basic needs (hidden energy poverty) and self-reported difficulties to heat the housing correctly (perceived energy poverty) (Meyer et al., 2018).

In Greece, a recent study has shown that the measurement of energy poverty based on classical objective and subjective indices leads to divergent results, with no relevance to each other (Ntaintasis et al., 2019). To a large extent, households characterized as energy-poor by one method are not classified as such by another. The use of composite indicators adjusted to local circumstances seems to form a more coherent framework for measuring energy poverty in an area and may provide additional information as regards the intensity of energy poverty, the study concluded. However, the quantification of these indicators is based on data that needs to be gathered through a survey involving a significant number of households.

In Spain, the traditional energy poverty 'objective' metrics are mostly focused on households spending a disproportionate share of income on energy. Nevertheless, vulnerable people could also restrict their energy consumption and this 'hidden energy poverty' is not sufficiently considered in metrics and policies. This phenomenon has been investigated in a recent study, and a new methodology to determine an absolute threshold below which households' actual energy expenditures are too low to meet their required energy needs is proposed: an income criterion is introduced as a proxy to exclude households that have low energy expenditures for reasons other than lack of affordability (Barrella et al., 2022). Thus, an alternative 'adjusted to reality' scenario is presented based on a sensitivity analysis.

The results of the Spanish case study show that, in 2019, 45% of households had low absolute energy expenditures, but only 56% of these (25% of the total households) were suffering from hidden energy poverty. Besides, the average annual 'energy poverty gap' per household was €374, and the national budget needed to potentially fill this gap was €1,692 m. Moreover, there was a broad regional disparity depending on climatology and income, and several key factors have been identified, i.e. household size, housing's energy efficiency and tenure, and locality's degree of urbanisation. Thus, the macro-level analysis carried out in this paper makes it possible to characterise hidden energy poverty in Spain, and the policy recommendations provided might guide policymakers to target assistance programs more effectively (Barrella et al., 2022).

Income /Expenditure Indicators

The income and expenditure approach is the most widely applied approach to characterise the energy poverty phenomenon, but it is also the most limited (Ambrose et al., 2019). Setting a percentile limit to indicate the spending threshold is not very sensitive to the particular sociocultural realities and needs that condition consumption habits (Gram-Hanssen, 2014). In addition, setting a spending limit also masks the impact of energy price inflation and complicates the task of monitoring interventions.

How the income is calculated can also be a constraint for getting a true picture of the financial resources available: whether it is calculated taking (or not) into account the size of the household; whether the income calculation is done before or after expenses are paid or whether all, some or none of the subsidies received by the household are taken into account. The same is true for the calculation of costs: although it can be obtained from the users themselves, households with lower incomes tend to voluntarily reduce their energy consumption and this is not reflected in the energy bill.

To know the energy demand of the house and to be able to check the bill, it is necessary to have a good knowledge of the energy performance of the building, which also implies in many cases assuming consumption levels and occupancy patterns, leading to poor or incorrect estimates. On the other hand, the consensual-based approach also has some limitations, mainly due to the high subjective content of this method, which makes the thermal perception of the dwelling vary from one household context to another. In general, the data collection process, based on a form, only leaves room for binary answers such as "Yes/No", losing all nuances of personal experience (Wise et al., 2021).

Several Southern European countries are paradoxical examples of high energy poverty, revealed by multiple indicators, despite their mild winter climates. Energy poverty may be quantified by using expenditure-based indicators that compare energy expenditure to net income, as a measure of how elastic is the net income to pay for energy. Because of the mild winter season and low-efficient buildings, paying for space heating is not a top priority expense for most households. This cultural behaviour exposes people to continuously cold conditions. Therefore, a reliable energy poverty indicator should rely on its capacity to evaluate net-income elasticity to pay for expected energy expenditure (Oliveira Panão, 2021).

Health Impact Indicators

A recent review to assess the impact of energy and fuel poverty on health indicated that twenty-nine out of 35 European Energy Poverty studies analysed focused exclusively on cold weather energy and fuel poverty, whereas only six articles explicitly included the inability to cool or maintain a comfortable household temperature during the warmer months. Among these, four studies measured or included findings specifically related to the health associations of an inability to cool the house. The correlated health associations included excess summer mortality and cardiovascular and respiratory diseases (Champagne et al., 2023). Focusing on the same topic, (Oliveras et al., 2020), frame energy poverty as a distinct condition of deprivation. Besides the identification of more structural and systemic factors driving energy poverty, his approach can provide a better understanding of the circumstances and mechanisms through which energy poverty affects health. Aiming to study health effects both in summer and in winter, targeting households that could not afford to maintain their dwellings at an adequate temperature during the cold months and in the warm months, the study found an overlap in 68% of the cases, a clear indication of the same root cause: low energy efficiency of dwellings or high energy prices.

3.3.3 Challenges and Main Gaps in Indicators

Scientific publications, studies, and technical reports with suggestions on specific energy poverty indicators and strategies to tackle Energy Poverty are widely available. The number of events focusing on energy poverty aspects is huge and the governments are also making policies to leave no one behind. However, the problem keeps growing and the urgent need for a clean energy transition puts more households at risk. Capturing the number of households living in energy poverty is however a challenging procedure, due to its multidimensionality, the variability over time and space, its private nature, etc.

According to the literature, experts are divided regarding the best indicators and metrics to measure EP due to its complexity: multi-faceted nature (Meyer et al., 2018), social sensible matter, and affecting several sectors (energy, infrastructure, health and mobility), among other options, but recognise the importance of measuring it (Faiella & Lavecchia, 2021) to be able to come up with solutions to tackle the problem. If the EP was already a major concern being tackled by different policies, 2022 brought an unprecedented challenge for European citizens when it comes to access to energy and energy bills. Recognised specialists working on energy poverty for a long time, have been reflecting on the developments regarding energy poverty during the past year and have opened the debate of what is the roadmap ahead for local governments that wish to address energy poverty.

During the EPAH lunch talk #3 organized on January 2023, Bouzarovski highlighted that *"energy poverty is not only just about poverty: it is about infrastructure, it is about how you provide energy and how you organise your housing sector. It has to do with the system and the chains through energy services are demanded by households"*. He explained that with the energy crisis of the past year, energy poverty became a major news item while worsening significantly. Moreover, the Social Climate Fund was signalised as a great step forward in the EU, *putting social consideration in the EU mandate as for many years it was for Energy*

Security. Nevertheless, there are several challenges ahead in energy poverty mitigation that need to be overcome. The main conclusions of the discussions are:

- Energy poverty is seen as a behavioural challenge, whereas it is about structural disempowerment. Addressing this challenge "is not about fixing the energy poor, it is about fixing the housing sector".
- There is a lack of some very significant indicators and data on different facets of energy poverty, such as information about heat waves and summer energy poverty, housing faults or well-being indicators.
- Responses are divergent across countries, regions and cities. Not every local government has the adequate awareness, capacity or resources to tackle the challenge.
- With the more aggressive decarbonization policies in force, there is a need to pay attention to their impacts on energy-poor households.
- Qualitative aspects of energy poverty need to be included in one energy poverty indicator/index

Based on the scoping review (Champagne et al., 2023) there is a significant and complex association between energy poverty and various domains of health. The review also indicates that women are at higher risk of energy poverty, while children and the elderly were identified as particularly vulnerable to energy poverty's adverse health repercussions. While the authors recognise there is heterogeneity across research being published, making it difficult to compare the findings, the conclusions are clear to support the use of health as a justification to address energy poverty and urge the involvement of public health in policymaking to mitigate energy poverty.

The main indicators gaps identified are related to summer energy poverty, housing faults or well-being, energy illiteracy but also digital illiteracy, gender sensitivity, resilience to climate change (how green? how digital?), resilience to vulnerabilities (how able to cope with adversity?), transport poverty and health-related impacts. Additionally, not all the parameters that are related to the energy poverty integrated are in the definition. Therefore, it is crucial to continue the research to determine all the parameters and then to find the required data.

One of the main difficulties in calculating EP indicators is related to the availability of appropriate data. Existing data is limited and the attempts to come up with an Energy Poverty Indicator that could be used by all countries to adequately measure energy poverty is a hot energy topic and is far from consensual.

4 EP and Building Renovation Roadmaps

The Long-Term Renovation Strategies (LTRS) of 10 EU member states[2] were analysed to identify the most essential aspects of the renovation roadmaps. Furthermore, the Action Plan for the alleviation of energy poverty in Greece was taken also into consideration focusing on the measures for the energy renovation of the energy poor's dwellings. It should be mentioned that the LTRS presents national building stock policies and actions to stimulate a cost-effective deep renovation of buildings, while they focus on several issues such as the worst performing buildings, split-incentive dilemmas, market failures, energy poverty and public buildings. Furthermore, an overview of national initiatives to promote smart technologies and skills and education in the construction and energy efficiency sectors is also a key part of these strategies. These strategies also include a roadmap with the required policy measures and measurable progress indicators, as well as indicative milestones by 2050. All the examined countries have utilized a common template for the preparation of the LTRS. Nevertheless, few countries decided to alter the proposed structure, while it was obvious the different levels of the provided information.

Apart from the LTRS, 4 individual renovation roadmaps were also examined concerning existing initiatives related to the concept of individual building roadmaps and passports: Belgium (Flanders – Woningpas and EPC+), France (Passeport Efficacité Énergétique), Germany (Individueller Sanierungsfahrplan) and Denmark (BetterHome)) to realize how the different elements can be designed and implemented and to assess potential differences compared to the respective initiatives at national level. It should be noted that the individual building roadmaps were analyzed extensively within the framework of the iBRoad project[3].

A specialized template was prepared to facilitate the collection of homogenous information about the examined roadmaps and to ensure their comparative analysis and the elicitation of robust conclusions and recommendations.

4.1 Overview of Roadmaps

The first fundamental difference between LTRS and the individual roadmaps was the fact that the first one can be considered as a more strategic one, while the individual is more specialized in the targeted area providing more tailored measures for the further promotion of the building renovation. Nevertheless, the examined types of roadmaps appear several similarities.

Firstly, the ministries, which are officially responsible for the design and implementation of energy efficiency policies in the building sector at the national level, have prepared the LTRS. In contrast, two of the examined individual roadmaps have been initiated by regional governments (Germany- Individueller Sanierungsfahrplan and Flanders- Woningpas and

[2] The EU member states, which were included in the analysis, are Finland, Lithuania, Spain, Hungary, Romania, Croatia, Bulgaria, Portugal, Latvia and Greece. The objective was to include representants from different regions and climates.

[3] https://ibroad-project.eu/

EPC+), while the others have been driven by private actors (Denmark- BetterHome and France- Passeport Efficacité Énergétique).

Figure 5 presents an overview of the examined individual roadmaps, while Figure 6 displays the main aspects, which were integrated into them.

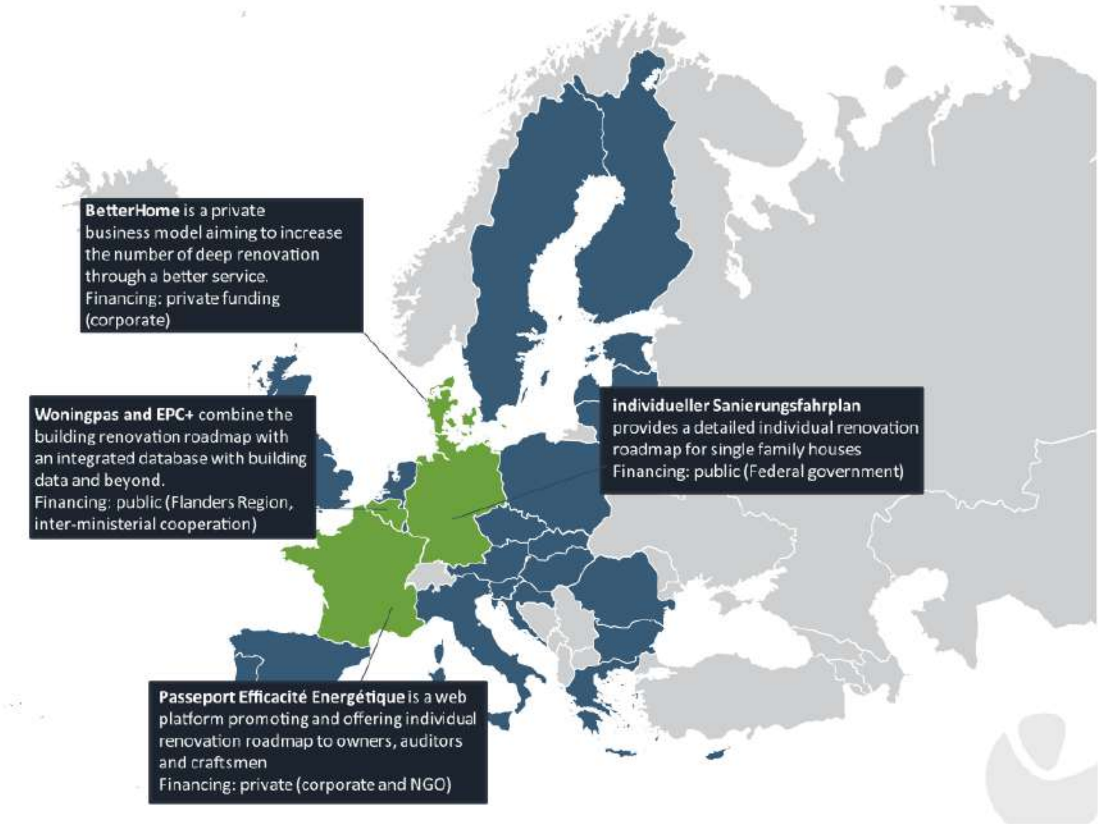

Figure 5: Overview of the examined individual roadmaps (Source: iBRoad project).

Process	BE-Flanders (EPC+)	France (PEE)	Germany (iSFP)	Denmark (BetterHome)
Definitions (Deep or staged deep renovation and/or alternative definition)	√	√	√	X
Long-term target for the existing building stock (2050)	√	√	√	X
Identified barriers	√	√	√	√
Stakeholders mapping	√	√	√	√
Stakeholders engagement	√	!	√	√
Market analysis	√	√	√	X
Energy Audit – On-site visit	X	√	√	√
Auditors training	X	√	√	√
Tailored solutions (renovation roadmap)	!	√	√	√
CO_2 reductions	√	!	√	√
Logbook/Database	√	!	X	!
Integrated financial support	!	N/A	√	!

√ = Yes ! = Under development/consideration X = No

Figure 6: Main integrated aspects into the individual roadmaps (Source: iBRoad project).:

LTRS focused both on buildings of the residential and tertiary sectors, apart from Greece's Action Plan for the alleviation of energy poverty, where only the residential is the targeted sector. All the individual roadmaps have focused mainly on single-family houses with few exemptions, such as the smaller multi-family houses (Germany – Individueller Sanierungsfahrplan) and the commercial buildings (Denmark - BetterHome).

The implemented analysis revealed that all the LTRS have already set specified renovation targets for 2050. No information was provided for individual roadmaps, while the action plan for the alleviation of energy poverty in Greece has specified a target for 2030.

All the LTRS have taken into account the mandatory renovation target for the Central State Administration of 3% of the gross floor area of heated and/or cooled buildings in the public building stock. Nevertheless, Hungary has decided to increase the annual renovation rate of the public buildings stock to 5%. Similarly, Portugal has already specified a more ambitious target for the case of public buildings.

The vast majority of the examined LTRS have expressed the renovation target about the share of the buildings, which will be renovated as presented in Table 6.

Table 6: Specified renovation targets within LTRS.

Countries	Renovation targets
Greece	2030: 23% of the residential buildings will be renovated 2040: 36%-42% of the residential buildings will be renovated 2050: 45%-49% of the residential buildings will be renovated
Lithuania	2030: 17% of the renovated buildings will be renovated 2040: 43% of the renovated buildings will be renovated 2050: 74% of the renovated buildings will be renovated
Bulgaria	2021-2030: 8% of the renovated area of existing housing stock 2031-2040: 18% of the renovated area of existing housing stock 2041-2050: 20% of the renovated area of existing housing stock
Hungary	2030: 3% per year for the total residential stock. During the same period, the aim is to increase the annual renovation rate of the public buildings stock of 5%
Latvia	2030: 30% of the renovated residential apartment buildings 2040: 30% of the renovated residential apartment buildings 2050: all new buildings are constructed as zero-energy buildings

Nevertheless, a different expression of the imposed renovation target was selected in specific cases. For instance, Hungary specified an annual renovation rate, which remains constant for the whole period. Furthermore, Hungary has introduced additional targets, such as the attainment of 20% savings in the energy use of residential buildings by 2030 and the 60% reduction of CO_2 emissions by 2040 related to the energy use of buildings compared with the average level in 2018-2020. Finally, the percentage of nearly zero-energy buildings should reach 90% by 2050.

A totally different time horizon stands for Croatia's LTRS, where the target rate of energy renovation of buildings for 2021 and 2022 was 1%, 1.5% for 2023 and 2024, 2.0% for 2025 and 2026, 2.5% for 2027 and 2028, and 3% for 2029 and 2030, followed by 3.5% between 2031 and 2040, and 4% between 2041 and 2050.

It is worth noting that there are no specified renovation targets for the cases of individual renovation roadmaps. However, two of them (i.e., Flanders- Woningpas and EPC+ and France-Passeport Efficacité Énergétique) present quantitative targets, other than renovation ones. More specifically, the target for the building stock is average primary energy consumption of 100 kWh/m2/year by 2050 in Flanders (Woningpas and EPC+), while all class F and G buildings must be renovated by 2025 in France (Passeport Efficacité Énergétique) and all buildings must be in class A or B by 2050, reaching BBC levels or equivalent (BBC levels of renovation by 2050 is equivalent to 80 kWh/m² of primary energy per year, including heating, hot water and cooling).

In the case of Germany (Individueller Sanierungsfahrplan), it is worth noting that the guideline for the renovation roadmap is based on the "best-possible-principle", implying that each building's renovation roadmap should be as ambitious as possible. Auditors must recommend the best solution to achieve the efficiency level established on average for the building stock and justify any deviation from the best standard.

4.2 Financial Instruments

The design and implementation of targeted policies and measures are required so as to achieve the specified renovation targets, All the LTRS includes a combination of economic, fiscal, regulatory and awareness-raising measures for the fulfilment of the renovation targets. The awareness-raising measures are foreseen in all individual roadmaps, while the energy auditors' training has been selected in France (Passeport Efficacité Énergétique) and Germany (Individueller Sanierungsfahrplan). Finally, a technical assistance programme will be launched in Denmark (BetterHome).

The main energy efficiency intervention in all the LTRS and individual renovation roadmaps refers to the energy upgrade of the building envelope (i.e., insulation of roofs and walls, replacement of windows and doors, new heating, hot water and cooling as well as heat-recovery ventilation systems and energy management controls, etc.), while in some cases there is a combination between energy efficiency and RES technologies. Furthermore, all of the LTRS provide estimates of anticipated renovation investments, with the exception of Greece and Finland.

Table 7 presents the anticipated renovation investments within the framework of the LTRS for the examined countries.

Table 7: Anticipated renovation investments in the LTRS for the examined countries.

Countries	Foreseen investments
Lithuania	2021-2023: €867 million/year 2024-2030: €1286 million/year 2031-2040: €2071 million/year 2041-2050: €2767 million/year
Spain	€27.1 billion
Hungary	HUF1.9 billion
Romania	€12.8 billion
Croatia	HRK 243.23 billion
Bulgaria	2021-2025: BGN 1.6 billion 2026-2030: BGN 3.1 billion 2031-2040: BGN 10.4 billion 2041-2050: BGN 11.7 billion
Portugal	€143.492 billion
Latvia	2030: €5.7 billion 2040: €5.7 billion 2050: €7.6 billion

The anticipated investments can be financed through several funding schemes, including subsidies, tax credits and incentives, among others, as shown in Table 8 analytically for each examined country separately.

Table 8: Financial instrument for mobilizing the anticipated investments within the LTRS.

Countries	Financial instruments
Bulgaria	subsidies, revolving funds, guarantee funds and special credit lines, green mortgages, on-bill financing, promotion of energy performance contracts, establishment of a National Decarbonisation Fund
Croatia	subsidies, revolving fund, interest subsidy of commercial loans, promotion of energy performance contracts, campaigns, tax incentives
Finland	subsidies, tax incentives, loans, leasing, technical support for green bonds
Greece	subsidies, fiscal and urban planning incentives, innovative blended financial schemes (energy communities and energy efficiency obligation scheme for energy-poor households)
Hungary	subsidies, promotion of energy performance contracts, non-reimbursable and repayable assistance in order to ensure the efficient use of EU funds, lower interest rates for loans
Latvia	subsidies, tax incentives where municipalities can benefit from tax relief under certain parameters, long-term low-interest loans, green bonds
Lithuania	subsidies, loans, lending funds, promotion of Energy Performance Contracts, introduction of a pollution tax for buildings consuming more than a certain limit of energy
Portugal	subsidies, reorientation of the fiscal revenue for the improvement of energy and environmental behaviour of buildings
Romania	subsidies, loans, sale or lease of buildings with the lowest energy performance
Spain	subsidies, promotion of energy performance contracts

All of the LTRS present a monitoring scheme for the successful implementation of renovation policies and measures, except for Greece. Only through its Action Plan for the alleviation of energy poverty, Greece has set a monitoring system combining a top-down and a bottom-up approach. The monitoring mechanism of renovation policies and measures has as a main purpose the identification of any possible deviations from what is considered in the initial plan.

Finally, the main market and non-market barriers, which affect the renovation of the building stock, have been mapped and reported within the framework of the LTRS. The most significant barriers include:

- The high renovation cost hinders any plans for further renovation of the buildings due to the longer payback periods.
- The limited access to financing for the end-users including the inability of them to borrow and the unwillingness of the banking sector to lend.
- The lack of awareness about the most appropriate energy efficiency interventions and the delivered impacts.
- The lack of skills and training among the actors involved.
- The high uncertainty regarding future developments in terms of technology, energy prices, and regulatory framework.
- The high bureaucracy for the participation in the existing renovation programmes.

- The complex regulatory framework for the renovation of the buildings.
- The ownership structure of the buildings.
- The split-incentive dilemma.

A detailed depiction of the identified barriers is presented in Table 39 in the Annex in section 12.

Concluding, the analysis of the existing roadmaps led to the following policy recommendations, which should be taken into consideration during the preparation of effective renovation roadmaps:

- Define explicitly the renovation target both in absolute values (number of buildings) and in percentage in relation to the total building stock.
- Determine the trajectory for the attainment of the renovation target including the specification of milestones.
- Identify the most cost-effective packages of the energy efficiency interventions for the building renovation.
- Estimate the required investments for the implementation of the energy efficiency interventions, which are required for the achievement of the specified renovation targets.
- Map and assess the potential barriers so as to propose the most suitable solutions for their effective confrontation.
- Identify the most effective policies and measures in order to mobilize the required investments and address the identified barriers.
- Establish the appropriate monitoring mechanism for assessing the achievement of the imposed renovation target.
- Consult the contents of the renovation roadmap with all the relevant stakeholders and try to reach a consensus.
- Design and implement early actions for the initiation of the renovation roadmap.

5 Deep Renovation Measures

Renovation depths can be categorized into three main categories, depending on the achieved primary energy savings (EC, 2019a):

- Light (less than 30%);
- Medium (between 30% and 60%);
- Deep (more than 60%).

Light renovations constitute mostly of several energy efficiency measures, which do not take a holistic approach to building fabric and technical system upgrades to address the ambitions targets of energy efficiency goals set out by the EU. Deep renovation is a critical component of Europe's sustainable development strategy, aiming to reduce the energy consumption and carbon footprint of existing buildings. It is essential to analyse the current state of building renovation and utilize these learnings to accelerate the transformation of Europe's building stock towards greater energy efficiency and environmental sustainability. The energy efficiency measures should be planned and designed to achieve the highest possible energy efficiency in a cost-optimal way with the lowest possible environmental impact, which should achieve the highest benefit to society. Deep renovation is a term, which describes the ambition of building renovation. Therefore, deep renovation can't be standardized or put in strictly defined brackets. Deep renovation is more of a building renovation strategy and philosophy, which (1) aims at reducing building energy needs as much as possible while maintaining high indoor environmental standards and (2) adapting building technical systems to facilitate optimal energy consumption with as minimal environmental impact as possible.

The European Commission suggests that the average EU non-residential building renovation rate stands below 1% a year, but accurate data is hard to come by, because of poor renovation monitoring (EC, 2016a). Furthermore, a report from the Buildings Performance Institute of Europe (BPIE), indicates that the current average deep renovation rate could be around 0.2% a year (BPIE, 2021). BPIE also highlights that with the current rate, the EU is not on track to achieve the set 2030 and 2050 climate targets. The current deep renovation rate must reach 3% per year, as fast as possible before 2030 and be maintained until 2050 if the set-out goals are to be accomplished.

BPIE found that between 2012 and 2016, 66.3% of the total of 127 billion EUR was spent on light renovations (3-30% of primary energy saving), 28.3% on medium renovations (30-60% primary energy savings) and only 5.4% spent on deep renovations (more than 60% primary energy savings). It is emphasized that this trend must be reversed to achieve the set-out goals (BPIE, 2021).

5.1 Definitions, Strategies, and Renovation Rates

In addition to the most recent 2023 recast proposal of the Energy Performance of Buildings Directive (EPBD), in which the European Parliament and the Council of the European Union have addressed the necessity and importance of deep renovation, setting out recommendations and requirements for member states, to implement in their legislation on the national level, the “Renovation wave” initiative is another regulatory instrument, which sets out to increase the renovation rate. Furthermore, the Directive on Energy Efficiency ((EU) 2018/2002) and Renewable Energy Directive (EU) 2018/2001 are some of the legislation that influence the building sector (Jiménez-Pulido et al., 2021).

The recast of the EPBD does not define what deep renovation is specifically but implies that through deep renovation buildings must reach near zero emissions building (nZEB) status, or for the worst performing buildings, which virtually cannot become an nZEB, achieve at least 60% reduction of their energy expenditure. The directive emphasizes that countries should promote, deep and staged deep renovation standards trough financial instruments, adequate support and information, including technical assistance and training. Renovation passports should also be introduced, to set out a roadmap to assist building owners in determining the correct steps to take, in regards to achieving nZEB (EC, 2023a).

The Long Term Renovation Strategy (LTRS), which each country had to develop, is the main peace of policy laying out a plan on how to achieve carbon neutrality in the building sector. In this strategy, some countries have laid out plans including deep renovation. As mentioned before the definition of deep renovation is not unified and concrete, and that shows in these strategies. Some countries refer to deep renovation as major renovation or nZEBs, and most of the countries do not define or mention deep renovation. In the case of Latvia, Bulgaria, Greece and Portugal, none of the member states give a clear definition of what constitutes deep renovation, in their LTRS (BPIE, 2021).

5.2 Technological Advancements in Deep Renovation

Energy efficiency measures in buildings are essential to reduce energy consumption, decrease greenhouse gas (GHG) emissions, and improve overall environmental sustainability and indoor air quality. To achieve deep renovation, it is necessary to upgrade the building envelope according to requirements set out in the national legislation and to upgrade building technical systems in order to ensure necessary energy delivery and management in the building. To achieve deep renovation levels, it is necessary to reduce building energy needs as much as possible and to provide the necessary energy to the building in the most efficient way. This is a complex and challenging task because at every step it is necessary to take into account economical, technical and environmental considerations. While specific measures can vary based on building type, climate conditions, and local regulations, the typical measures applied in building deep renovation can be summarized in several important energy efficiency measure groups.

Even though most of the technologies needed to renovate the buildings sector are known and already commercially available, the most effective improvements, building envelope measures, are still costly and may require government support to attain wide market uptake. The future challenges in the technology for buildings are not a technological development issue, but rather a concerted effort to facilitate enabling policy design and stakeholder engagement to support the implementation of strategic and effective mechanisms in accordance with national priorities.

One of the most important strategic tools to address these challenges has been promoted by the European Commission in 2010 by the enforcement of the EPBD recast, requiring all buildings to become "nearly zero energy" by 2020. Yet, in 2023, these still represent a very small percentage of the market today in most EU countries. The Directive is being revised again, coming up with more stringent rules and higher ambition, but the buildings sector is extremely complex, and the market barriers speak louder therefore, an integrated and comprehensive effort is needed to assist households in overcoming the remaining barriers associated with higher initial prices, lack of awareness of technologies and their potential, and the split of incentives, between tenants and homeowners, clients and utilities. Such concerted effort, around an integrated strategy, which uses the best available technology in combination with adequate strategies ensuring that all available options are employed in an optimized approach, can overcome these barriers. However, this strategy requires exceptional effort and coordination among an oversized set of stakeholders, from policy makers to builders, technology developers, manufacturers, equipment installers, financial institutions, businesses and users.

With due caution, as each country has its particular characteristics, the assessment presented herein (Table 9) allows to identify overall opportunities and threats for energy renovation as perceived in the four REVERTER Pilots. These opportunities and threats are corroborated by other projects and work available (Aelenei & Aelenei, 2023; Mlecnik et al., 2019; Monteiro et al., 2017).

Table 9: Opportunities and threats in deep renovation

Type	Opportunities	Threats
Political	Ageing neighbourhood's in need of upgrading are receiving support from local development funds and public grants for upgrading	On average, the perceived budgets for renovation are low, as house sales prices are comparatively high. Energy prices are too low to support SFB energy renovation decisions.
Economic	Low-carbon solutions can be translated into possible energy savings or increased property value and lower insurance fees after upgrading. Some market segments have a high potential, for example: - Younger households taking over older homes, particularly houses built between 1960 and 1990 - High-income homeowners able to invest	There is competition with companies (often eastern European) that offer low-carbon measures, sometimes at a lower cost because of unregistered invoicing, and with demolishing and building a new house. Architects lack interest in energy upgrading due to low fees, and thus prefer to construct new houses instead
Social	Strong focus on upgrading and good design in a collaborative way; Social engagement.	There is a do-it-yourself trend, i.e. homeowners find quick fixes online. There is a strong focus on what is visible (paintings, new kitchen, photovoltaics) rather than on thermal performance and proper ventilation.
Technological	Technologies are developing rapidly and the cost of low-carbon solutions is decreasing.	There is still little knowledge about the concept and the Best Available Solutions such as passive houses

Legal	Energy requirements (MEPS) for new homes are strengthening. An increased demand for highly energy-efficient houses and higher legal requirements for renovations can be expected soon.	There is too much administrative burden for achieving public grants; moreover, renovation process is not trivial, and households do not know how to start
Environmental	An increased focus on the environment and scarcity of fossil fuels leads to increased knowledge and increase demand for renovation services.	There is a lack of specialized contractors and installers (both for renovation works, electricians and technicians)

5.2.1 Building Envelope Improvements

The building envelope is the building's outer fabric which consists of building walls, roof, attic, ground, unheated basement, building doors, windows and other construction, which separates indoor space from the outside. Each country sets out minimal requirements towards building envelope U-value, which describes the building element's ability to transfer heat energy – the lower the U-value, the less heat is transmitted through the respective building element. Although each country sets out its own goals toward building envelope, to achieve nZEB standards a set of values defined by the Passive House Institute for building renovations EnerPHit (Passive House Institute, 2023) could be used as a reference point. EnerPHit standard defines the U values which should be achieved by the building renovation – insulation upgrades for roofs, walls, and floors to reduce heat loss in winter and heat gain in summer.

Table 10: EnrPHit component criteria (Passive House Institute, 2023)

Climate zone according to PHPP	**Opaque envelope, U value W/m²K**		**Windows, U value W/m²K**
	Exterior insulation	Interior insulation	Vertical windows
Arctic	0.09	0.25	0.45
Cold	0.12	0.30	0.65
Cool-temperature	0.15	0.35	0.85
Warm-temperature	0.30	0.50	1.05
Warm	0.50	0.75	1.25
Hot	0.50	0.75	1.25
Very hot	0.25	0.45	1.05

The U-value is mainly dependent on the existing situation – existing wall layers, their thickness and thermal properties. In order to achieve lower U values of the building envelope components, it is necessary to apply a heat insulation layer. Heat insulation can be made of different materials and it can be in different forms, which is dependent on the necessary application. Insulation material's main thermodynamic property, which provides additional thermal resistance to the building envelope, is thermal conductivity measured in W/mK. Most commonly used insulation material declared thermal conductivity values are in the range between 0.032 W/mK to around 0.038 W/mK. However, there are also materials with considerably lower and higher heat thermal conductivity values. For example, Vacuum insulation panels (VIPs) have a thermal conductivity of 0.008 W/mK. These materials mainly are used in places with limited space and high requirements for thermal resistance. On the other hand, there are also insulation materials with considerably higher thermal conductivity. For example, there are calcium silicate insulation boards with a thermal conductivity of 0.055 W/mK. These insulation materials are capillary open and they allow moisture transfer within the building envelope. They are usually used in historic building renovations and they facilitate moisture movement in the masonry walls.

In Figure 7, different U values are calculated after the application of insulation material to building envelope elements with different existing U values.

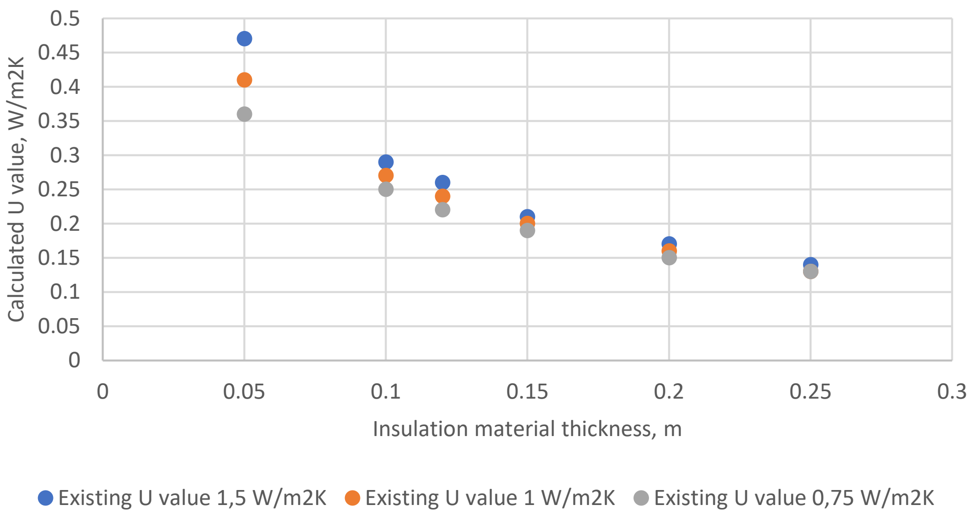

Figure 7: U values after application of insulation material to building elements with different existing U values

From the calculations displayed in Figure 7, it can be seen, that the efficacy of adding an additional insulation layer on the building envelope diminishes with each additional insulation material thickness. However, the cost of insulation material application on the existing building envelope considerably increases with additional insulation layer thickness due to material costs and the necessity for more rigid fastening techniques to existing walls.

Installation of air-tight windows and doors with low U-value to minimize air leakage and heat loss also greatly contributes to energy savings. For windows, it is also necessary to take into account the appropriate choice of the g-value, which describes the window glazing's ability to deflect sunlight from the windows and minimize the internal heat gains. In the areas with warmer climates and higher necessity for cooling loads, the appropriate g-value should be in the range from 0.2 to 0.4 and in regions with colder climates and predominantly colder climates, the appropriate g-value should be in the range of 0.6 to 0.8. In warmer climates, it is also advisable to implement external shading with shutters, external awnings or some other passive or active shading strategy. Additional benefits of improving the building envelope, other than energy efficiency improvement, are prolongation of the building service life and predictable maintenance costs.

5.2.2 Technical Building Systems

It is recommended, that the replacement or upgrade to the HVAC system of a building should be ideally planned during the renovation of the building envelope or after the building envelope has been renovated. If HVAC system upgrades are planned for existing buildings with relatively high energy needs, then there is a high risk of oversizing the HVAC system in the case, if at some later time, the building envelope is insulated, and energy needs are greatly reduced. By replacing old boilers/furnaces with higher efficiency models it is possible to reduce the primary energy consumption of the building. The replacement of the heat source also provides the possibility to correctly size the heating source to better suite the building heating load, therefore allowing the boiler to operate in optimal performance range more frequently. If substantial upgrades to the building envelope are made, the HVAC system evaluation and, if necessary, overhaul are crucial to achieve planned energy savings. The HVAC system should be able to control energy flow in the building to maximize indoor comfort and reduce primary energy consumption.

More often than not, when the building is renovated and no major upgrades to the building's technical systems are made, the overall building renovation energy targets are missed. This is due to the fact that building technical systems are responsible for energy delivery to building indoor spaces in just the right quantity to equalize energy losses, or energy gains in the case of cooling, and loose as little energy as possible during the energy delivery process. If the building's technical systems are old, inefficient and with limited control possibilities, then it is hard to reach optimal energy performance in the building.

For more inefficient buildings, which are renovated, a heating and/or cooling source change may be considered, i.e., the use of heat pumps instead of gas boilers or the installation of heat pump / gas boiler hybrid systems. When retrofitting a heating or cooling system it is necessary to take into account the possible limitations of each technology.

Installation of programmable thermostats and smart HVAC controls, which adjust the heat load according to user behaviour is advisable as these measures lower the risk of human behavioural errors. Regular maintenance of HVAC systems also ensures their operation in optimal performance range.

For residential buildings, the HVAC systems can be generally divided into different sections:

- Heating or cooling source;
- Heating or cooling energy distribution system and control;
- Ventilation system.

For buildings undergoing deep renovation, all three subsystems need to be taken into account when considering the operation of the building which is renovation according to the deep renovation approach. Furthermore, building occupants need to be trained on the new building parameters to be able to fully utilize the energy-saving potential, that has been incorporated into the building.

Building envelope and building HVAC systems work in tandem. The main aim of the building envelope is to achieve as low heat energy losses as possible during the heating period and as low heat gains as possible during cooling periods. However, the HVAC system is responsible for maintaining the desired indoor parameters in the building in the most efficient way possible for a specific building's thermodynamic properties.

5.2.3 Supplementary Energy Efficiency Measures

The measures summarized in this section are mainly related to behavioural change and small improvements in the use of household appliances. In general, these measures are important, because they allow the households to better understand their influence on energy consumption and spark desire to undertake measures with more substantial and higher energy savings.

5.2.3.1 Lighting

Replacement of traditional incandescent bulbs with energy-efficient LED lighting is one of the first measures, which is typically performed by households. Installation of occupancy sensors and daylight harvesting systems to control lighting usage may further lower the risks of lighting system misuse by automating lighting controls where it is possible. More efficient lighting also contributes to lower internal gains and hence, lower necessity for cooling loads. When choosing appropriate LED lighting, special attention should be placed on the technical specifications of the LED light source – colour temperature, appropriate power sizing to reach necessary lumens, possibility to dim the lighting and flickering, which usually occurs in lower quality LED lighting.

5.2.3.2 Energy-Efficient Appliances and Equipment:

Use of more efficient appliances and equipment for lower energy consumption, which also lowers the internal heat gains and hence reduces the necessary cooling loads. This also includes the appropriate maintenance of the equipment, i.e., cleaning the heat-dissipating fins on cooling units and ensuring appropriate air flow on these surfaces.

5.2.3.3 Behaviour and Occupant Engagement:

Energy awareness campaigns to promote responsible energy use. Occupant education on energy-saving practices and habits. This section is especially important if the building has undergone a deep renovation process. The inhabitants must be informed on proper temperature and air quality maintenance in the building after renovation, to ensure, that the planned energy savings are actually reached.

5.2.4 Renewable Energy Integration:

After the optimization of the building envelope and building technical systems, it is possible to evaluate the potential of Renewable Energy Source (RES) implementation to further reduce buildings' primary energy consumption. According to Eurostat data (Eurostat, 2022), in 2020 households accounted for 27% of final energy consumption in the EU. Renewable energy accounts for 20.3% of household final energy consumption. The majority of final energy in households is provided via natural gas (31.7%) and electricity (24.8%). Space heating takes up 62.8% of total final energy consumption in households, followed by 15.1% for hot water preparation and 14.5% for lighting and appliances, 6.1% for cooking, 0.4% for cooling and 1.0% for other use cases. Although precise information is not available, the most commonly used RES sources in the residential sector could be solar photovoltaic (PV) panels for electricity generation, solar collectors for domestic hot water production and biomass boilers for heating in northern climate zones.

There are several significant parameters which need to be taken into account when evaluating renewable energy system integration:

1. legislative framework – are there any power limitations, legal limitations, or grid operator limitations which may hinder the use of a specific technology;
2. space and surrounding limitations – are there any limitations due to available space or are there any other objects on the site which may influence the decision-making process;
3. energy usage patterns –any foreseeable energy usage patterns which may change or are there any energy usage patterns which are incompatible with RES power generation.

Appropriate sizing of the RES system is essential to ensure that the installed RES power is used with maximum capacity.

5.2.4.1 PV panel integration

For PV panels it is necessary to analyse the available solar intensity in the region, existing energy usage patterns and the availability of space for system placement. In Figure 8 it is possible to compare solar intensity in different parts of Europe.

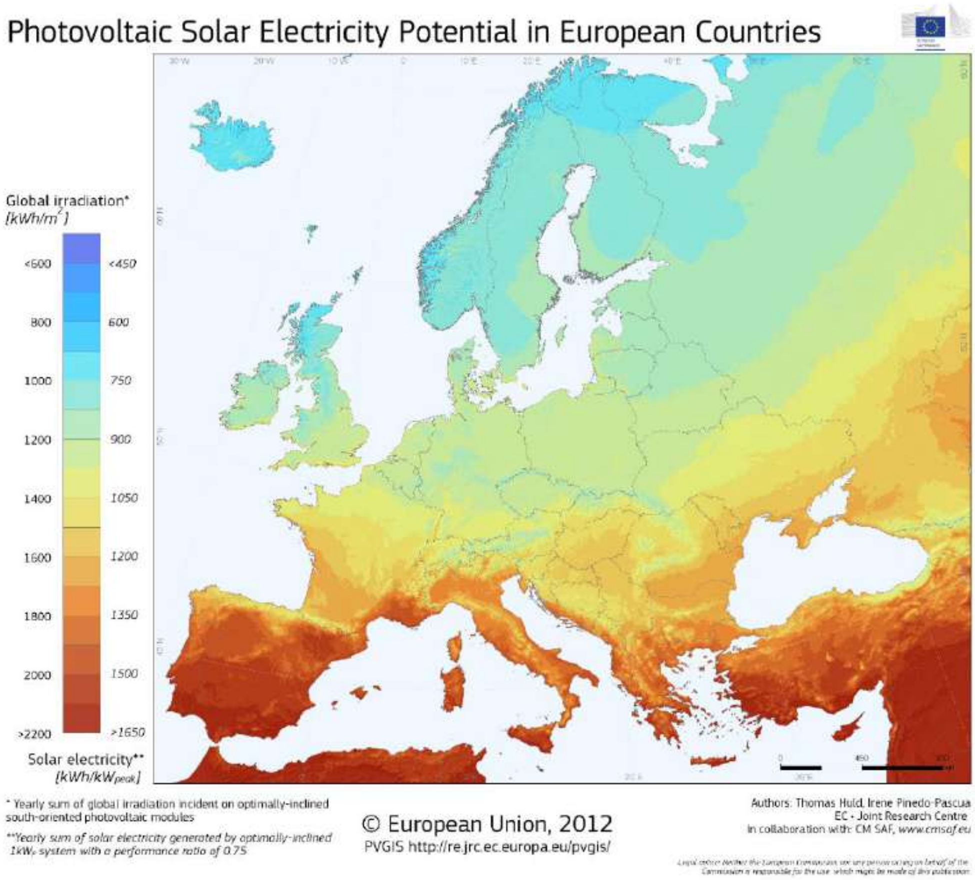

Figure 8: Solar irradiation map of Europe (EC, 2017)

The global irradiation map shows, that there is a high potential for solar PV utilization across Europe. In some countries the potential is higher than in others – as can be seen in Figure 8, the global irradiation in Southern Europe is as much as double that in Northern Europe. However, solar PV panel efficiency is also affected by the outside temperature. Every solar PV panel has its temperature coefficient, which determines the PV panel efficiency change depending on the surrounding temperature. PV panel efficiency is tested at 25^{o}C and, i.e., if a PV panel has an efficiency coefficient of -0.3 percent, then PV panel efficiency decreases by -0.3% for every degree above 25^{o}C. Another important factor in PV installations is the existing electricity usage patterns. The highest economic viability of PV panels is reached when all of the produced energy can be used on-site. This is due to the fact, that exporting energy to the grid and importing electricity back when it is necessary, results in different fees for the usage of the electricity grid.

5.2.4.2 Solar water heating

Solar water heating is obtained by using solar collectors. Different types and configurations are used for solar collectors depending on the intended use and climatic conditions. Just as with solar PV systems, it is also essential to ensure appropriate sizing to ensure the most efficient operation of the system. Solar water heating systems can get very expensive as there are a lot of components, which need to be installed in order for the system to run efficiently and safely. A hot water storage tank with high enough capacity and a secondary heating source is necessary to ensure the availability of hot water independently of weather conditions. Additionally, it is necessary to foresee a reliable safety mechanism to prevent overheating in the case if power is cut to the circulation pump or there is no demand for heat energy.

5.2.4.3 Biomass

Biomass boilers are mainly installed in the Northern and Central parts of Europe where heating energy consumption is predominantly higher than cooling energy consumption. However, there are conditions for biomass to be truly classified as RES. Biomass must be produced and used sustainably, to minimize GHG emissions and maintain healthy ecosystems. Biomass use should be restricted for use outside densely populated areas, as with small-scale biomass boilers it is not economically feasible to completely prevent biomass combustion products in the surroundings, which may irritate other people living in the near vicinity. Biomass boilers require frequent maintenance to ensure proper operation. Depending on the boiler automation level, it is necessary to perform boiler cleaning procedures and maintain an adequate amount of biomass (i.e. wood pellets) in the reservoir. However, heating with biomass is usually a cheaper and more environmentally friendly alternative to gas boilers.

5.2.5 Specific Energy Efficiency Measures in Latvia, Greece, Portugal and Bulgaria

The energy simulations performed for the four Pilots were carried out by the REVERTER Simulator Tool which was developed in T2.2 based on ISO 52016-1-2017, tailored to each climate region and characteristics. The simulations, based on real housing characteristics, provided the building’s overall energy needs for heating, cooling ventilation and DHW. The energy needs for space heating and DHW has been transformed into final energy use by applying an estimated global seasonal energy efficiency of gas boilers for the baseline of 0.9 and COP of 2.5.

In relation to the retrofit scenarios, the REVERTER assessment was based on three different packages of energy renovation measures, such as:

- **Bulgaria:** Building envelope upgrades to address colder winter conditions. Integration of efficient heating systems like heat pumps and biomass boilers. Use of renewable energy sources like solar and wind where suitable.
- **Greece:** Building shading and cooling strategies to address hot summers. Implementation of heat pumps for space heating and cooling. Solar water heaters to harness abundant solar energy and solar PV panels for electricity production.
- **Latvia:** Building insulation and building technical system improvements to combat cold winters. High-efficiency biomass boilers and heat pumps for heating. Integration of district heating systems in urban areas. Use of renewable energy sources like solar and wind where suitable.
- **Portugal:** Solar PV integration to harness solar potential. Solar water heaters for hot water production. Use of heat pumps and biomass boilers for heating and cooling. Building retrofit projects to improve energy performance in older structures.

These are the main energy efficiency measures which play a crucial role in reducing energy consumption and greenhouse gas emissions, leading to more sustainable and environmentally friendly buildings in each respective country. The specific measures and energy savings reached along with financial and environmental benefits are analysed further.

5.3 Environmental Impact and Benefits

The environmental impact assessment for building renovation is steadily picking up pace in the EU. The current developments in EU legislation prevail, that it will be necessary to account for the environmental impact of the insulation materials and other energy efficiency measures which are introduced to the building. The environmental impact of building materials can be assessed by accounting for their life cycle Green House Gas (GHG) emissions. This is done by carrying out a life cycle assessment (LCA) of a specific product. The results are aggregated into specific stages of product production and expressed as CO_2 equivalent.

The environmental impacts of a product are summarized in an Environmental Product Declaration (EPD), in which product LCA calculation methodology, along with restrictions and evaluation borders, is described. The EPDs are verified by an independent verifier and published in the database. The EPD database provides the basis for environmental impact indicator acquisition for a specific building material.

In the framework of the project, a concentrated database was compiled in order to assess the environmental impact of energy efficiency measures. By compiling the list of energy efficiency measures and their environmental impact, several inconsistencies in data interpretation were observed. By analysing EPD databases, it could be seen that for the same product category, i.e., heat insulation materials, different functional units may be used. For example in one EPD of a heat insulation material, a functional unit was set as – insulation material of "1 m^2 when R=1 m^2K/W" (PAROC, 2021) and in another case a functional unit is described as "1 kg of insulation material" (TENAPORS, 2022), both EPDs are compiled according to relevant standards - ISO 14025:2006 and EN 15804:2012+A2:2019/AC: 2021. These inconsistencies may cause confusion in data interpretation and may cause errors in the environmental impact evaluation. Additionally, there are different product life cycle stages, which are portrayed in the EPD of a specific product. ISO standard LVS EN 15804+A2:2020 "Sustainability of construction works – Environmental product declarations – Core rules for the product category of the construction products" provides an overview of the product stages, which should be included in the EPD (see Figure 2).

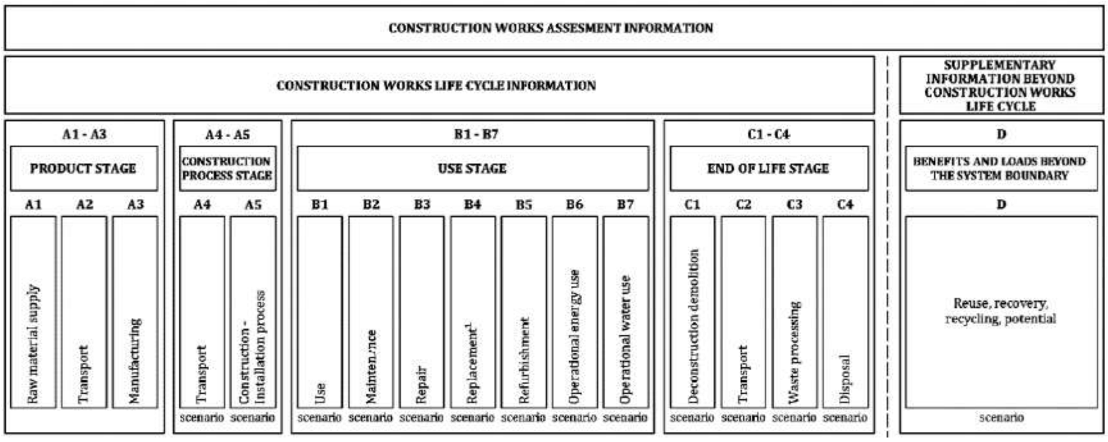

Figure 9: Different construction work life cycle assessment stages

Depending on which stages of a product life cycle are used, the results may differ. Therefore, before starting the environmental impact evaluation process for deep renovation, it is necessary to define concrete evaluation boundaries. Each product stage is defined as an environmental performance factor expressed as CO_2 equivalent per building material unit of measure, i.e., m^2, m^3, kg, 1 mK/W, etc. Further details about the product stages used and the environmental impacts considered are provided in Section 5.5.1.

5.4 Deep Renovation Targets in Pilot Regions

The main aim of this task is to evaluate different energy efficiency measures and determine the most suitable set of energy efficiency measures for reference buildings defined for each of the pilot regions, for each type of building – Multi-family building (MFB) and Single-Family building (SFB). The reference buildings are chosen as a representation of typical targeted buildings in the region and according to the Grant Agreement:

- In Bulgaria – 3 reference buildings, one MFB, one SFB and one public building.
- In Greece – 2 reference buildings, one MFB and one SFB
- In Latvia – 1 reference building, Multifamily buildings
- In Portugal – 2 reference buildings, one MFB and one SFB

To analyse the impacts of different energy efficiency measures in each of the pilot regions, a simplified calculation tool according to the monthly calculation method described in ISO 52016:2017 “Energy performance of buildings — Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads — Part 1: Calculation procedures” was developed. The aim is to provide preliminary results of energy efficiency measure implementation to evaluate energy savings potential and energy-related GHG reduction. The calculation tool also allows the evaluation of the GWP of used insulation materials and the evaluation of the environmental impacts.

The Annex in section 13 presents the data of the reference buildings, as well as the results from the considered renovation packages.

In this section, a brief summary of the calculation results is presented to provide an overview of the reference buildings and renovation packages applied. For each building type, three different renovation packages were applied to evaluate the renovation package's impact on the energy need reduction, delivered energy reduction as well as on the energy related CO_2 emissions reduction. The Assessment and Prioritisation of Alternative Energy-Saving Measures is done in section 5.5.

5.4.1 Bulgaria

In Bulgaria three different reference buildings were devised – MFB, SFB and a Public building, as shown in Table 11, Table 12 and Table 13.

In general, the renovation packages for SFB (Table 11) consist of building envelope insulation and window and door changes. Renovation packages 2 and 3 are the same in regards to the building envelope, however, in Renovation package 3 an addition of a heat pump is examined to achieve higher reductions in operational CO_2 emissions and final energy.

Table 11. SFB calculation results for Bulgaria

Heated space	384	m^2	
Specific heat transfer coefficient	2.65	W/m^2K	
	Package 1	**Package 2**	**Package 3**
Energy need reduction	49.0%	55.4%	55.4%
Delivered energy reduction	55.7%	64.5%	84.2%
CO_2 emissions reduction	55.7%	64.5%	84.2%

The renovation packages for MFB (Table 12) consist of building envelope insulation and window and door changes. Renovation packages 2 and 3 are the same in regards to the building envelope, however, in Renovation package 3 an addition of a heat pump is examined to achieve higher reductions in operational CO_2 emissions and final energy.

Table 12. MFB calculation results for Bulgaria

Heated space	1725	m^2	
Specific heat transfer coefficient	2.25	W/m^2K	
	Package 1	**Package 2**	**Package 3**
Energy need reduction	56.6%	57.4%	57.4%
Delivered energy reduction	58.7%	59.6%	65.4%
CO_2 emissions reduction	58.7%	59.6%	65.4%

The renovation packages for a Public building (Table 13) consist of building envelope insulation and window and door changes. Renovation packages consist of different measures for building envelope with increasing insulation thickness for the building envelope. Additionally in Renovation Package 3, an addition of a heat pump is examined to achieve higher reductions in operational CO_2 emissions and final energy.

Table 13. MFB calculation results for Bulgaria

Heated space	2030	m^2	
Specific heat transfer coefficient	1..88	W/m^2K	
	Package 1	Package 2	Package 3
Energy need reduction	50.8%	56.6%	57.7%
Delivered energy reduction	58.2%	65.6%	84.8%
CO_2 emissions reduction	52.5%	59.0%	69.3%

5.4.2 Greece

In Greece two different reference buildings were devised – MFB and SFB, as shown in Table 14 and Table 15.

Energy efficiency measures of SFB (Table 14) in Greece for different packages are designed to examine different stages to achieve deep renovation. In the first package, only the addition of a heat pump is examined. In the second package building walls, roof and basement are insulated. In the third package, additionally to measures from the second package, building doors and windows are changed as well as solar collector system for DHW production is added.

Table 14. SFB calculation results for Greece

Heated space	85.2	m^2	
Specific heat transfer coefficient	11.1	W/m^2K	
	Package 1	**Package 2**	**Package 3**
Energy need reduction	0.%	53.7%	70.3%
Delivered energy reduction	64.3%	80.4%	88.4%
CO_2 emissions reduction	35.6%	64.7%	79.0%

Energy efficiency measures of MFB (Table 15) in Greece for different packages are chosen to examine different stages to achieve deep renovation. In the first package, only the addition of a heat pump is examined. In the second package building walls, roof and basement are insulated. In the third package, additionally to measures from the second package, building doors and windows are changed as well as solar collector system for DHW production is added.

Table 15. MFB calculation results for Greece

Heated space	400	m^2	
Specific heat transfer coefficient	3.32	W/m^2K	
	Package 1	**Package 2**	**Package 3**
Energy need reduction	0.0%	51.7%	61.6%
Delivered energy reduction	60.4%	76.9%	88.4%
CO_2 emissions reduction	31.8%	60.3%	80.1%

5.4.3 Latvia

In Latvia, one reference building for a MFB is devised. The results are shown in Table 16.

Energy efficiency measures of MFB in Latvia for different packages are designed to evaluate how the selection of different insulation materials with similar thermal properties can change the employed CO_2 emissions and energy reduction. In renovation packages 1 and 2 similar in relation to the chosen insulation material thickness, which is applied to the building envelope with different materials. However, in the third renovation package, the overall thickness of the insulation material is increased.

Table 16. SFB calculation results for Latvia

Heated space	3917,9	m^2	
Specific heat transfer coefficient	1.34	W/m^2K	
	Package 1	**Package 2**	**Package 3**
Energy need reduction	54.1%	54.2%	55.6%
Delivered energy reduction	59.2%	60.2%	61.5%
CO_2 emissions reduction	63.4%	64.2%	65.6%

5.4.4 Portugal

In Portugal two different reference buildings were devised – MFB and SFB, as shown in Table 25 and Table 26.

SFB energy efficiency measures (Table 25) for different packages are selected to evaluate different possibilities of delivered energy reduction and operational CO_2 emissions savings. In the first energy efficiency measure package the old windows and doors are changed as well as new heat pump for space heating, DHW and cooling is installed. In the second package, only the building envelope is improved by insulating the walls and roof and changing the old wooden windows and doors. The technical systems are not improved. However, in the third renovation package, all measures are combined.

Table 17. SFB calculation results for Portugal

Heated space	60.9	m^2	
Specific heat transfer coefficient	4.2	W/m^2K	
	Package 1	**Package 2**	**Package 3**
Energy need reduction	8.2%	64.0%	64.0%
Delivered energy reduction	68.7%	66.7%	87.2%
CO_2 emissions reduction	68.7%	66.6%	87.2%

MFB energy efficiency measures (Table 26) for different packages are selected to evaluate different possibilities of delivered energy reduction and operational CO_2 emissions savings. In the first energy efficiency measure package the old windows and doors are changed as well as new heat pump for space heating, DHW and cooling is installed. In the second package, only the building envelope is improved by insulating the walls and roof and changing the old wooden windows and doors. The technical systems are not improved. However, in the third renovation package, all measures are combined.

Table 18. MFB calculation results for Portugal

Heated space	528	m^2	
Specific heat transfer coefficient	3.57	W/m^2K	
	Package 1	**Package 2**	**Package 3**
Energy need reduction	15.7%	65.9%	61.5%
Delivered energy reduction	69.1%	69.1%	63.3%
CO_2 emissions reduction	69.1%	69.1%	65.0%

5.5 Assessment and Prioritisation of Alternative Energy-Saving Measures

5.5.1 Methodology and Data

A methodology was developed to assess and prioritise the alternative deep renovation packages, for each reference building in each of the pilots. The assessment took into account financial (net present value of life-cycle costs and payback period), technical (delivery time/minimisation of disturbance for building occupants and modularity), social (improved thermal comfort, improved health, local employment) and environmental criteria (minimisation of carbon emissions and local environmental pollutants). Particular emphasis was given to the use of Life Cycle Assessment (LCA) as a means to identify measures that reduce overall energy consumption and environmental pressures from ‘cradle-to-grave’.

In alignment with the goals of REVERTER, the LCA model seeks to minimize both the environmental and economic impacts throughout the life cycle of the refurbished building. The choice of life cycle GHG emissions in kilogram of carbon dioxide equivalent (kg CO_2eq) as a performance indicator reflects its significance as the primary environmental indicator in the EU and the LIFE programme. The life cycle GHG emissions are estimated, as follows:

$$LCGHG = Embodied\ GHG + Emitted\ GHG\ during\ the\ life\ of\ the\ buildings\ (in\ kg\ CO_2eq)$$

Additionally, the net present value was employed as the principal economic performance indicator, capturing the present value (NPV) of all costs associated with a retrofitting project over its life cycle using constant prices, according to the following equation:

$$NPV_{LCC} = IRC + \sum_{t=1}^{n} \frac{OM}{(1+r)^t} - \frac{SV}{(1+r)^n}$$

Where NPV_{LCC} is the net present value of all costs associated with a retrofitting project over its life cycle, IRC is the initial renovation cost, OM is the annual operating and maintenance cost (constant prices), SV is the salvage value at the end of the project, r is the discount rate, t is the year and n is the project lifetime, i.e. 20 years in this case.

The LCA model is based on previous research efforts (Apostolopoulos et al., 2023; Gustafsson et al., 2019; Zhang et al., 2021). More specifically, emissions produced from the manufacturing and operational stages were taken into account because previous studies have shown that transportation and construction emissions are negligible (Prabatha et al., 2020) and it is challenging to obtain GHG emissions from the disposal stage due to data unavailability and complicated waste management processes (Zhang et al., 2021). Nevertheless, the credibility of the analysis remains unaffected by the latter assumption since each LCA model is tailored to a specific building situated in a particular location, while the focus is solely on examining trade-offs between the environmental and economic performances of different deep renovation packages.

The alternative deep renovation packages (DRPs) are prioritised using financial analysis that takes into account homeowners' expectations, a social cost-benefit analysis that includes total costs and benefits from the perspective of all stakeholders (i.e., from the point of view of society as a whole), and multi-criteria analysis (i.e., the Analytic Hierarchy Process) as a complement.

As mentioned in Section 5.4, environmental life cycle data were collected from Environmental Product Declarations (EPD), specialised databases (e.g., the ÖKOBAUDAT platform[4]) and literature data (e.g., Bienert, et al., 2023; Finnegan et al., 2018; Menzies & Roderick, 2010; O'Hegarty et al., 2020). Economic data regarding investment costs, energy costs, VAT and other taxes and levies, etc., and energy mix GHG emission factors were provided by REVERTER pilots' partners. Finally, the net present value of the various DRPs was calculated using a 5.7% financial discount rate and a 3.3% societal discount rate, i.e., the rates used by the EU Commission for calculating the system costs of the different 2030 target scenarios (Krabbe et al., 2018). Finally, as far as the indirect benefits are concerned, the monetisation results of

[4] The ÖKOBAUDAT platform (https://www.oekobaudat.de/en.html) is a standardised database for ecological evaluations of buildings offered by the Federal Ministry for Housing, Urban Development and Building. The online database of the platform provides life cycle assessment datasets on building materials, construction, transport, energy and disposal processes.

COMBI online tool (COMBI project, 2018) are used, expressed in €/kWh saved (see for details Section 6.2.4and specifically Table 33).

The flowchart of the overall methodology is illustrated in Figure 10.

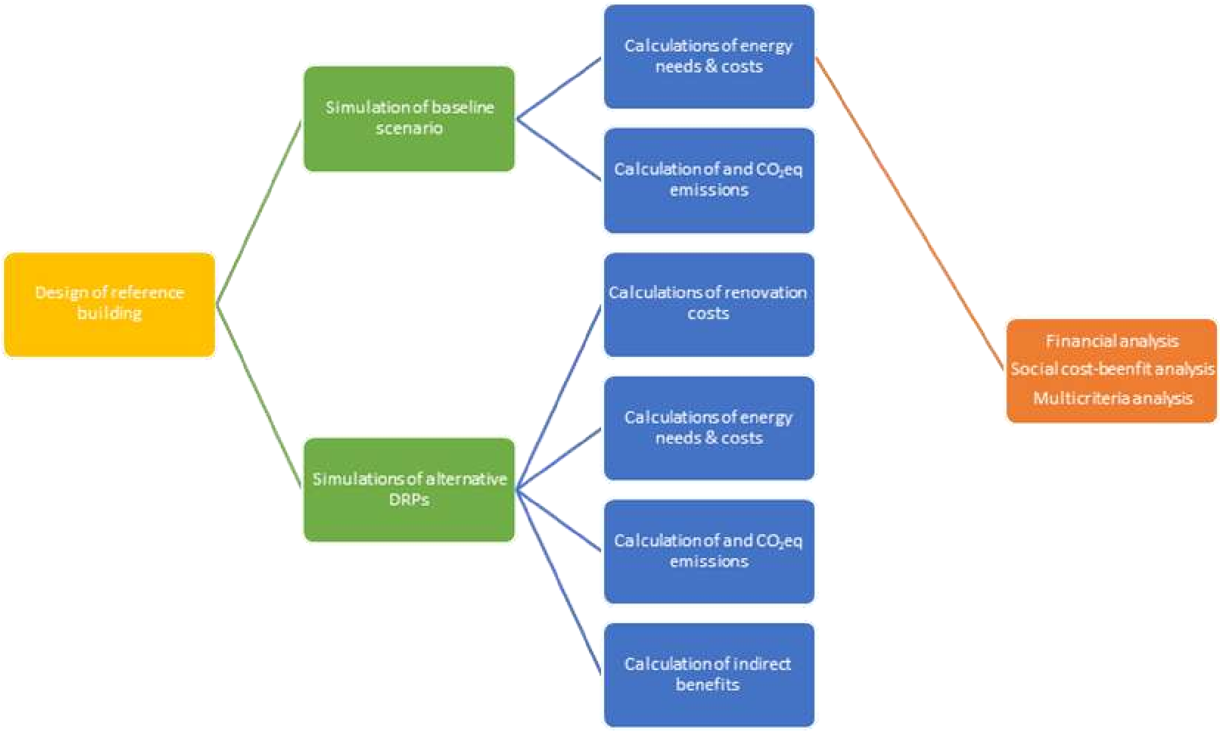

Figure 10. Methodological flowchart

Furthermore, Table 19 presents the indicators used and calculated by the LCA model with respect to the financial and social cost-benefit analysis.

As regards the multicriteria model, the Analytic Hierarchy Process (AHP) was used to select the most suitable DRP from a field of three alternative DPRs. The AHP hierarchy, which is presented in Figure 11, includes four main criteria (i.e., Financial, Environmental, Technical and Social) and ten sub-criteria (i.e., Renovation cost-RC, operating and maintenance cost-O&M, Life-cycle economic performance-LCP, Embodied carbon-EC, Carbon emission reductions (during operation)-CE, Local emission reductions (other pollutants - operation)-LER, Delivery time / Minimisation of disturbance for building occupants-DEL, Modularity-MOD, Improved comfort and health at household level (indoor)-IHC and Creation of employment at local/national level-LE). The pairwise comparisons of the alternatives against the sub-criteria and of the sub-criteria against the main criteria were conducted using the SCBUK AHP template[5]. The results of the analysis are presented in the following sections.

[5] https://www.scbuk.com/AHP%20Template%20SCBUK.xls

Table 19. Indicators used and calculated by the LCA model

Indicator	Description	Unit
Financial analysis		
IRC	Initial renovation cost	€
OM	Annual operating and maintenance cost	€
SV	Salvage (i.e., residual) value	€
DF	Discount factor (5.7%)	%
DE-H	Annual delivered (i.e., final) energy for heating	MWh
DE-C	Annual delivered (i.e., final) energy for cooling	MWh
DE-DHW	Annual delivered (i.e., final) energy for DHW	MWh
EC-H	Heating energy cost	€/MWh
EC-C	Cooling energy cost	€/MWh
EC-DHW	DHW energy cost	€/MWh
Lifespan	Project lifetime (20 years)	Years
$FNPV_{LCC}$	Financial net present value of all costs associated with a retrofitting project over its life cycle	€
FPBP	Financial payback period of renovation	Years
Social cost-benefit analysis (additional indicators)		
GHG_{emb}	Embodied CO_2 emissions in materials and equipment	$tnCO_2eq$
GHG_{ef}	CO_2 emissions factor	$tnCO_2eq/MWh$
GHG_{OP}	Operational CO_2 emissions	$tnCO_2eq/year$
GHG_{LC}	Life cycle GHG emissions	$tnCO_2eq$
Asthma	Avoided asthma morbidity due to indoor dampness	€/year
AvElGen	Avoided electricity generation from combustibles-based power plants	€/year
AvGHGem	Avoided direct GHG emissions	€/year
AvMort-HC	Avoided premature mortality due to inadequate heating and cooling	€/year
AvMorb-Indoor	Avoided Morbidity due to indoor air pollution	€/year
AvYD-Ozone	Avoided yearly deaths due to reduced ozone exposure	€/year
AvYD-PM2.5	Avoided yearly deaths due to PM2.5 exposure	€/year
AvLifeloss-PM2.5	Avoided life expectancy loss due to PM2.5	€/year
Tax	VAT and other taxes and levies	%
$SNPV_{LCC}$	Social net present value of all costs associated with a retrofitting project over its life cycle	€
SPBP	Social payback period of renovation	Years
GHGPBP	Year required to recover embodied CO_2eq. from CO_2eq. emission savings	Years

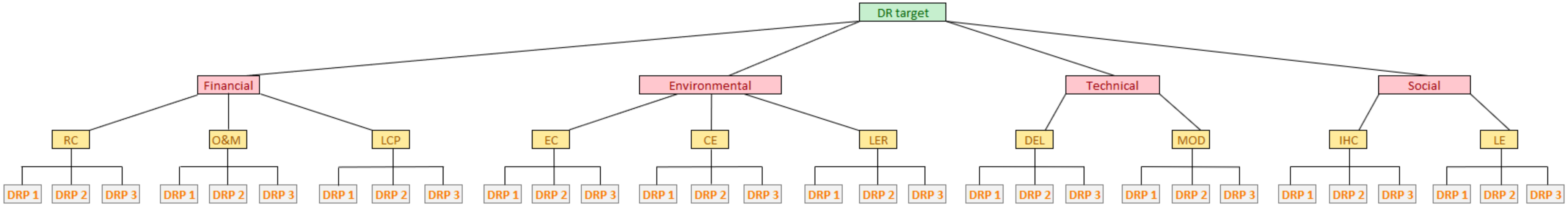

Figure 11. The AHP hierarchy

5.5.2 Life-Cycle Assessment

The following sections summarise the results of the LCA models per reference building in the four REVERTER pilots. For conciseness reasons, only the main indicators are reported.

5.5.2.1 Brezovo Pilot

The results for the three reference buildings in the Brezovo pilot are presented in Table 20, Table 21, and Table 22, respectively.

Table 20. LCA results for the single-family reference building in Brezovo

Indicator	Baseline	DRP 1	DRP 2	DRP 3
$FNPV_{LCC}$	116,267 €	157,532 €	160,957 €	151,590 €
FPBP	--	24.5 years	23.7 years	19.7 years
$SNPV_{LCC}$	129,564 €	172,419 €	175,281 €	156,127 €
SPBP	--	17.1 years	16.7 years	14.1 years
GHG_{LC}	760.4 ton	356.1 ton	298.2 ton	148.8 ton
GHGPBP	--	0.9 years	1.2 years	1.0 years

Table 21. LCA results for the multi-family reference building in Brezovo

Indicator	Baseline	DRP 1	DRP 2	DRP 3
$FNPV_{LCC}$	233,482 €	294,231 €	303,582 €	327,928 €
FPBP	--	22.4 years	23.3 years	24.3 years
$SNPV_{LCC}$	259,219 €	319,354 €	330,399 €	244,847 €
SPBP	--	15.2 years	15.9 years	16.7 years
GHG_{LC}	1478.2 ton	700.9 ton	693.7 ton	603.7 ton
GHGPBP	--	2.1 years	2.2 years	1.9 years

Table 22. LCA results for the public reference building in Brezovo

Indicator	Baseline	DRP 1	DRP 2	DRP 3
$FNPV_{LCC}$	285,193 €	289,375 €	300,738 €	339,894 €
FPBP	--	15.9 years	16.3 years	19.1 years
$SNPV_{LCC}$	317,518 €	274,743 €	282,012 €	311,268 €
SPBP	--	9.4 years	10.0 years	11.3 years
GHG_{LC}	1691.5 ton	879.8 ton	791.6 ton	627.7 ton
GHGPBP	--	1.7 years	2.0 years	1.8 years

The evaluation of the single-family reference building reveals that none of the DRPs exhibit a discernible advantage over the current building scenario. This holds true for both the financial and social cost-benefit analyses. Additionally, the payback periods extend to almost 20 years or more.

Nevertheless, in the realm of environmental considerations, all three alternatives outshine the existing building. To be specific, DPR 1, 2, and 3 showcase reductions of approximately 53%, 61%, and 80%, respectively, in life cycle GHG emissions compared to the baseline building.

Similar findings emerge when examining the multi-family reference building, where the NPV of life cycle costs remains lower in the present state of the building. The three alternatives yield extended payback periods and heightened private and social life cycle costs. Despite these drawbacks, they once again offer substantial environmental benefits in terms of GHG emissions. Precisely, all alternatives exhibit lower life cycle GHG emissions ranging from 53% to 60%.

In contrast, the results diverge for the public reference building. The financial life cycle costs (measured by NPV) of DPR 1 and 2 align closely with those of the existing building. Notably, from a societal standpoint, all three alternatives prove to be superior to the status quo. Furthermore, mirroring the scenarios of single- and multi-family buildings, the alternative DRPs result in significantly diminished life cycle GHG emissions, ranging between 48% and 63%.

5.5.2.2 Athens Urban Area Pilot

The results of the LCA model for the single-family and multi-family reference buildings in Athens Urban Area are given in Table 23 and Table 24, respectively.

Table 23. LCA results for the single-family reference building in Athens Urban Area

Indicator	Baseline	DRP 1	DRP 2	DRP 3
$FNPV_{LCC}$	58,887 €	40,646 €	44,934 €	50,708 €
FPBP	--	2.9 years	9.5 years	12.1 years
$SNPV_{LCC}$	48,956 €	32,532 €	24,501 €	23,168 €
SPBP	--	2.8 years	7.8 years	9.6 years
GHG_{LC}	201.0 ton	130.1 ton	76.5 ton	53.3 ton
GHGPBP	--	0.2 years	0.9 years	1.4 years

Table 24. LCA results for the multi-family reference building in Athens Urban Area

Indicator	Baseline	DRP 1	DRP 2	DRP 3
$FNPV_{LCC}$	86,843 €	78,258 €	89,260 €	113,382 €
FPBP	--	10.8 years	16.4 years	20.8 years
$SNPV_{LCC}$	75,305 €	64,945 €	56,098 €	63,231 €
SPBP	--	9.3 years	12.7 years	15.6 years
GHG_{LC}	282.3 ton	195.4 ton	119.9 ton	75.2 ton
GHGPBP	--	0.7 years	0.9 years	1.7 years

As far as the single-family reference building is concerned, the minimum NPV of all costs associated with a retrofitting project is calculated for DRP 1, which includes only the replacement of the heating oil boiler with a heat pump. As expected, the same DRP presents the minimum payback period from a homeowner's perspective. Nonetheless, the most desirable alternative DRP from a societal viewpoint is DPR 3, which results in the lowest NPV of the retrofitting project over its life cycle. This alternative maximises the indirect benefits associated with energy savings and minimises the life cycle GHG emissions (by almost 2.5 times compared to DRP 1).

DRP 1 (again, only replacement of the oil-fired heating system by a heat pump is foreseen) is also the most favourable alternative in the case of the multi-family reference building. DRP 1 shows the lowest NPV of life cycle costs and the lowest payback period. The social cost-benefit analysis, however, favours DRP 2. The social NPV of life cycle costs of DRP 3 is also lower than that of DRP 1, but higher than that of DRP 2. Nevertheless, from an environmental point of view, DRP 3 is superior as it minimises life cycle GHG emissions (they are 2.6 times lower than those of DRP 1 and 1.6 times lower than those of DRP 2).

5.5.2.3 Riga Pilot

The results of the LCA model for the multi-family reference building in the Riga pilot are presented in Table 25.

Table 25. LCA results for the multi-family reference building in Riga

Indicator	Baseline	DRP 1	DRP 2	DRP 3
$FNPV_{LCC}$	1,169,703 €	1,412,695 €	1,347,878 €	1,430,642 €
FPBP	--	20.6 years	19.0 years	20.8 years
$SNPV_{LCC}$	1,256,777 €	1,545,287 €	1,467,753 €	1,566,042 €
SPBP	--	15.7 years	14.8 years	15.9 years
GHG_{LC}	3,904.5 ton	1,750.3 ton	1,708.6 ton	1,665.7 ton
GHGPBP	--	2.7 years	2.5 years	2.5 years

The financial and social NPV of life cycle costs minimises for the baseline scenario. Hence, from both a private and societal perspective the economic performance of all DRPs is lagging behind the existing building situation. This is related to the long payback periods of all DPRs (minimum 19 years). However, from an environmental perspective, it's apparent that all DPRs outperform compared to the baseline scenario, as the life cycle GHG emissions (for a 20-year lifetime) decrease by more than 55%.

5.5.2.4 Coimbra Pilot

The results of the LCA model for the single-family and multi-family reference buildings in the Coimbra pilot are illustrated in Table 26 and Table 27, respectively.

Table 26. LCA results for the single-family reference building in Coimbra

Indicator	Baseline	DRP 1	DRP 2	DRP 3
$FNPV_{LCC}$	21,615 €	13,813 €	21,096 €	21,537 €
FPBP	--	4.3 years	12.6 years	12.3 years
$SNPV_{LCC}$	20,493 €	7,470 €	17,568 €	15,805 €
SPBP	--	3.3 years	9.7 years	9.4 years
GHG_{LC}	27.6 ton	9.7 ton	11.1 ton	5.5 ton
GHGPBP	--	1.8 years	2.1 years	2.1 years

Table 27. LCA results for the multi-family reference building in Coimbra

Indicator	Baseline	DRP 1	DRP 2	DRP 3
$FNPV_{LCC}$	346,230 €	186,882 €	243,531 €	240,140 €
FPBP	--	3.8 years	7.5 years	6.6 years
$SNPV_{LCC}$	328,254 €	141,156 €	216,472 €	211,771 €
SPBP	--	3.3 years	6.4 years	5.7 years
GHG_{LC}	203.2 ton	79.1 ton	91.1 ton	99.9 ton
GHGPBP	--	2.3 years	3.8 years	2.7 years

Focusing on the single-family reference building, the minimum NPV of life cycle cost is observed in DRP 1, which includes the replacement of old wooden doors and windows and the installation of "A class" inverter heat pump for heating and cooling (COP3/EER2.6) and air-water heat pump compact system (COP 2.6) for DWH. The same DRP presents the minimum payback period from a homeowner's perspective, as expected. The same DRP is also the most desirable alternative DRP from a societal viewpoint. Nevertheless, from an environmental perspective (i.e., considering the life cycle GHG emissions) the most desirable alternative is DRP 3.

As far as the multi-family building is concerned, DRP 1 (deep renovation measures are like those foreseen for the DRP 1 in the case of single-family reference building) is also the most favourable alternative, as it presents the lowest NPV of life cycle costs and the lowest payback period. The social cost-benefit analysis also favours DRP 1. From an environmental point of view, DRP 1 is again the most favourable alternative as it minimises life cycle GHG emissions (life cycle GHG emissions decrease by more than 60% compared to the baseline scenario).

5.5.3 Multicriteria Assessment

As already mentioned, the multicriteria analysis was used in complementary to the financial and social cost-benefit analysis. The criteria and sub-criteria used and the AHP hierarchy were common to all four pilots. Nevertheless, the weights were defined through pairwise comparisons by the partners of each pilot and, consequently, may differ. For this reason, the AHP models, which are provided in the following sections, illustrate not only the final ranking but also the weights used for each criterion and sub-criterion.

5.5.3.1 Brezovo pilot

The AHP model for the single-family reference building in the Brezovo pilot is illustrated in Figure 12. According to the model outcomes, DRP 1 is the most favoured alternative, having an overall priority score of 0.372. Following closely is DRP 3 with an overall priority score of 0.346. The preference for DRP 1 is primarily attributed to reduced capital costs, which carry a higher weight in the assessment.

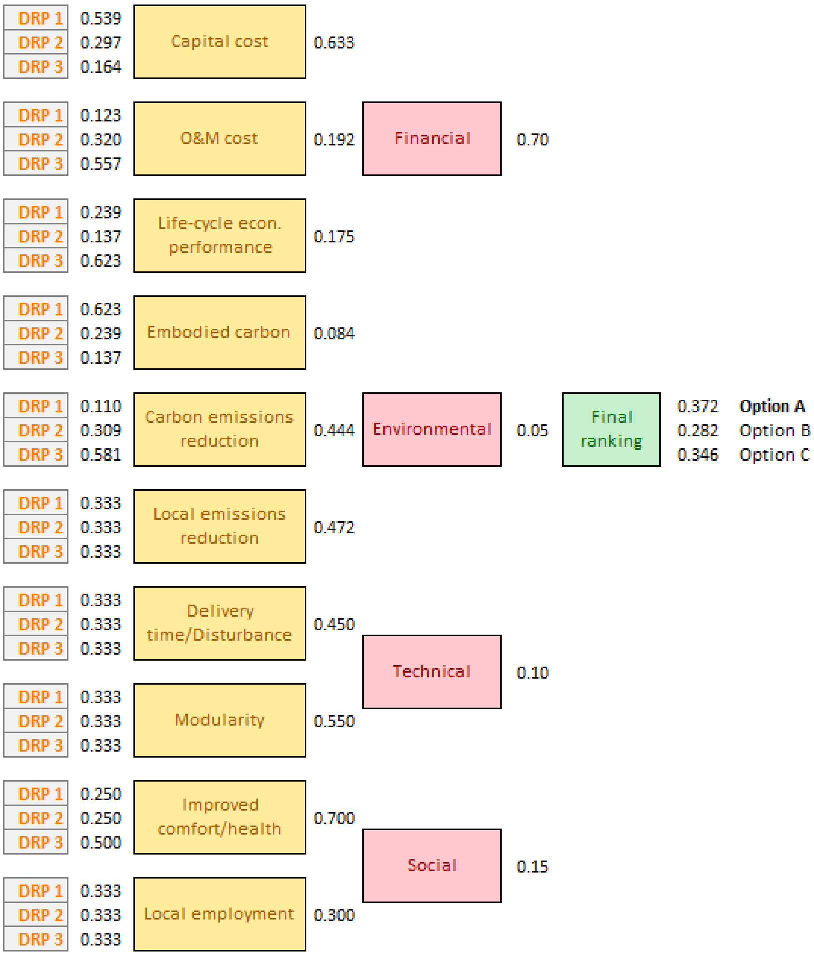

Figure 12. The AHP model of the single-family reference building in Brezovo

Similarly, Figure 13 depicts the AHP model for the multi-family building. DRP 1, sharing common deep renovation interventions with the single-family building's DRP 1, once again stands out as the most preferable alternative with an overall priority score of 0.404. The other two alternatives hold equal preference in this case. The prominence of DRP 1 is not only due to lower capital costs but also its superior life cycle economic performance.

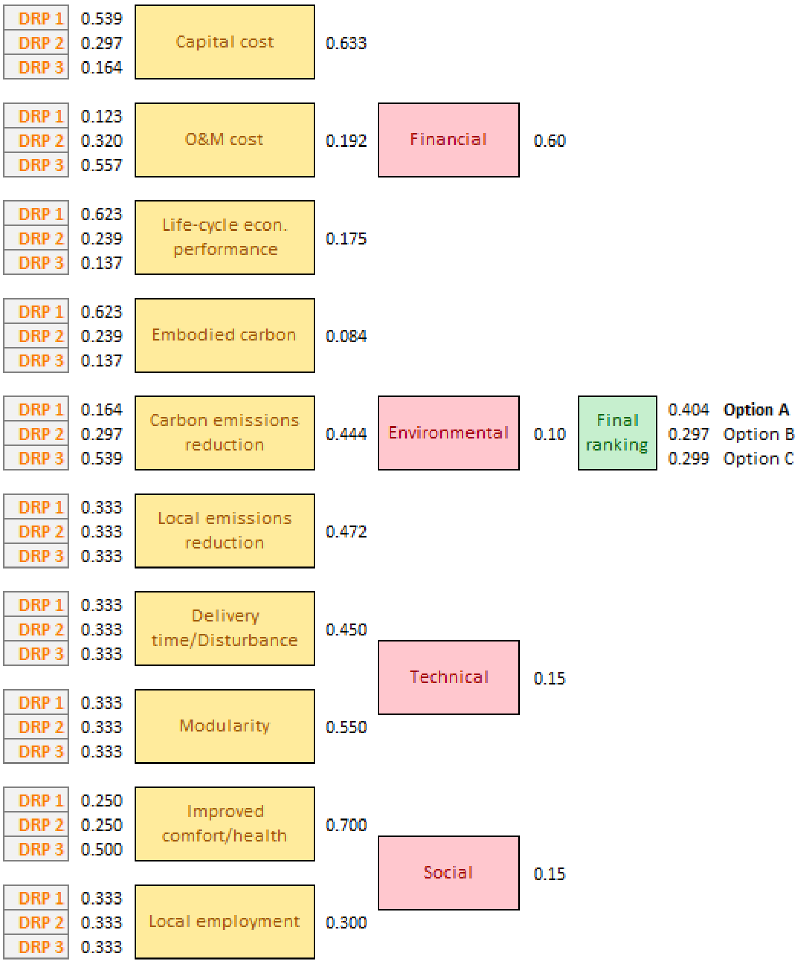

Figure 13. The AHP model of the multi-family reference building in Brezovo

Lastly, Figure 14 illustrates the results of the AHP model for the public reference building. DRP 1 claims the top spot with the highest priority (i.e., 0.425). The key factors contributing to this result are the lower capital cost and the superior life cycle economic performance, taking into account the weights assigned to the financial criterion and these two sub-criteria. As for the other alternatives, DRP 2 follows, albeit at a distance, owing to its performance in operating and maintenance costs and the reduction of GHG in the operational phase.

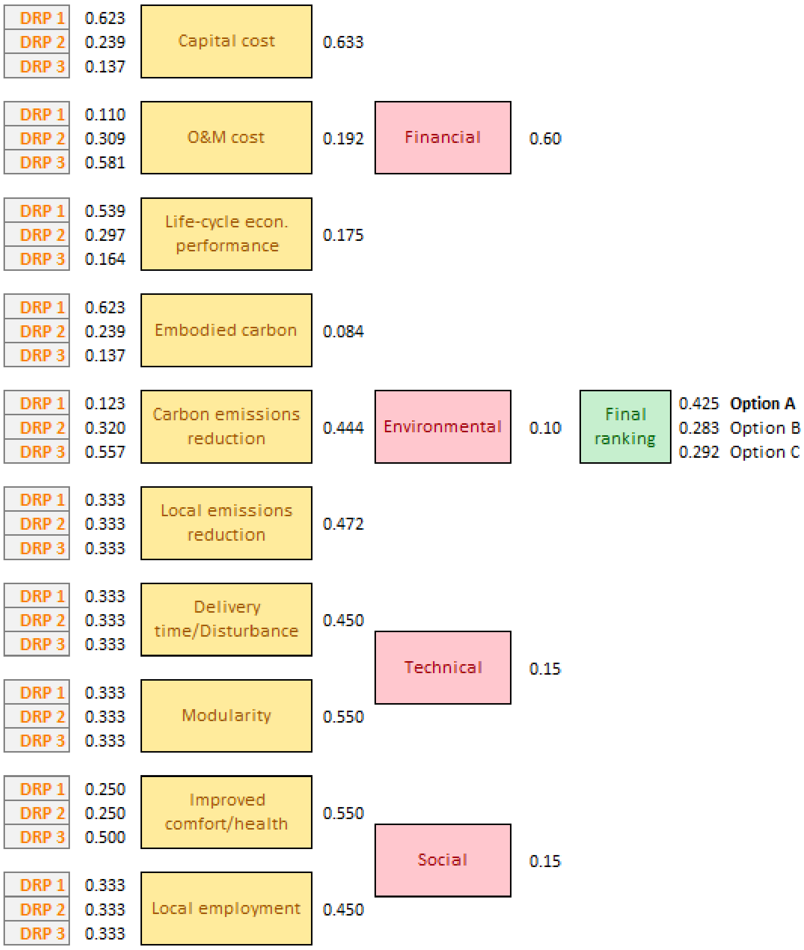

Figure 14. The AHP model of the public reference building in Brezovo

5.5.3.2 Athens Urban Area Pilot

The AHP model of the single-family reference building in the Greek pilot is given in Figure 15. Based on the model outcomes, DRP 3 emerges as the most favoured alternative, boasting an overall priority score of 0.393. Subsequently, DRP 1 follows closely with an overall priority score of 0.362. The precedence of DRP 3 is primarily attributable to reduced operational costs and GHG emissions during the operational phase. Secondarily, it can be attributed to superior performance in terms of social sub-criteria and lower emissions of other pollutants at the local level.

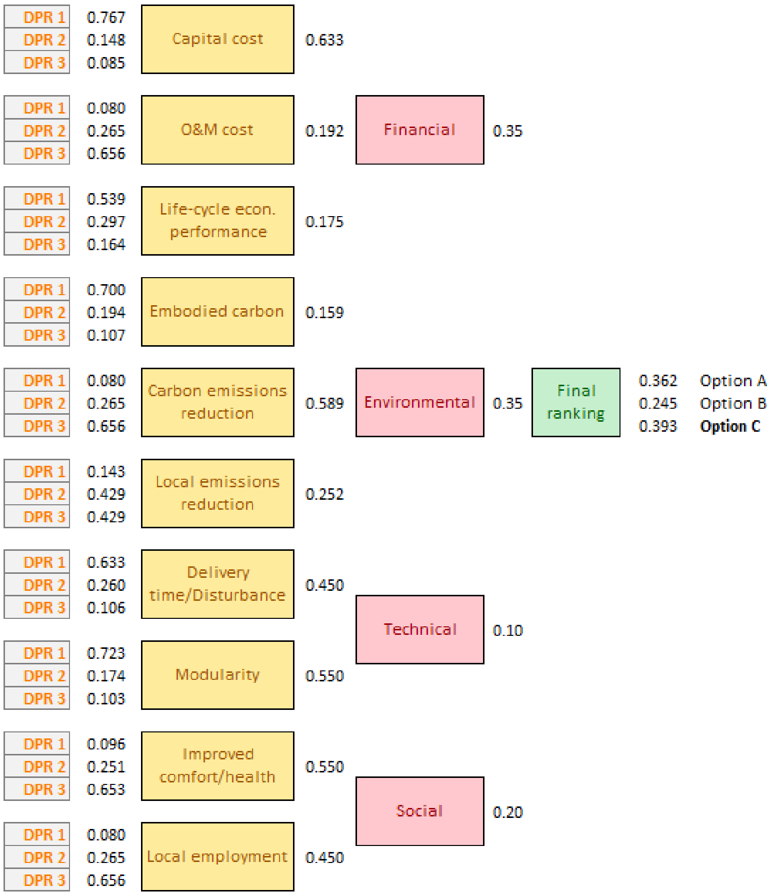

Figure 15. The AHP model of the single-family reference building in Athens Urban Area

Figure 16 shows the AHP model of the multi-family reference building in Athens Urban Area pilot. Once more, DRP 3 takes the lead as the preferred option, presenting an overall priority score of 0.398. Following closely, DRP 1 presents an overall priority score of 0.362. The prominence of DRP 3 can be attributed again to diminished operational costs and GHG in the operational phase. Additionally, its superiority is underscored by commendable performance in social sub-criteria and lower emissions of other pollutants at the local level.

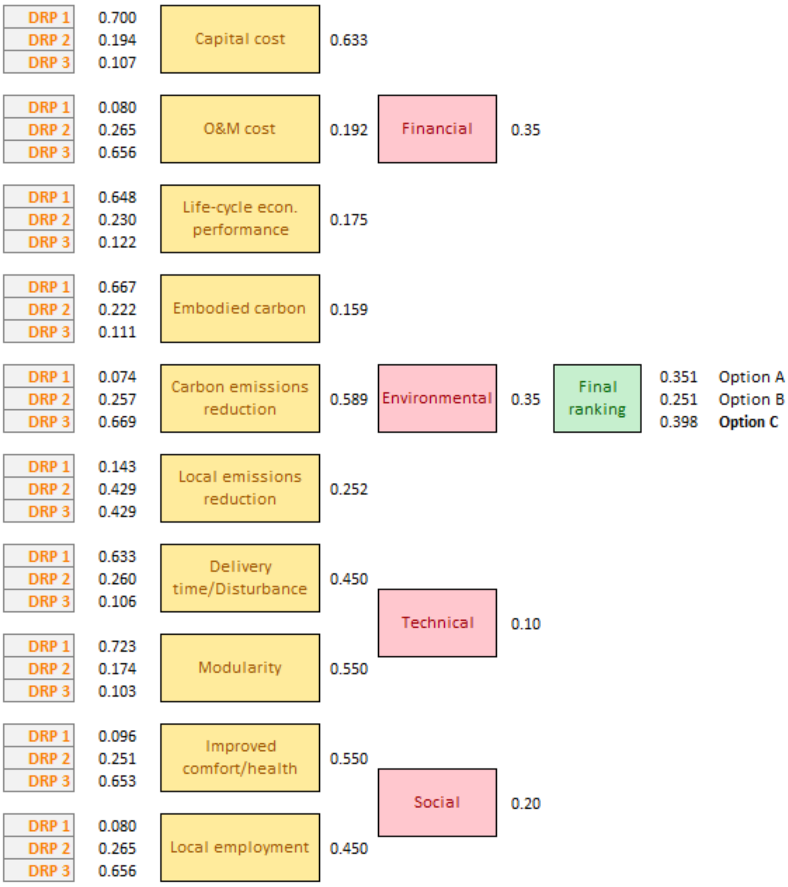

Figure 16. The AHP model of the multi-family reference building in Athens Urban Area

5.5.3.3 Riga Pilot

The AHP model of the multi-family reference building in the Riga pilot is presented in Figure 17Figure 15. Based on the model, DRP 2 is the most favoured alternative, presenting an overall priority score of 0.397. DRP 2 offers benefits stemming from diminished capital expenses, enhanced economic efficiency, decreased embodied GHG emissions, and improved technical features. DRP 3 follows closely with an overall priority score of 0.361 because of the reduced operational costs and GHG emissions during the operational phase.

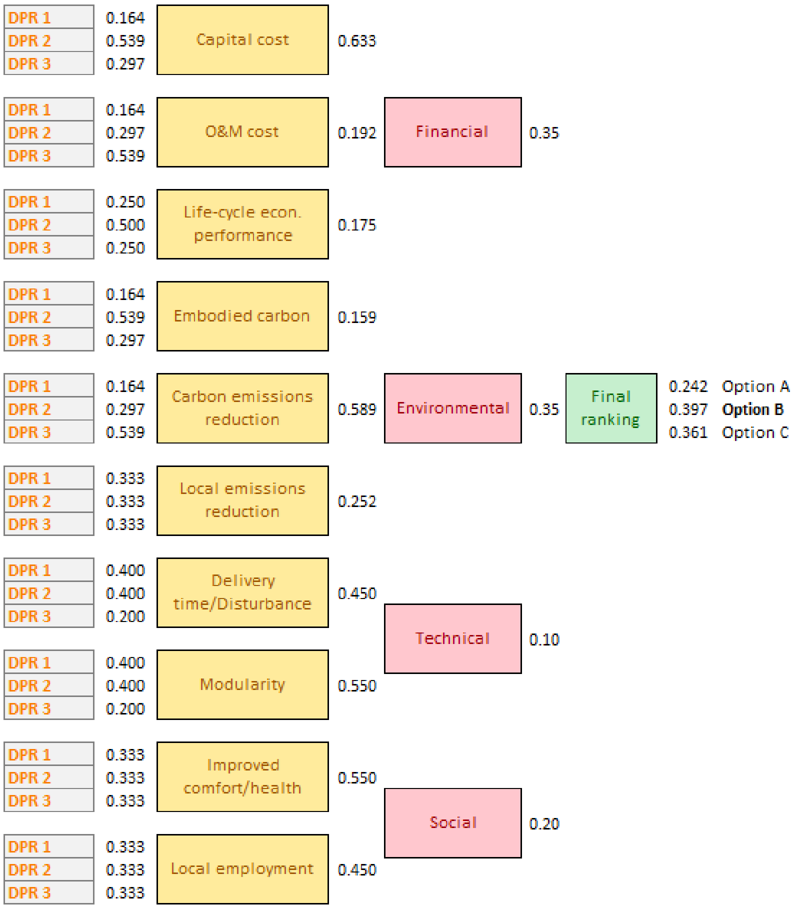

Figure 17. The AHP model of the multi-family reference building in Riga

5.5.3.4 Coimbra Pilot

The AHP model for the selection of the most preferred alternative DRP for the single-family reference building in Coimbra is given in Figure 18. According to the model results, DRP 1 emerges as the most favoured alternative, reaching an overall priority score of 0.398. followed by DRP 3, which has an overall priority score of 0.378. DRP 1 is primarily preferred due to reduced capital costs, better life cycle economic performance, lower embodied carbon and better technical performance. DPR 3 follows closely, as mentioned, because of the lower operating costs and reduced GHG emissions during the operational phase.

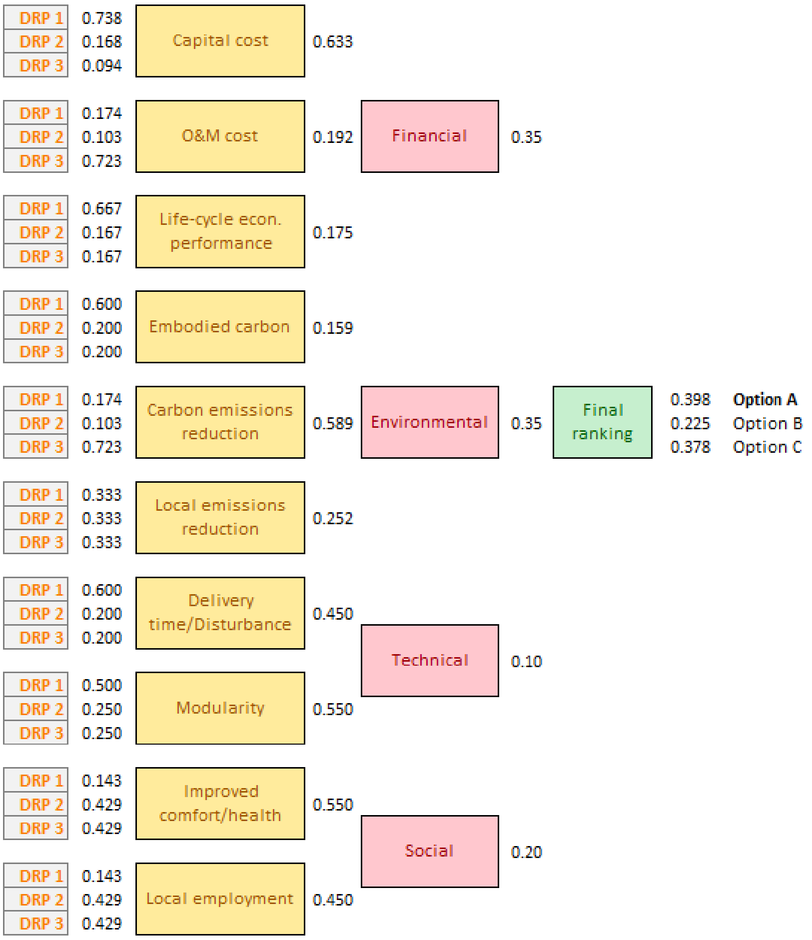

Figure 18. The AHP model of the single-family reference building in Coimbra

The AHP model of the multi-family reference building in the Coimbra pilot is illustrated in Figure 19. DRP 1 emerges as the favoured choice, having a priority score of 0.484, nearly double that of the other two alternatives. The dominance of DRP 1 can be traced to its lower capital and operational costs, as well as superior economic and technical performance. Although the other two alternatives excel in the social criterion, they fall behind in the remaining three criteria.

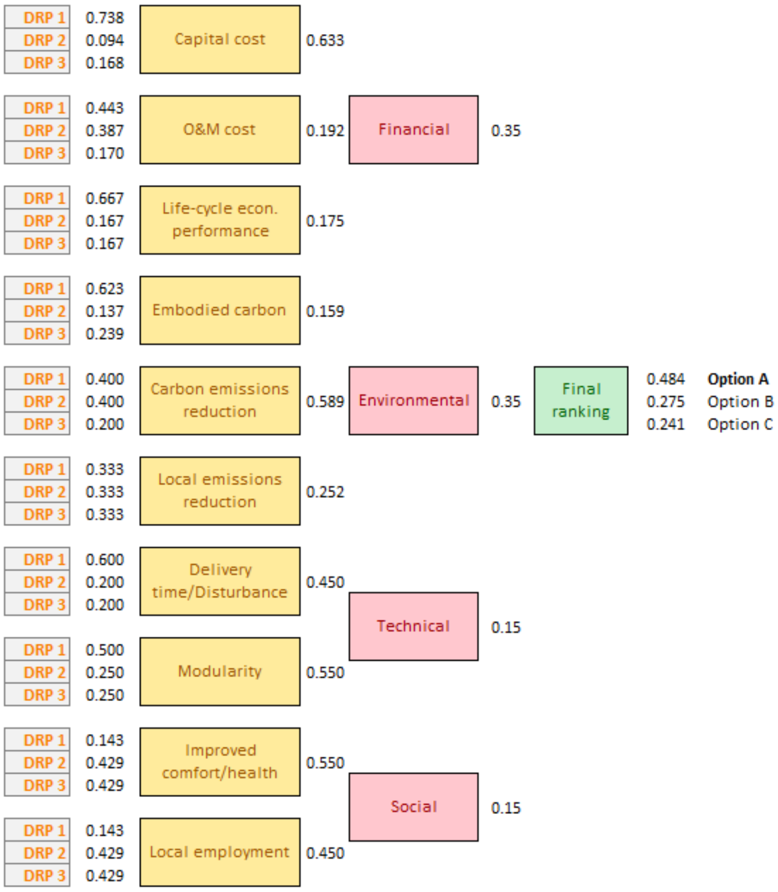

Figure 19. The AHP model of the multi-family reference building in Coimbra

5.5.4 Uncertainty Analysis

As mentioned, the economic analysis was conducted using constant prices for energy products. Moreover, changes in energy mixes related to GHG emissions and effects on heating and cooling needs were neglected. To assess the potential impact of these factors on the assessment and prioritisation of DRPs, uncertainty analysis is carried out considering the projection of following parameters over the next two decades:

- Energy prices (changes related to demand and supply factors, ignoring inflation), considering assumptions for the projection of energy prices described in the “EU Reference Scenario 2020” (European Commission et al., 2021).
- Heating and cooling degree days to account for climate change, using the Copernicus ERA5 analysis for indoor heating and cooling demand in the near, mid, and far future at NUTS2 level for the RCP4.5 climate projection (Copernicus, 2023) (Figure 20).
- Carbon intensities for electricity mixes reflecting the EU targets on CO_2 emissions based on relevant publications (European Commission et al., 2019; Scarlat et al., 2022).

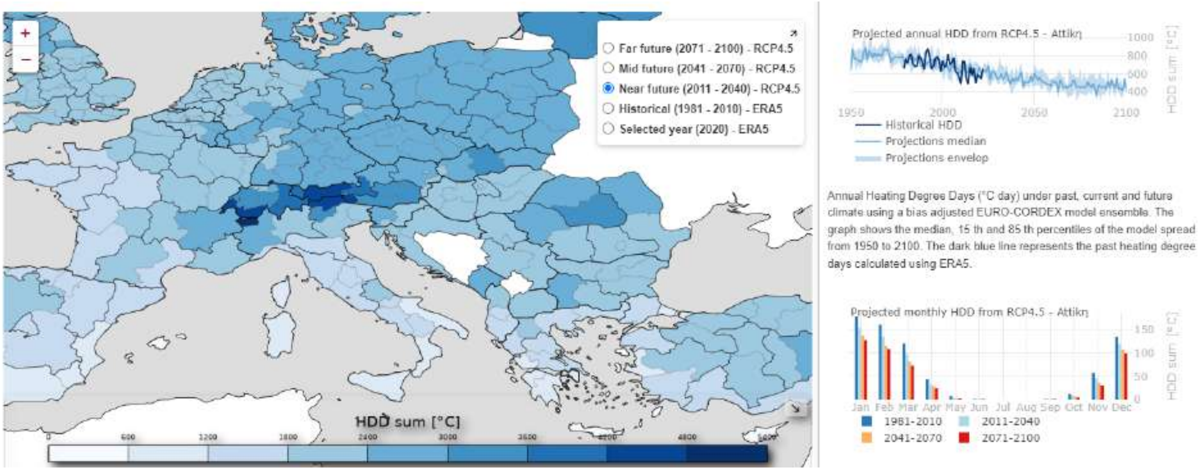

Figure 20. The Copernicus user environment (Copernicus, 2023)

More specifically, the assumptions adopted for the uncertainty analysis are given in the next table.

Table 28. Percentage changes in selected variables, at the end of the next 20 years

Parameter	**Brezovo pilot**	**AUA pilot**	**Riga pilot**	**Coimbra pilot**
Heating cost	+15.0%	+75.0%	+15.0%	+10.3%
Electricity cost	+10.3%	+10.3%	+10.3%	+10.3%
HDDs	-10.0%	-25.0%	-5.0%	-30.0%
CDDs	+10.0%	+30.0%	+20.0%	+35.0%
Carbon intensity	-65.0%	-65.0%	-75.0%	-70.0%

Having defined the current value ($Value_0$) and the value at the end of the next 20 years ($Value_{20}$), the average annual change factor is estimated as follows:

$$k = \frac{1}{20} ln \frac{Value_{20}}{Value_0}$$

The uncertainty analysis is based on a random walk-based stochastic process. Since the growth (or decline) rate is a continuous process, it is expressed as a differential process:

$$d\alpha(t) = kdt + \sigma dW(t)$$

where $\alpha(t)$ is the total growth (or decline) rate at time t, k is the drift (i.e., the average annual factor), σ is the volatility and *W(t)* is a Wiener process, i.e., $\sigma dW(t)$ controls the "random noise" effect.

For each parameter, 100 simulations of the growth (or decline) rate $\alpha(t)$ were performed, leading to 100 paths of value evolutions (see for example Figure 21 and Figure 22), which were then used as input to the LCA models.

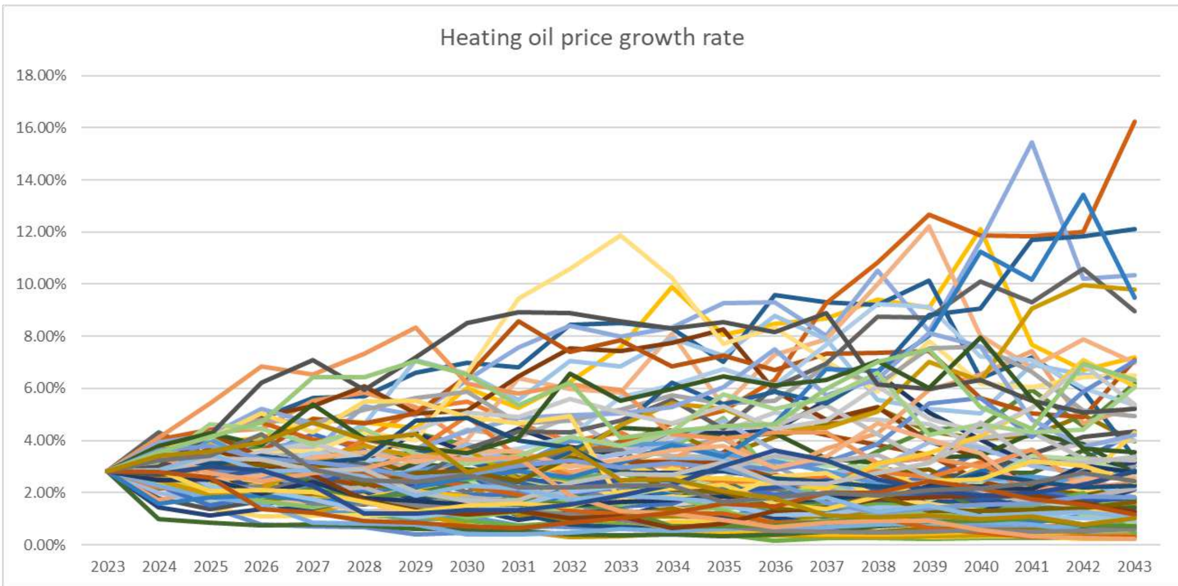

Figure 21. Random walks of heating oil growth rate

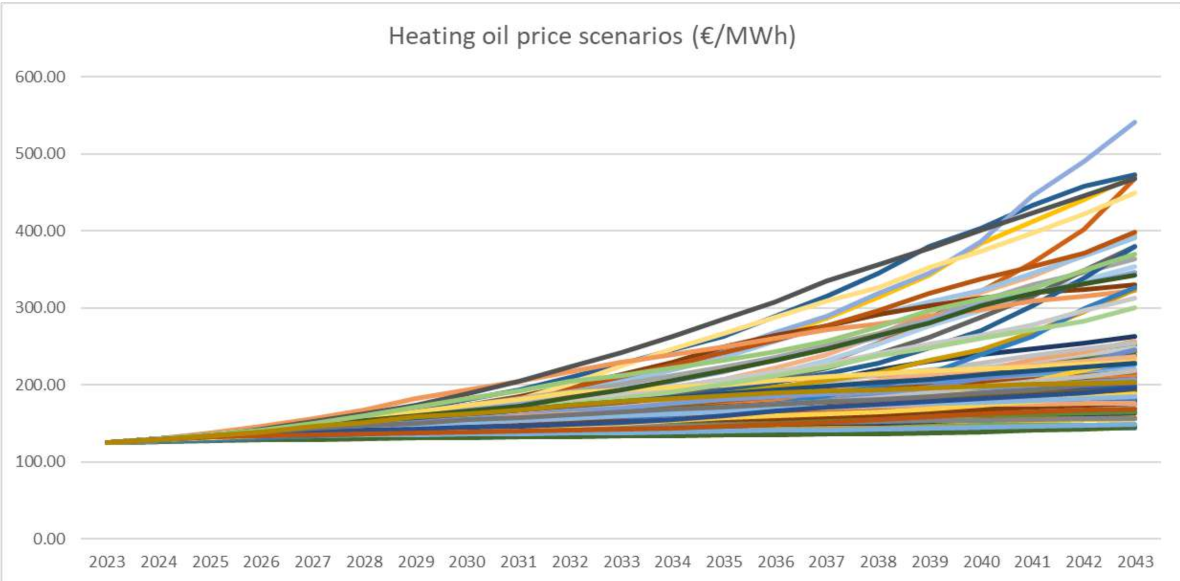

Figure 22. Projected heating oil prices

For comparison purposes, the uncertainty analysis is carried out for the four pilots only on the multi-family reference buildings. Summary statistics on the NPV of life cycle costs are presented in Table 29 to Table 32, while Figure 23 to Figure 26 show the distribution of the results in the form of histograms.

Table 29. Life cycle costs NPV simulation statistics for the MFB in Brezovo pilot

Statistics	Baseline	DRP 1	DRP 2	DRP 3
Average	234,043	352,388	363,981	387,366
Min	221,244	350,010	361,615	385,287
Max	276,450	357,547	368,817	392,189
St. Dev.	6,117	1,468	1,420	1,304

Table 30. Life cycle costs NPV simulation statistics for the MFB in AUA pilot

Statistics	Baseline	DRP 1	DRP 2	DRP 3
Average	96,954	68,599	98,537	129,434
Min	86,089	64,934	97,080	128,494
Max	131,601	75,272	100,814	131,008
St. Dev.	8,538	2,012	759	558

Table 31. Life cycle costs NPV simulation statistics for the MFB in Riga pilot

Statistics	Baseline	DRP 1	DRP 2	DRP 3
Average	1,196,181	1,556,262	1,477,179	1,576,782
Min	1,152,360	1,540,678	1,461,110	1,561,366
Max	1,301,638	1,594,902	1,524,919	1,622,512
St. Dev.	29,420	9,308	9,218	8,851

Table 32. Life cycle costs NPV simulation statistics for the MFB in Coimbra pilot

Statistics	Baseline	DRP 1	DRP 2	DRP 3
Average	323,816	187,441	266,437	255,344
Min	291,459	177,108	259,395	245,981
Max	344,217	194,123	271,769	262,106
St. Dev.	12,025	3,812	2,747	3,637

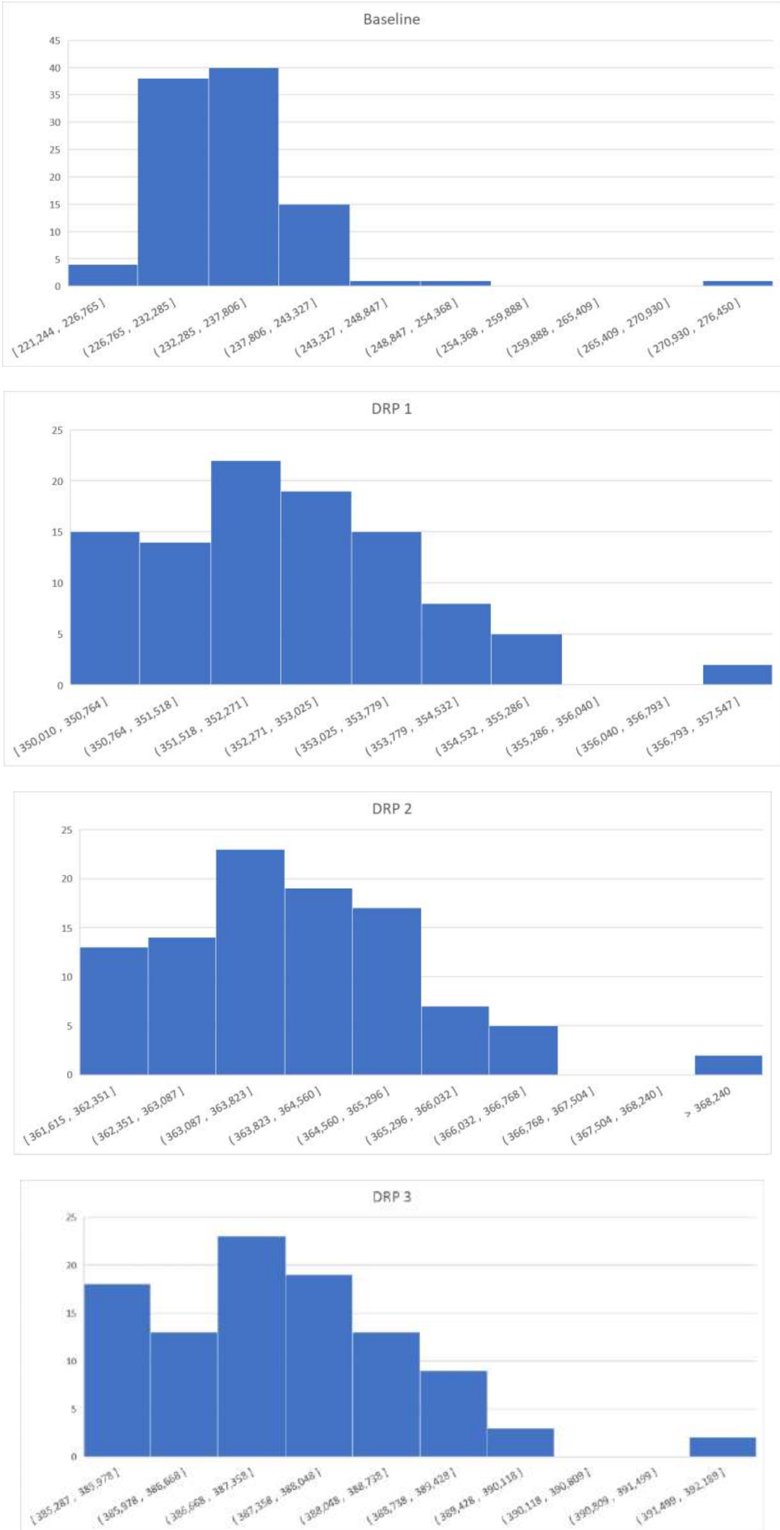

Figure 23. Life cycle costs NPV for the MFB in Brezovo pilot

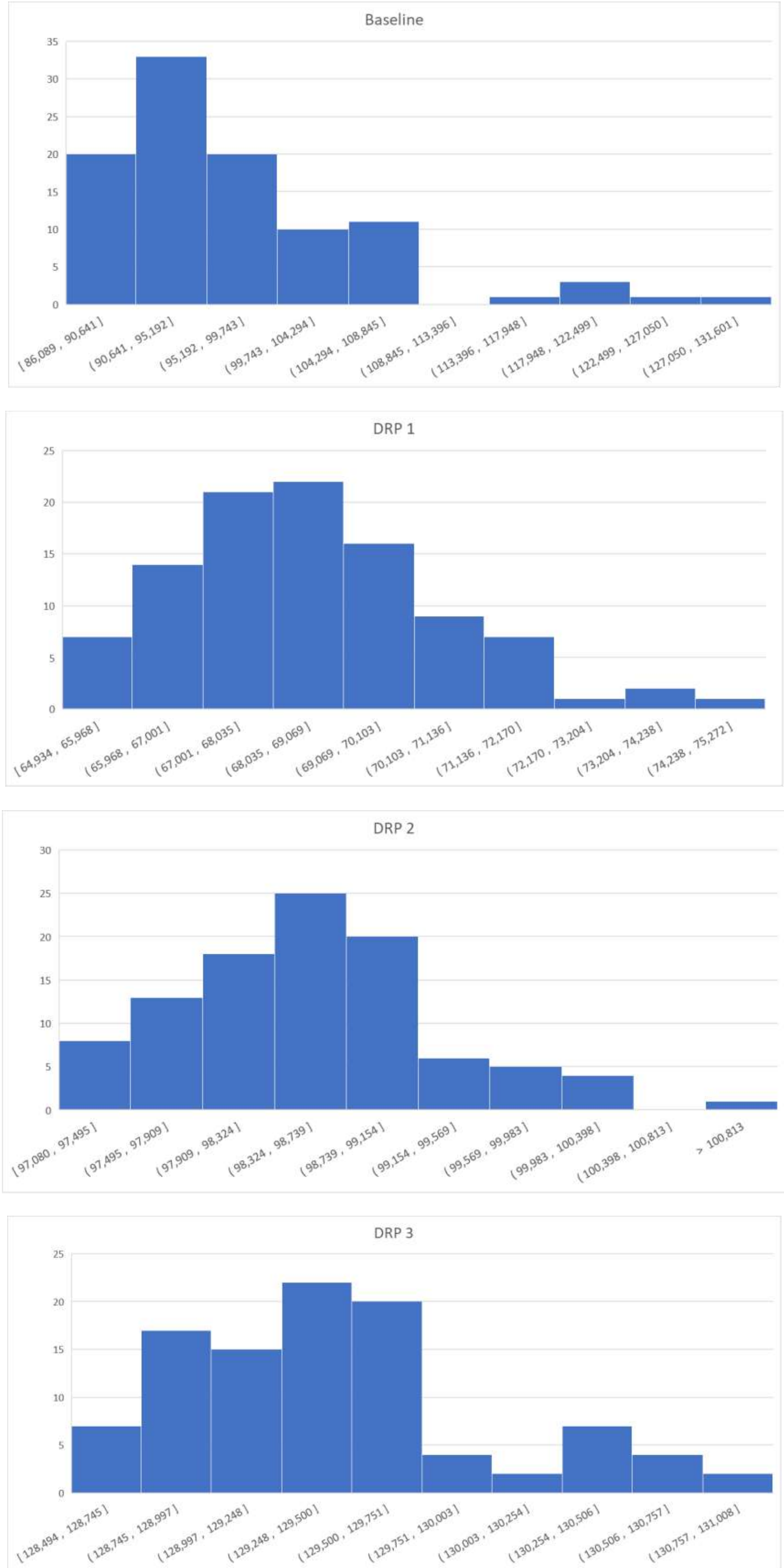

Figure 24. Life cycle costs NPV for the MFB in AUA pilot

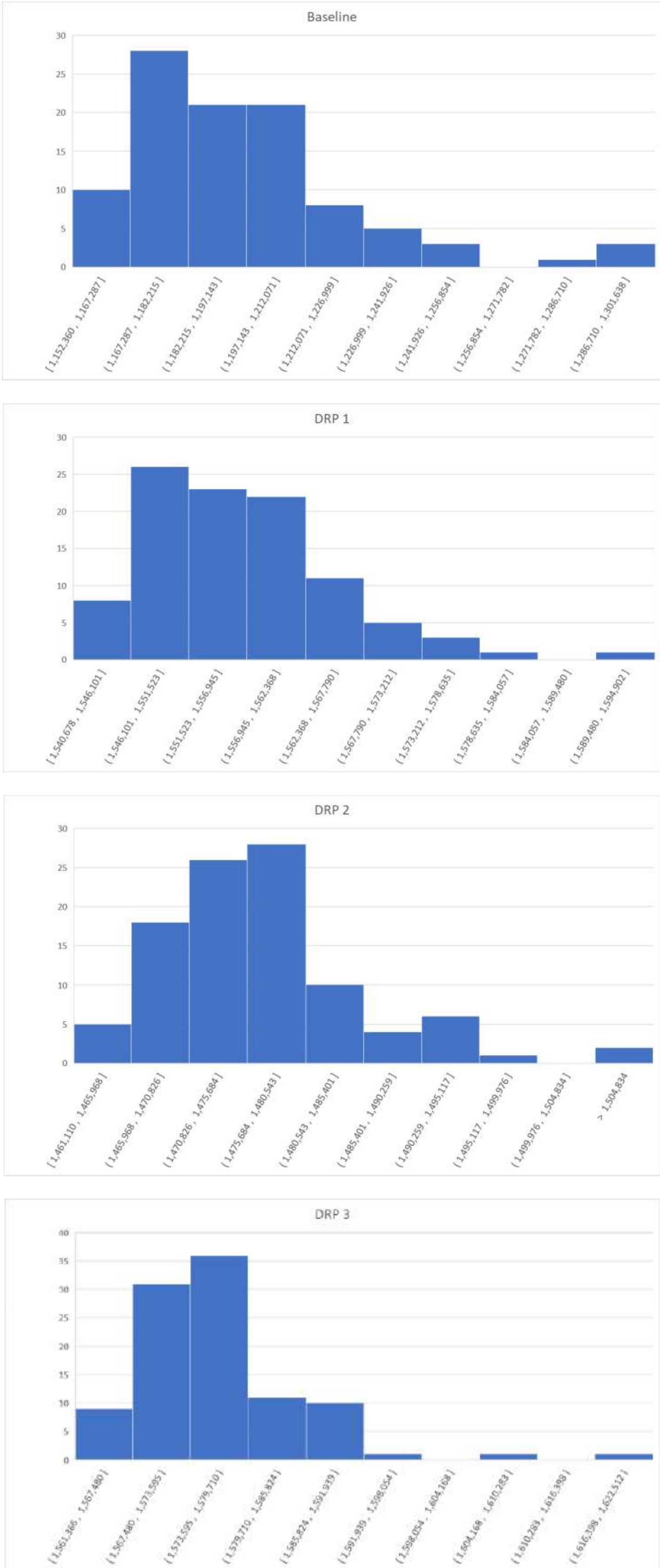

Figure 25. Life cycle costs NPV for the MFB in Riga pilot

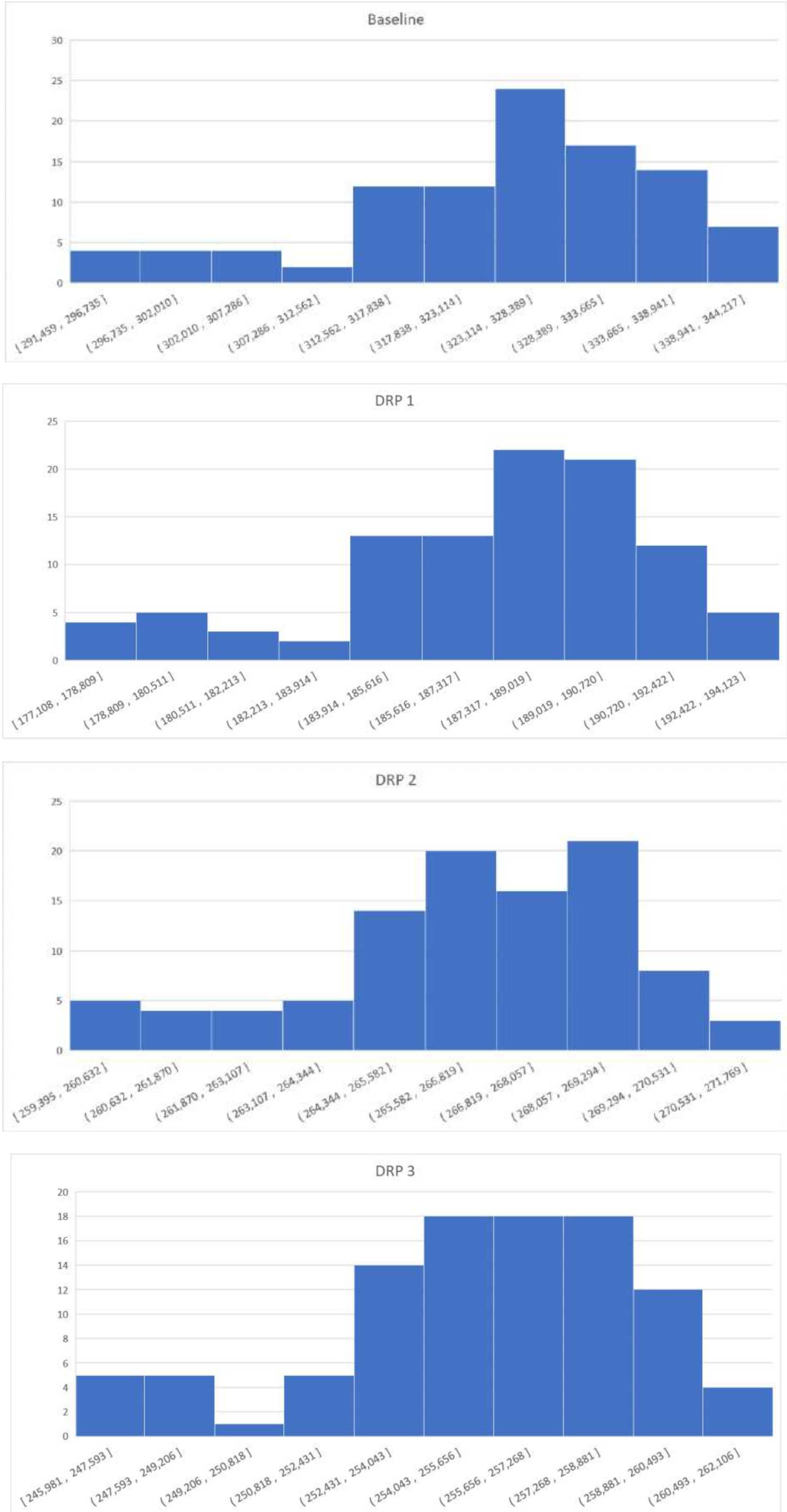

Figure 26. Life cycle costs NPV for the MFB in Coimbra pilot

While the ranking of the alternatives remains consistent, the uncertainty analysis highlights the breadth of potential estimates influenced by the simulated pathways. Across all pilot studies, it is evident that the range (and standard deviation) of life cycle cost estimates for the current configuration of reference buildings is notably greater than that of the alternative DRPs. This discrepancy can be attributed to either the shift in heating fuel, such as the transition from oil to electricity in the Greek pilot, or the enhancement of the building envelope insulation, a common factor across all pilots. In both situations, the reduction in not only the cost but also, and mainly, in variability becomes apparent.

6 Renovation Barriers and Multiple Benefits

This section summarises the results of the literature review conducted to identify the main barriers to and benefits of adopting deep renovation measures with the aim to recognise factors affecting individuals' decisions to implement energy renovations and, thus, to design more effective policies promoting building energy efficiency, especially among vulnerable households.

6.1 Renovation Barriers

Energy renovation barriers refer to the obstacles, challenges, or factors that hinder the adoption, implementation, or success of energy retrofit projects in buildings, a phenomenon known as the "energy efficiency gap" or "energy paradox" more generally. These barriers can exist at various levels, e.g., individual, organisational, societal, etc., and may vary depending on the specific context, such as the country, region, or type of building type. Understanding and addressing these barriers is essential for overcoming resistance, unlocking the full potential of energy retrofits, and facilitating their widespread adoption to achieve energy efficiency goals in the built environment.

The literature review identified about 25 relevant sources and from them collected about 330 mentions of renovation barriers. Given that there is no single categorisation of barriers related to the renovation of residential buildings, the REVERTER team tried to unify the different views and classified the barriers according to the following six general categories (Figure 27):

- Behavioural/Social barriers (e.g., demographic factors, disturbance during construction works, etc.);
- Financial barriers (e.g., access to capital, diseconomies of scale, etc.);
- Knowledge/informative barriers (e.g., asymmetric information, awareness of benefits, etc.);
- Organisational and decision-making barriers (e.g., investor/society split incentives, lack of coordination, etc.);
- Regulatory barriers (e.g., inconsistent policy, institutional barriers and complexities, etc.);
- Technical barriers (e.g., lack of codes and standards, lack of technical capacity, etc.)

Behavioural/Social barriers

- Resistance to change and comfort with existing routines and habits
- Inertia and reluctance to invest time and effort in retrofit initiatives
- Limited motivation and perceived lack of personal benefit from energy retrofits
- Perception of renovation as a complex and irreversible undertaking
- Lack of a 'culture of saving'
- Limited social norms and peer influence promoting energy-efficient behaviors and retrofits
- Lack of trust in authorities, institutions, or contractors involved in retrofit programs
- Uncertainty about functionality requirements
- Lack of consumer acceptance of new technologies
- Disruption factor, such as noise and dust or the need to move out during renovation work
- Variation in attitudes toward renovation based on factors like age, gender, education, and cultural values, etc.

Financial barriers

- High investment cost of deep renovations
- Long payback periods for energy savings measures
- Limited access to finance (especially for vulnerable households)
- Reluctance of traditional lenders to provide loans for renovation projects
- Reduced availability of subsidies and grants
- Risk of free-rider effect in subsidy programs
- Difficulty in demonstrating increased asset value due to energy performance improvements
- Energy pricing structures that do not fully reflect negative externalities
- Lack of consideration for lifecycle costs
- Diseconomies of scale and lack of ongoing capacity for maintenance (especially for RES)

Knowledge/informative barriers

- Lack of awareness and understanding of energy retrofit benefits and cost-saving opportunities
- Technical complexity and overwhelming terminology
- Limited access to clear, accurate, and impartial information from trusted sources
- Lack of reliable and accessible tools and databases
- Lack of easily accessible and up-to-date information on energy efficiency programs, incentives, and financing options
- Absence of centralized platforms or easily navigable websites
- Conflicting advice and outdated guidelines
- Difficulty in calculating costs for new technologies (for contractors)

Organisational and decision-making barriers

- Challenges in decision-making and coordination for complex ownership structures
- Lack of engagement and collaboration among stakeholders
- Delays and abandonment of projects due to disagreements and lack of accountability
- Complex legal considerations and uncertainties (in collective housing)
- Insufficient communication channels and standardized processes
- Insufficient involvement of occupants or tenants in the retrofit process
- Split incentives and misalignment of incentives in rental properties
- Limited participation of small and medium-sized enterprises in public procurement schemes
- Fragmentation of the supply chain in the construction industry

Regulatory barriers

- Complexity of rules and regulations at EU and national
- Inconsistencies, delays, and gaps in energy performance targets, efficiency standards, and retrofit obligations
- One-size-fits-all approaches overlooking variations
- Unclear, unambitious, and maladapted national strategies
- Lack of common approaches and definitions
- Overlaps, conflicts, and delays in policy schemes, and lack of legislation on specific issues
- Uncertainty due to frequent changes in regulations
- Inadequate monitoring and enforcement
- Excessive administrative burden
- Inconsistent standards and labeling requirements
- Insufficient government subsidies and programs

Technical barriers

- Lack of skilled professionals and trained workforce
- Scarcity of examples of successful deep renovation projects
- Lack of standardised solutions and assessment tools
- Discrepancies between predicted energy savings and actual performance
- Concerns about maintenance, durability, and long-term performance of retrofit systems
- Complexity of integrating new solutions with existing infrastructure
- Limited availability of energy-efficient materials and components
- Safety and seismic risks associated with deep renovation processes

Figure 27. Main barriers to deep renovation

6.1.1 Behavioural/Social Barriers

Behavioural barriers are related to resistance to change and comfort with existing routines and habits, limited motivation and perceived lack of personal benefit from energy retrofits, inertia and reluctance to invest time and effort in retrofit initiatives, perceiving renovation as a complex and irreversible undertaking, lack of a 'culture of saving', lack of trust in authorities, institutions, or contractors involved in retrofit programs, and other cultural and social barriers that affect decision-making and prioritisation of energy retrofits (Bagaini et al., 2020; Bjørneboe et al., 2018; Carlander & Thollander, 2023; European Union, 2021; Haase et al., 2020; Mata et al., 2021). For instance, some stakeholders in the building sector tend to resist change and prefer to stick with familiar practices, even if they are not optimal and fear of trying new things. They also feel uncertain about functionality requirements and are affected by the presentation of information about new technologies and ideas. Trust and credibility of the source are also important factors (Carlander & Thollander, 2023).

Social aspects also play a vital role in deep renovation projects (Bjørneboe et al., 2018; Mainali et al., 2021; McCabe, Pojani, & van Groenou, 2018). For instance, lack of education about the available solutions and their customisability or lack of consumer acceptance of new technologies (which is related to risk aversion), are key challenges. In addition, the disruption factor, referring to the inconvenience caused by renovation work, such as noise and dust or the need to move out during the works, can also deter homeowners from pursuing renovations (in this case, pre-fabricated solutions that limit on-site interventions can help overcome this barrier) (Bjørneboe et al., 2018; Haase et al., 2020). Furthermore, limited social norms and peer influence promoting energy-efficient behaviours and retrofits can impact homeowners' decisions (Bjørneboe et al., 2018; Mainali et al., 2021). For instance, factors such as environmental consciousness, a do-it-yourself mindset, or the perception of renovation as a lifestyle choice can serve as motivators for some homeowners, while the fact that aesthetic renovation may take priority over energy renovation may have the opposite results. Also. It has been found that the lack of active support from the community can impede the development of renewable energy projects in social housing (McCabe, Pojani, & van Groenou, 2018). However, it is important to recognize that homeowners are not a homogeneous group, and attitudes toward renovation can vary based on factors such as age, gender, location, education, and historical and cultural values (Bjørneboe et al., 2018; Mainali et al., 2021). Different age groups, for example, have varying levels of enthusiasm, income/savings, and time availability for deep renovation (Mainali et al., 2021). Furthermore, as regards energy production from RES, identifying different user profiles (such as interested users, non-users, conscious users, and opportunistic users) or tailoring usage patterns and demand management to suit different user demographics, such as elderly residents, is important (McCabe, Pojani, & van Groenou, 2018).

6.1.2 Financial Barriers

Financial barriers are considered a high priority in most EU countries towards facilitating deep renovation (Economidou et al., 2011; Staniaszek et al., 2013). One of the most acknowledged financial barriers is the high investment cost. Deep renovations involve significant investments in upgrading building systems, improving insulation, and replacing outdated equipment. The initial cost of these renovations can be substantial, making it difficult for homeowners or building owners to finance renovation projects, especially for low-income households or younger homeowners, who often face financial constraints (Artola et al., 2016; Bjørneboe et al., 2018; D'Oca et al., 2018; Economidou et al., 2011; European Union, 2021; Fotiou et al., 2022; Haase et al., 2020; Palm & Reindl, 2018; Van Opstal & Smeets, 2022). The problem is exacerbated by competing purchase decisions, e.g., in electronic gadgets, kitchens, etc., which are perceived to yield higher social benefits (Economidou et al., 2011).

The high upfront costs are also related to a second commonly mentioned barrier namely the long payback periods. Despite energy savings measures being financially rational with positive net present value (NPV) or high internal rate of return (IRR), they often have long payback periods. Property owners may hesitate to invest in renovations that take several years to recoup the initial costs, especially if they plan to sell the property in the near future (Artola et al., 2016; Bjørneboe et al., 2018; D'Oca et al., 2018; Economidou et al., 2011; Fotiou et al., 2022; Haase et al., 2020; McCabe, Pojani, & van Groenou, 2018). Moreover, the longer the payback period the higher the perceived risk due to the uncertainty for future conditions (e.g., energy prices) (Bagaini et al., 2020; Bjørneboe et al., 2018). There also concerns about the technology not working as intended, and buildings not meeting new regulations. The perceived risks are also associated with using unfamiliar or untested technology (Carlander & Thollander, 2023).

Obtaining financing for deep renovations can also be challenging, especially for individual homeowners or small-scale property owners (Bagaini et al., 2020). Traditional lenders, e.g. commercial banks, may be reluctant to provide loans for renovation projects, particularly if the borrower has limited collateral or a less-than-perfect credit history and also because deep renovations are perceived as high-risk investments (Mainali et al., 2021). Thus, limited access to finance is a common obstacle for individuals, social housing providers, and even businesses operating in this sector (Artola et al., 2016; Bjørneboe et al., 2018; European Union, 2021; Fotiou et al., 2022; Haase et al., 2020; Mainali et al., 2021; McCabe, Pojani, & van Groenou, 2018; Tuominen et al., 2012). For instance, limited financing options for energy service companies (ESCOs) creates challenges that hinder the development of the renovation market, particularly for ESCOs (Laffont-Eloire et al., 2019). The recent financial crisis and its impact on lending markets have also affected the willingness to take risks (Economidou et al., 2011). Also, in many cases households are discouraged due to inability to secure finance on acceptable terms (D'Oca et al., 2018). As a result, they are reluctant to take out loans for housing renovation (Streimikiene & Balezentis, 2020).

Subsidies are necessary to overcome the upfront cost barrier of energy renovation and, thus, they act as financial motivator for energy renovation (Mainali et al., 2021; Mata et al., 2021; Palm & Reindl, 2018). However, the availability of such incentives varies between countries, and, in some cases, they are reduced by policy-makers (Haase et al., 2020; Mainali et al., 2021). Reduction of grants is usually replaced by promotion of financial support combining public and private resources (D'Oca et al., 2018) or reduced taxes (Palm & Reindl, 2018). However, it should be noted that in all subsidy schemes there is a risk of a free-rider effect, i.e., individuals receive subsidies for improvements they would have implemented regardless. Therefore, subsidy programs should be designed and implemented carefully to maximize their effectiveness (Bjørneboe et al., 2018).

The potential cost savings associated with energy renovation can be a significant motivator, since homeowners can benefit financially in the long run by reducing their running costs (Bjørneboe et al., 2018). Price signals play a role in financial barriers as well. If the financial incentive for investing in energy savings measures were more significant, there would be a higher propensity for households to undertake such investments (Artola et al., 2016; Economidou et al., 2011; EMBuild, 2017). This is, at least partially, attributed to energy pricing structures that do not fully reflect the negative externalities (both environmental and social), including those associated with climate change, and leads to a lack of motivation for consumers to take action (Economidou et al., 2011; Tuominen et al., 2012).

Energy-efficient renovations have been shown to increase the overall value of a property (Bjørneboe et al., 2018). In the case of rented properties, however, it is argued that there is lack of consideration for lifecycle costs in rental properties and difficulty in demonstrating increased asset value due to energy performance improvements (Palm & Reindl, 2018). Also, in some cases energy efficiency improvements do not raise the rent and this stands especially for some countries, such as the Czech Republic, due to a price ceiling in rents (Tuominen et al., 2012).

Finally, the main barriers to RES installations include, besides the high upfront investment, diseconomies of scale (Van Opstal & Smeets, 2022) and lack of ongoing capacity to maintain renewable energy projects (McCabe, Pojani, & van Groenou, 2018). On the other hand, however, it is mentioned that photovoltaic systems are often more attractive compared to energy efficiency measures because they are more heavily subsidised (Economidou et al., 2011).

6.1.3 Knowledge/Informative Barriers

Knowledge and informative barriers hinder the widespread adoption of retrofit measures (Fotiou et al., 2022). A primary barrier to energy retrofits in residential buildings is the lack of awareness and understanding. Energy efficiency measures, such as insulation, efficient heating and cooling systems, and energy-saving appliances, can significantly reduce utility bills and enhance comfort levels. However, without knowledge of these benefits, homeowners may fail to prioritise retrofitting their properties. Many individuals are simply unaware of the potential benefits and cost-saving opportunities associated with retrofitting their homes (Artola et al., 2016; D'Oca et al., 2018; European Union, 2021; Haase et al., 2020; Palm & Reindl, 2018; Tuominen et al., 2012).

Moreover, the technical complexity and terminology used in the energy retrofit field often overwhelm homeowners, making it difficult for them to grasp the concepts and make informed decisions. The technical jargon associated with energy audits, building envelope improvements, and energy performance ratings can be confusing and alienating to individuals without a background in the field (Artola et al., 2016). For example, a study in Lithuania showed that a significant majority (90%) of respondents in a survey did not know the energy class of their houses (Streimikiene & Balezentis, 2020). As a result, homeowners may feel intimidated and unsure about the best retrofit options for their specific needs.

Another significant barrier hindering energy retrofits is the limited access to comprehensive information and resources (European Union, 2021; Tuominen et al., 2012). Homeowners often struggle to find reliable sources of information regarding available retrofit options, their costs, and potential energy savings. The absence of accessible, user-friendly tools and databases makes it challenging for individuals to assess the feasibility and effectiveness of retrofit measures for their specific dwellings (Carlander & Thollander, 2023). In addition to limited access, the quality and credibility of available information can also be a concern. Homeowners may encounter conflicting advice or outdated guidelines, leading to confusion and mistrust (D'Oca et al., 2018; Haase et al., 2020). Contractors may also find it difficult to calculate costs for new technologies, leading to high quotations or reluctance to provide a quotation at all (Carlander & Thollander, 2023). Clear, accurate, and impartial information from trusted sources is essential to empower homeowners to make informed decisions about energy retrofits. In this direction, building professionals and advisors need to be trained to provide accurate information, and independent resources should be made available to empower homeowners to make informed decisions (Haase et al., 2020).

Furthermore, there is a lack of easily accessible and up-to-date information on local, regional, and national energy efficiency programs, incentives, and financing options. Homeowners may be unaware of government initiatives, tax credits, grants, or rebates that can significantly reduce the financial burden of retrofitting (European Union, 2021). The absence of centralized platforms or easily navigable websites compounds this challenge. Community energy groups, key contact organisations that provides information and initiatives like one-stop-shops can act as visible contacts within the community, offering support and information, and are crucial for successful implementation of deep renovation projects (Laffont-Eloire et al., 2019; McCabe, Pojani, & Broese van Groenou, 2018).

Lack of awareness about energy consumption, cost, and savings potential poses a significant hurdle to energy-efficient renovation. Additionally, the complexity of estimating energy savings and payback periods further contributes to the financial uncertainty. Many homeowners perceive retrofits as expensive investments and are uncertain about the potential returns on their investments because they are unaware of the amount of energy their homes consume, the associated costs, and the potential savings achievable through renovation. This lack of awareness, coupled with the upfront costs associated with retrofitting, the lack of clear financial incentives and financing options, can lead to a perception that energy renovation is irrelevant or unimportant and deters individuals from pursuing retrofit projects (Mainali et al., 2021). Furthermore, the significance of thermal comfort and indoor climate in motivating homeowners to undertake energy renovations should not be underestimated. Studies have shown that emphasizing the benefits of improved comfort and overall well-being resulting from renovations can be a persuasive factor for homeowners. Similarly, highlighting the environmental impact and the concept of future-proofing buildings can also serve as strong motivators for energy improvements (Artola et al., 2016; European Union, 2021; Mainali et al., 2021).

6.1.4 Organisational and Decision-Making Barriers

One of the primary organisational and decision-making barriers to energy retrofits is the complexity of decision-making processes. Retrofit projects involve multiple stakeholders, including homeowners, building owners, contractors, architects, and energy consultants. Coordinating these various parties, aligning interests, and making collective decisions can be challenging and time-consuming. The involvement of multiple decision-makers can lead to conflicting priorities, lack of consensus, and delays in project implementation (Tuominen et al., 2012).

Complex ownership structures, such as multi-tenant buildings or condominiums, involve multiple stakeholders, including owners, tenants, property managers, and other relevant parties and pose significant challenges in decision-making and coordination for retrofit projects, especially in innovative applications (McCabe, Pojani, & Broese van Groenou, 2018). In such cases, multiple owners or tenants may have different interests, priorities, and responsibilities, making it difficult to reach consensus on implementing retrofits (Artola et al., 2016). For example, there are unequal abilities among owners to pay for renovations, and certain groups, such as pensioners, show no interest in investing (Economidou et al., 2011). Furthermore, uneven distribution of costs and benefits among social housing tenants can lead to disengagement and distrust (McCabe, Pojani, & Broese van Groenou, 2018). This process can be complex and time-consuming, as it requires coordination and consensus-building among these stakeholders. Disagreements, lack of knowledge about energy renovations, and conflicting priorities can impede decision-making, leading to delays or the abandonment of energy renovation projects. The absence of housing associations is also a barrier (Streimikiene & Balezentis, 2020). The decision-making process becomes more complex as it involves negotiations, legal considerations, and collective agreements among various stakeholders. Additionally, the lack of clear ownership boundaries and responsibility allocation may result in a lack of accountability for energy retrofit initiatives (Economidou et al., 2011). For instance, in collective housing, the complexity of decision-making processes and legal regulations pose challenges for solar PV investments. The association of co-owners, which makes investment decisions, needs to consider various factors such as ownership rights, cost division, billing methods, energy sharing, and contractual uncertainties (Van Opstal & Smeets, 2022). Finally, another problem may be the lack of information sharing that hinders collective decision-making (EMBuild, 2017).

The lack of engagement and collaboration between different stakeholders involved in the retrofit process is a significant barrier. Coordinating communication among these stakeholders can be challenging, leading to delays, misalignment of expectations, and increased project costs. Inefficient communication channels, a lack of standardized processes, and insufficient collaboration platforms hinder effective coordination and decision-making, project planning, and implementation. Also, insufficient engagement and involvement of occupants or tenants in the retrofit process may result in resistance to changes or lack of support. This problem is exacerbated by the limited capacity of stakeholders, including building owners, homeowner associations, or property management companies to identify, plan, and execute retrofit initiatives effectively. A special case of lack of collaboration is split incentives which occur in rental properties due to misalignment of incentives. Landlords who are responsible for investing in energy renovations may be hesitant to invest if the tenants directly benefit from the energy savings by paying lower utility bills. For example, in private rental housing, private landlords have less leverage to invest in solar PV compared to social housing associations (McCabe, Pojani, & Broese van Groenou, 2018; Van Opstal & Smeets, 2022). Community energy initiatives can mitigate split-incentives by ensuring more equitable cost distribution and providing additional organizational support (McCabe, Pojani, & Broese van Groenou, 2018). Split incentives may also appear between contractors and homeowners. Contractors may try to lock homeowners into using their components exclusively, while clients have conflicting priorities regarding operating costs and construction expenses (Carlander & Thollander, 2023).

Organisational and decision-making barriers can also occur on the supply side. For instance, small and medium-sized enterprises (SMEs) in the construction industry may face barriers in participating in public procurement schemes for energy renovation projects. These schemes often have complex application processes, stringent requirements, and financial constraints that SMEs may struggle to meet (Laffont-Eloire et al., 2019). Furthermore, the fragmentation of the supply chain in the construction industry can pose challenges for energy renovation projects (Artola et al., 2016). The involvement of multiple contractors, suppliers, and subcontractors can lead to coordination issues, information gaps, and difficulties in ensuring the quality and timeliness of work (Palm & Reindl, 2018). Lack of standardized processes, communication breakdowns, and subcontractor selection can further complicate the renovation process and hinder decision-making (Palm & Reindl, 2018).

6.1.5 Regulatory Barriers

Regulatory and institutional barriers hinder energy retrofits. The considerable variety of rules and regulations pertaining to energy retrofits adds complexity and creates barriers. The multitude of regulations at EU, national, and local levels can be overwhelming for homeowners, building owners, and retrofit professionals (Artola et al., 2016; European Union, 2021). Navigating through the legal framework, understanding compliance requirements, and ensuring adherence to multiple regulations increase transaction costs and hinder the retrofit process. For example, inconsistencies, delays and gaps in energy performance targets, efficiency standards, and retrofit obligations can lead to disparities in retrofit activities and hinder harmonization efforts across regions (Economidou et al., 2011). Nevertheless, failing to consider the diversity of contexts across the EU and national levels is also a problem. The one-size-fits-all approach overlooks variations in climate, building stock, socioeconomic conditions, and energy consumption patterns. Energy retrofit policies and regulations need to be tailored to address the specific challenges and opportunities within each context. The same issue appears at national level. Unclear, unambitious, and maladapted national strategies pose obstacles to local and regional authorities (European Union, 2021). National strategies that lack clarity and ambition do not provide clear guidance for local decision-makers, hindering their ability to develop and implement effective retrofit policies. Moreover, strategies that do not align with local needs, priorities, and capacities can impede progress in energy retrofits (European Union, 2021). There is a need for national strategies that are well-defined, ambitious, and flexible enough to accommodate regional variations and local circumstances.

The lack of common approaches regarding definitions and methods is another regulatory barrier to energy retrofits (Artola et al., 2016). Varying definitions and methodologies for energy performance assessment, energy efficiency targets, and retrofit standards across different jurisdictions create confusion and complicate decision-making (European Union, 2021). For example, different interpretations of what constitutes a renovation (especially a deep one) can lead to inconsistent application of regulations, varying eligibility for incentives, and confusion among stakeholders. The absence of harmonised approaches undermines comparability, inhibits knowledge sharing, and limits the scalability of successful retrofit practices. For instance, slow adoption of European standards for building energy efficiency and the absence of common software for energy efficiency calculations further compound the issue (Economidou et al., 2011). Overlaps between laws, political obstruction, conflicting guidelines in governance structures, delays in adopting policy schemes and the lack of legislation concerning specific issues, e.g., the split incentives between tenants and owners, are also barriers reported under this category (Bagaini et al., 2020; EMBuild, 2017).

Frequent changes in regulations introduce uncertainty and can impede energy retrofits. The lack of stability and continuity in regulatory frameworks can discourage investments, create confusion among stakeholders, and hinder long-term planning for energy renovation projects (Tuominen et al., 2012; Van Opstal & Smeets, 2022). Changing regulations, shifting policy priorities, and the absence of stable frameworks can even disrupt ongoing retrofit projects. Furthermore, the lack of coherence between regulations related to competition, state support, and banking creates barriers to financing energy retrofits. Inconsistent regulations and conflicting requirements across these domains may discourage financial institutions from providing loans or other forms of financing for energy retrofit projects.

Insufficient or lax regulation, weak monitoring and enforcement of energy performance standards, building codes, and retrofit regulations can result in low-quality retrofits, inadequate energy savings, and increased risks for consumers (Tuominen et al., 2012). On the other hand, the rigidity of rules related to energy performance contracting, and other administrative aspects may also act as a regulatory barrier. Stringent rules and inflexible procedures may impede the involvement of qualified contractors, hinder innovation, and limit the potential for cost-effective retrofit solutions. Moreover, a complex administrative process leads to high transaction costs. Excessive paperwork, lengthy approval procedures, and bureaucratic hurdles add to the financial burden of implementing energy retrofits.

Inconsistent standards, unclear labelling requirements, and varying implementation practices make it difficult for homeowners, tenants, and potential buyers to assess the energy performance of buildings accurately (Mainali et al., 2021; Tuominen et al., 2012). Inadequate visibility and limited public awareness of labelling schemes may also hinder the market recognition and appreciation of energy-efficient buildings (Tuominen et al., 2012).

A final regulatory barrier, which is inevitably linked to financial barriers, is insufficient government subsidies and programs (McCabe, Pojani, & van Groenou, 2018; Tuominen et al., 2012). For instance, housing tax policies in Sweden and Denmark favour new constructions over renovating existing buildings, creating a barrier to deep renovation (Mainali et al., 2021). Inadequate financial support limits the affordability and attractiveness of retrofit projects, particularly for low-income households or building owners with limited financial resources and may fail to motivate homeowners or building owners to invest in energy retrofits. For example, a survey in Lithuania revealed that over 80% of respondents believed that government support did not provide adequate incentives for renovating their houses and, thus, existing support measures were seen as insufficient to drive energy renovation initiatives (Streimikiene & Balezentis, 2020).

6.1.6 Technical Barriers

Key technical barriers, including insufficient technical capacity and knowledge, limited examples of deep renovation projects, lack of standardised solutions, technological shortcomings, and compatibility issues hinder the implementation of deep renovations.

Skilled professionals, such as energy auditors, architects, engineers, and specialized contractors, are essential for executing complex retrofit projects. However, the lack of a trained workforce with expertise in energy-efficient technologies and deep renovation techniques limits the capacity to implement deep energy retrofits at scale (Artola et al., 2016; Economidou et al., 2011; Mainali et al., 2021). The shortage of skilled workers is another technical barrier to deep energy renovations (D'Oca et al., 2018; Haase et al., 2020). This problem is due, to a certain extent, to the scarcity of examples of successful deep renovation projects. Many renovation projects focus on shallow improvements, such as replacing windows or adding insulation, rather than comprehensive deep retrofits. The lack of demonstration projects showcasing the benefits, feasibility, and cost-effectiveness of deep energy renovations inhibits confidence among stakeholders (McCabe, Pojani,

& Broese van Groenou, 2018). For instance, existing energy service companies are not equipped to handle deep renovations due to the complex process, small project size, and multi-stakeholder involvement, which discourages their interest (Economidou et al., 2011).

The absence of consistent and standardised solutions is also a significant technical barrier to deep energy renovations (D'Oca et al., 2018; Haase et al., 2020). Compliance with varying building standards and energy-saving requirements across different jurisdictions creates challenges in selecting and implementing appropriate retrofit measures. The lack of standardised methodologies and assessment tools for evaluating the performance and impact of retrofit strategies hinders decision-making and quality assurance (Haase et al., 2020). The absence of standardised processes and quality assurance measures may undermine confidence in the construction industry. As a result, homeowners may have concerns about the effectiveness and reliability of retrofit measures, as well as scepticism about the claims made by retrofit service providers (Economidou et al., 2011). Performance gaps, concerns regarding maintenance, and uncertainty about the long-term performance of retrofitted buildings also pose barriers (European Union, 2021; Mata et al., 2021). For example, there can be discrepancies between predicted energy savings and actual performance (due to factors such as occupant behaviour, maintenance practices, and system interactions), concerns about the durability of retrofit measures, and uncertainty about future energy prices and regulatory changes (Palm & Reindl, 2018).

Furthermore, the complexity and uncertainty surrounding retrofit technologies and their compatibility with existing building systems present technical barriers. Retrofitting existing buildings involves integrating new solutions with the existing infrastructure, which can be challenging due to compatibility issues, and uncertainty about the performance and long-term benefits of new systems (Mata et al., 2021). However, some energy-efficient approaches are not readily available or may have uncertainties regarding their performance (Artola et al., 2016). For example, retrofitting may require integrating new energy-efficient systems and technologies with older equipment, which may not be designed for compatibility. The need for equipment upgrades or replacements adds complexity and cost to retrofit projects. In addition, the availability of energy-efficient building materials, components, and systems that meet specific retrofit requirements and are compatible with existing infrastructure can be limited. Conducting comprehensive building assessments about the existing building envelope, heating, ventilation, and air conditioning (HVAC) systems, and energy consumption patterns can provide critical information for the effective and efficient design and implementation of deep energy renovation projects (e.g. to avoid oversizing of HVAC systems) (EMBuild, 2017; Palm & Reindl, 2018).

Finally, safety and seismic risks associated with deep renovation processes are technical barriers that need to be addressed (D'Oca et al., 2018). Intensive retrofit activities, such as structural changes, may introduce safety concerns and seismic vulnerabilities if not properly considered and implemented (Haase et al., 2020).

6.1.7 Barriers to Deep Renovation in the Four REVERTER Pilots

All four pilot areas show, to a greater or lesser extent, the challenges mentioned in the previous sections. In the following, some critical aspects of these challenges are discussed, based on literature and the experience of local partners.

A. Brezovo, Bulgaria

The main barriers to deep renovation in the Bulgarian pilot are, as follows (EMBuild, 2017; Ministry of Regional Development, Public Works & JSC - Bulgarian-Austrian Consulting Company, 2020; Turcu & Persson, 2015):

- Regulatory barriers: the current framework does not encourage deep renovation, as there are no requirements or incentives to renovate public buildings to levels higher than class B. The complex administrative process and the need for unanimous agreement among owners in multi-unit buildings hinder deep renovation efforts. Furthermore, there is a lack of restrictions on the use of non-environmental solid fuels. Finally, shortfalls include the absence of Energy Performance Certificates (EPCs) for residential buildings smaller than 1,000 m^2.
- Financial barriers: the reliance on grants provided by the National Programme for Energy Efficiency in Multifamily Residential Buildings blocks other forms of financing because homeowners are unable to finance energy-efficiency renovations themselves. Municipalities often limit renovation projects to shallow measures due to cost concerns. Additionally, low energy prices and the high transaction costs associated with the complex administrative process further impede deep renovation.
- Knowledge/informative barriers: there is a lack of awareness among customers and investors about the benefits of deep renovation. Municipalities, which manage the program, lack motivation to design and implement new renovation programs and often limit renovation projects to shallow measures due to a lack of understanding of the wider benefits.
- Technical barriers: incomplete inventories of public buildings, limited information on energy consumption and efficiency measures, and the absence of detailed renovation plans create significant challenges. R&D efforts in deep renovation are fragmented and not part of a holistic local or national plan. Technical capacity and knowledge for deep renovation are also insufficient in many municipalities, there is a lack of specialized intermediaries to provide expert assistance and a lack of necessary skills of professionals to adequately promote energy efficiency products.
- Organisational and decision-making: there is a lack of reliable mechanisms for effective control of compliance with the law and unprofessional and insufficient management of multi-family buildings. Also, challenges are created due to the presence of unoccupied apartments in multi-family residential buildings.

B. Athens metropolitan area, Greece

As far as the Greek pilot is concerned, the main barriers identified are the following (Fotiou et al., 2022; Greek Ministry of Environment & Energy, 2018):

- Financial barriers: the economic benefits derived from energy-efficiency renovations are often undervalued over time, making the returns uncertain compared to other investments. Given Greece's economic crisis and increased country risk, the uncertainty and risk associated with long-term investments are more pronounced. The reduction in bank loans, traditionally a primary funding source for building renovations, has further impacted investment in this sector. Additionally, the decrease in income and changes in consumption habits due to the recession have made energy-efficiency renovations a lower priority for many. This is particularly true for the most vulnerable households. The existing subsidy scheme offers a 75% grant for personal income up to 5,000 Euros per year and family income up to 10,000 Euros per year. Given their very low income, most of the time these households do not have access to loans from commercial banks.

- Regulatory barriers: Greece lacks an established national standard for accurately measuring the actual energy consumption of buildings. The existing calculation method, based on the asset method rather than the operational method, is insufficient for recording actual consumption. Establishing a reliable standard for energy and water savings measurement is crucial. Internationally recognized protocols have been developed for this purpose.
- Technical barriers: the market for energy-efficiency renovations is still in its early stages and faces common challenges associated with new markets. Technical restrictions, such as architectural and infrastructure access issues, common heating systems, and outdated regulations in apartment blocks, complicate the decision-making process. Inadequate renovation service supply chains, a lack of energy labelling and certification schemes for construction materials, and insufficient technical support further hinder progress. Additionally, the absence of meters or direct mechanisms to showcase energy savings from renovations poses a problem.
- Knowledge/informative barriers: there is a shortage of skills and training among professionals responsible for implementing energy-efficiency renovation works. Insufficient knowledge of energy-saving technologies and renewable energy sources used in renovations is prevalent. The scarcity of reliable information on deep renovation's energy efficiency delays the adoption of new techniques. The general information available is often challenging to adapt to specific investor and user circumstances, making it difficult to assess the overall benefits of energy-efficiency investments. Educational institutions need to update their curricula to include energy-saving concepts in building renovation, covering both technical and financial aspects.
- Organisational and decision-making: many vulnerable households live in homes that they do not formally own, e.g. they may belong to parents who have passed away but have not been inherited for financial reasons (inheritance taxes have not been paid). Therefore, they are not entitled to a subsidy from state programmes.
- Behavioural/social barriers: many vulnerable households, even if they have access to loan capital, prefer not to implement energy-saving projects. Given the uncertainty in their future financial situation, they find it easier to reduce their energy expenditure than to take the risk of repaying a loan.

C. Riga, Latvia

The most important barriers to deep renovations identified in the Latvian pilot are the following (Kamenders et al., 2018; Turcu & Persson, 2015):

- Regulatory barriers: subsidy and policy uncertainty (e.g., support schemes for apartment building renovation were discontinued for over 2 years between 20014 and 2016, some of the potential projects were frozen and business activities stopped overall).

- Financial barriers: low energy prices, the high-risk level of financial investment in territories with low economic activity that increases loan interest rates, ESCOs are typically small and cannot borrow to further their business (long-term commercial financing continues to be a major barrier because banks are reluctant to lend against long-term energy efficiency projects).
- Knowledge/informative barriers: lack of information about and complexity of the concept (both at the policy level and at the level of residents/owners), insufficient information dissemination and training for stakeholders.
- Technical barriers: lack of knowledge, energy advice, audits, and construction supervision on a large scale, lack of and measurement and verification practices.
- Organisational and decision-making: lack of standardised contracts.
- Behavioural/social barriers: lack of trust from the clients, reluctance to acquire debt.

D. Coimbra, Portugal

As far as the Portuguese pilot is concerned, there are several barriers to energy renovations including:

- Financial barriers: One of the main barriers is the high cost of energy renovations (higher than new construction, per square meter, which can make it difficult for homeowners and businesses to invest in energy-efficient solutions. Access to financing for energy renovations can be limited, especially for homeowners and small businesses that may not have the financial resources to undertake large-scale projects.
- Regulatory barriers: Portugal has a complex regulatory framework for energy efficiency and renewable energy, which can make it difficult for homeowners and businesses.
- Knowledge/informative barriers: Many people in Portugal are not aware of the benefits of energy renovations and the available financial incentives to support them.
- Technical barriers: There is a shortage of skilled labour in the energy renovation sector, which can make it challenging to find qualified professionals to undertake renovations. Moreover, many buildings in Portugal are old and have design constraints or are located in heritage-protected areas that make it difficult to retrofit energy-efficient solutions. Finally, there may be a limited availability of energy-efficient products and services, making it challenging for homeowners and businesses to find the right solutions for their needs.

6.2 Renovation Benefits

In addition to reducing consumption and energy bills, energy renovations offer several other benefits, such as indirect economic effects (e.g., job creation, macroeconomic effects, energy security, etc.), social benefits (e.g., health and well-being improvements, especially for vulnerable groups), and environmental benefits (e.g., less GHG emissions and harmful emissions) related to building renovations. Like in the case of barriers, the benefits can exist at various levels, e.g., individual, societal, etc., and may vary depending on the country, the type of building, the renovation measure, the building ownership status, etc. Identifying and, most importantly, quantifying and monetising these benefits, is essential to attract more private and public funds to energy retrofit actions.

The literature review identified about 20 relevant sources and from them collected about 100 mentions of renovation barriers (peer reviewed journals: 40%; policy and other reports: 27%; project outputs: 33%). The analysis of the literature sources was based on more than 30 decoding variables that included, besides the names of authors, the full citation, the year of study, the resource type, etc., the country, the scale (e.g., European, national, etc.), the general category of benefits and the specific benefits, the valuation method, the physical and monetary estimates, etc. In total, about 38% of the observations are on a European scale, 48% on a national scale and 14% on a global scale. Further, about 51% refer to macro- or meso-scale (e.g. the national economy or the society) and the rest are related to micro-scale (i.e. households). In general, the benefits refer to building quality, economic, environmental and social benefits, user well-being, e.g., air pollutants reduction, improved indoor health, increased property values, energy system & security, GHG reduction and climate change, job creation, etc. Also, some studies have monetised overall renovation benefits (i.e., they do not refer to specific benefits).

In general, the co-benefits of renovation can be categorised, as follows (Artola et al., 2016):

- Environmental benefits
  - Energy savings & GHG emissions reduction
  - Reduced usage of materials
- Economic benefits
  - Employment
  - GDP and public budgets
  - Innovation
  - Sectoral modernisation
  - Energy Security
  - Productivity benefits
- Social benefits
  - Health benefits
  - Reduction energy poverty
  - Wellbeing / Comfort benefits
  - Energy bill savings
  - Increase in property value and tenant satisfaction.

These co-benefits can be distinguished with regard to two different perspectives, private (i.e., building quality, economic and well-being) and societal (i.e., environmental, economic and social) (Ferreira et al., 2017). Ryan & Campbell (2012) suggest an alternative categorisation to individual benefits, i.e., those experienced at a personal, household and enterprise level; sector-specific benefits, which are those having important impacts for particular sectors or industries; national benefits, i.e., economy-wide benefits that affect a variety of sectors and markets; and international benefits, which have an impact beyond national borders (e.g., reduced GHG emissions). As (Ryan & Campbell, 2012) note, these benefits can be observed simultaneously on different levels. Therefore, great care is needed to avoid double-counting when conducting cost-benefit analyses for measures or programs.

The renovation benefits are discussed in more detail below following the general categorization, i.e., environmental, economic, and social.

6.2.1 Environmental Benefits

By decreasing the demand for electricity and heating fuels, building energy renovations contribute to reducing the emission of CO_2 and other greenhouse gases and help to mitigate global warming. For instance, energy efficiency measures are expected to contribute 44% of the carbon abatement needed by 2035 (Ryan & Campbell, 2012), and deep renovation, in particular, can lead to a 75% reduction in final energy consumption by 2050, compared to 2010 (Artola et al., 2016). According to COMBI online tool, residential building renovations could help avoid 0.264, 0.207, 0.005 and 0.107 TWh/yr (in 2030) in Greece, Bulgaria, Latvia and Portugal, respectively, of electricity generation from combustibles-based power plants in 2030 (COMBI project, 2018). The avoided electricity generation results in less direct GHG emissions, which are estimated at 0.720, 0.205, 0.109 and 0.033 Mt CO2eq in Greece, Bulgaria, Latvia and Portugal, respectively (COMBI project, 2018). Further, compared with other climate mitigation measures, energy efficiency is generally more cost effective and can be implemented quickly (Ryan & Campbell, 2012).

Furthermore, integrating renewable energy systems and generating energy on-site can reduce society's reliance on fossil fuels. Also, building renovations by reusing and recycling materials, reducing waste generation, and choosing eco-friendly alternatives, contribute to resource conservation and minimise the environmental impact associated with construction and demolition activities or the construction of new buildings (Artola et al., 2016; Ferreira et al., 2017). Finally, deep renovations help to protect the environment and reduce emissions detrimental to air quality, and water supplies and alleviate the pressure on ecosystems (Ferreira et al., 2017; Ryan & Campbell, 2012). These environmental benefits can also translate into cost savings for society through the reduction of negative externalities associated with climate change impacts, air pollution-related healthcare expenses, and natural resource depletion (Economidou et al., 2011; Tuominen et al., 2012).

6.2.2 Economic Benefits

Deep renovations can yield various indirect economic benefits for households and the national economy. By implementing deep renovation, households can save money on their monthly energy expenses, and increase their disposable income, which can be spent on other goods and services inducing rebound effects, thereby stimulating the economy (Ferreira et al., 2017; Ryan & Campbell, 2012). Consumer choices on how to spend increased disposable income are affected by several factors, e.g., income level, personal preferences, education, availability of information, etc. (Ryan & Campbell, 2012). Also, energy efficiency improvements in buildings can ease pressure on public finances because they lower government outlays needed to finance these subsidies (Ferreira et al., 2017; Ryan & Campbell, 2012).

Another economic benefit at both individual and sectoral levels is that renovations can increase property values. Energy-efficient buildings improve energy performance, indoor comfort, and sustainability features and, thus, are often considered more desirable because they offer lower operating costs and improved quality of life (Artola et al., 2016; Ryan & Campbell, 2012).

Building energy renovations require skilled professionals and workers for design, installation, and maintenance. As a result, they can generate employment opportunities across various sectors, such as construction, manufacturing, and engineering among others, and stimulate economic growth in local communities and at the national level (Artola et al., 2016; Ryan & Campbell, 2012). Although estimates vary greatly, because job creation by renovation depends on the size and structure of financing and the type of energy savings intervention being supported an estimated net impact of about 17 to 19 jobs created for every million Euros spent on energy efficiency interventions is generally considered acceptable (Economidou et al., 2011). As mentioned by (Artola et al., 2016), other studies estimate that a 'deep renovation' scenario defined as "*a high level of energy efficiency improvement at a rate of 2.3% of the building stock, with a high focus on the efficiency of the building envelope and high use of renewable energy*" would lead to the creation of an additional 1.4 million jobs by 2050 (Ecofys, 2014). In another study, (Pikas et al., 2015) estimated economic benefits, including tax revenue, job generation, and disposable net income per 1 M€ of investment, and energy savings on both an individual and national level, in Estonia. As far as employment is concerned, the findings show that, in total, 17 jobs per 1 M€ of investment in renovation are generated, directly and indirectly, per year. Directly, on the construction site, 10 jobs are created. Additionally, 1 and 6 jobs are created in the consultancy and manufacturing industries, respectively. Besides employment, renovation creates tax revenues. In the study of (Pikas et al., 2015), tax revenue from renovation construction projects was 28% and increased to 32–33% of the total renovation project cost when tax revenues from consultancy and manufacturing activities were included.

Building renovations decrease the overall energy demand, reducing the need for imported energy resources and moderating energy consumption prices (although the impact of reduced energy demand on energy prices is not likely to be felt when the change in demand is limited to local or national level) (Ryan & Campbell, 2012). At a national level, by reducing energy imports, this can lead to decreased reliance on foreign energy sources. Consequently, energy security, balance of trade, and macroeconomic stability can be improved (Ryan & Campbell, 2012). This is particularly important for those Member States that are reliant on imported gas from one single supplier (Artola et al., 2016).

Energy renovations improve indoor air quality and thermal comfort, and, for this reason, occupants may experience fewer respiratory issues, allergies, and other health problems. As a result, renovations can have indirect economic benefits related to reduced healthcare costs and improved productivity (Artola et al., 2016; Ferreira et al., 2017; Ryan & Campbell, 2012). This can lead to lower healthcare expenses for households and a decrease in the burden on the national healthcare system and higher private benefits to individual companies. According to previous research, productivity improvements due to better air quality can reach 8-11% and it has been estimated that every euro invested in insulation, results in 0.78 euros benefits in reduced days of work missed (Artola et al., 2016).

Building renovations drive innovation and the development of new technologies and solutions, e.g., energy-efficient materials, smart building technologies, etc. (Artola et al., 2016), and foster new business opportunities such as energy service companies (ESCOs) (Ferreira et al., 2017).

Finally, the environmental benefits resulting from building renovations, can also translate into cost savings for society through the reduction of negative externalities associated with climate change impacts, air pollution-related healthcare expenses, and natural resource depletion (Economidou et al., 2011; Tuominen et al., 2012).

6.2.3 Social Benefits

Building renovations can help alleviate energy poverty by reducing energy bills, making energy services more affordable and accessible particularly for low-income households and by ensuring a basic level of comfort and well-being (Artola et al., 2016; Ferreira et al., 2017).

In the same direction, renovations can reduce mortality and morbidity rates associated with extreme temperatures and indoor air pollution by preventing, through reduced thermal stress, temperature-related illnesses and deaths during cold winter or hot summer months, especially for vulnerable populations (e.g., those suffering from high blood pressure, heart, lung and kidney disease, asthma, etc.) (Ferreira et al., 2017; Ryan & Campbell, 2012). Also, renovation reduces morbidity and mortality incidents by reducing energy production and associated air pollution from burning fossil fuels (Artola et al., 2016).

Based on the COMBI online tool (COMBI project, 2018), the asthma morbidity avoided due to indoor dampness from building renovation in 2030 compared to 2015 (expressed in disability adjusted life years - DALYs) is estimated at 82.7, 35.2, 27 and 259.6 avoided DALYs for Greece, Bulgaria, Latvia and Portugal, respectively. Furthermore, by improving indoor air quality building renovations would reduce morbidity due to indoor air pollution. For Greece, Bulgaria, Latvia and Portugal, the avoided DALYs are estimated at 577, 285, 73, and 434, respectively. As far as excess winter mortality and premature mortality due to inadequate heating and cooling is concerned, using the COMBI online tool it is estimated that building renovations could lead to a reduction in excess winter deaths per year by 121.2 cases in Greece, 209.3 cases in Bulgaria, 61.3 cases in Latvia, and 317.2 cases in Portugal (COMBI project, 2018).

Additional health benefits can be attributed to building renovations through the protection of the environment and the reduction of waste and emissions. Based on COMBI online tool results, it is estimated that the number of avoided yearly deaths due to avoided PM2.5 and reduced ozone exposure would be, as follows:

- Number of avoided yearly deaths due to avoided PM2.5 exposure – Greece: 57, Bulgaria: 12, Latvia: 6.843, Portugal: 1.873
- Number of avoided yearly deaths due to reduced ozone exposure – Greece: 1.906, Bulgaria: 1.070, Latvia: 0.152, Portugal: 0.161

Building renovations create opportunities for knowledge and skill development in energy efficiency technologies and practices related to construction, retrofitting, and maintenance. Thus, they can empower individuals with the necessary expertise to participate in the green economy. In parallel, building renovations can raise environmental awareness, encourage sustainable behaviours among peers and, thus, can contribute to a broader societal shift towards a more sustainable and greener mindset.

Finally, it is argued that building energy renovations, through job creation, improved health and wellbeing, and more affordable and accessible energy services, can promote social equity and inclusion. However, there are also concerns that renovations may reinforce existing social inequalities through gentrification and renovictions (Ramboll, 2021). There are both negative and positive implications from building renovations that should be considered by policymakers to address inequalities in energy access, ensure that positive impacts prevail, and create more equitable living conditions (BPIE, 2022).

6.2.4 Monetisation of Benefits

The literature review identified 12 recent studies (after 2015) carried out to monetise the benefits derived from building renovation. The monetary values are based on households' (either homeowners or renters) willingness to pay (WTP) for adopting energy efficiency measures or RES micro generation technologies or for renting more energy efficient dwellings. Of these studies, only one has been carried out in a country of the REVERTER pilots (i.e. Damigos et al., 2021). However, this study concerns an area with very different characteristics from those of the Athens pilot area.

In order to use the results of these studies in possible cost-benefit analyses, the so-called Value (or Benefit) Transfer method should be implemented. Thus, it is decided to make use of the monetization results of COMBI online tool (COMBI project, 2018). COMBI project quantified all impacts by EU28 member states and 21 energy efficiency improvement actions. In total, impacts cover energy savings, investment costs and 30 additional impacts, 17 of which monetisation was possible. However, to avoid double-counting, only 11 were taken into consideration for cost-benefit analyses (the quantification approaches applied in the COMBI project and main findings can be found in Thema & Rass, 2018). One of the main benefits of using COMBI's estimates is the ability that the online tool provides to express the benefits per-energy saved values, i.e., in €/kWh. In this way, the monetisation of the energy saved by renovations becomes straightforward. These unit values are summarised per pilot area in the following table (**Error! Reference source not found.**).

Table 33. Levelised net value of building renovations (€/kWh)

REVERTER pilots	Avoided asthma morbidity due to indoor dampness (€/kWh)	Avoided electricity generation from combustibles-based power plants (€/kWh)	Avoided direct GHG emissions (€/kWh)	Avoided premature mortality due to inadequate heating and cooling (€/kWh)	Avoided Morbidity due to indoor air pollution (€/kWh)	Avoided yearly deaths due to reduced ozone exposure (€/kWh)	Avoided yearly deaths due to PM2.5 exposure (€/kWh)	Avoided life expectancy loss due to PM2.5 (€/kWh)
Brezovo, Bulgaria	0.00025	0.00362	0.00486	0.00136	0.01000	0.00000	0.00004	0.00107
Athens MA, Greece	0.00113	0.00216	0.00795	0.00167	0.00938	0.00002	0.00038	0.01632
Riga, Latvia	0.00053	0.00011	0.00334	0.00122	0.00329	0.00000	0.00005	0.00223
Coimbra, Portugal	0.01222	0.00349	0.00138	0.01491	0.02683	0.00000	0.00000	0.00175

Source: (COMBI project, 2018)

7 Policies, Initiatives, and Strategies at National, Regional and Local Levels

This section presents the results of the assessment of policies, initiatives, and strategies for the alleviation of EP and the promotion of deep renovation at the national, regional and local levels. The emphasis will mostly be focused on existing and foreseen policies, National and regional initiatives, strategies, measures, good practices, etc., both at EU level and within the pilot countries, taking into account their capacity to contribute to the alleviation of EP through the extended renovation of the building sector, including best practices in usage of RES.

In this regard, new ways of financing incentives for collective purchases, organising consumers to become prosumers, grouping them in citizen renewable energy communities, facilitating self-sufficiency, etc. are needed and, thus, innovative financing mechanisms (e.g. power purchase agreements, ESCO, crowdfunding and systems for collective purchases of RES, etc.) will be analysed in terms of:

- the offered services, and
- the stakeholders and initiators of the best practices.

The aim of this analysis, based on desktop research, best practices, experiences from previous projects and communication with financial sector stakeholders, will be the identification of the best practices highlighting the most replicable aspects, which should be integrated into the foreseen roadmaps in Task 3.5.

The specific research questions identified for this task are:

- How the topics of energy poverty and energy renovation are addressed in the national legislation, strategic documents and programs?
- What are the goals, measures and action plans to tackle energy poverty at the national level?
- What schemes of financing incentives exist – at the national level, at the European level?
- What innovative financing mechanisms, initiatives and strategies exist – at the national level, at the European level?

The specific keywords and topics are:

- Innovative financing mechanisms;
- Promotion of deep renovation;
- ESCO, crowdfunding, collective purchases of Renewable Energy Sources, prosumers.

7.1 Methodology of the Analysis

In order to systemically identify and catalogue different policies and practices across European countries, an Excel tool was developed to analyse the different aspects of the policies, related to size, scale, scope, objectives, budget, etc.

The partners identified a total of 68 policies, not only from the pilot countries but also from other EU countries so that more good practices could be analysed and replicated to a greater extent of implementation in the roadmaps in T3.5. The identified policies were from the following countries: Bulgaria, Greece, Latvia, Portugal, Spain, the UK, France, Denmark, Poland, Ireland, Austria, and Italy.

The methodology for collecting data included the following information for all of the policies:

- Country
- Title
- Implementation period
- Regional Scope – European/National/Local
- Type of the policy :
- Legislative document, Strategic document, Policy document, Initiative, Financial scheme, Best practise, Regulation, Social incentives
- Topics covered:
- Energy efficiency, Deep renovation, Heating aids, Renewables, Social incentives, Regulation, Energy advising
- Brief description
- Final beneficiaries
- All households, Vulnerable households, Municipalities, NGOs, Business
- Managing body
- Volume of funding
- How energy poverty is specifically addressed in this policy
- What is the main goal of the policy
- Are there any specific actions identified to achieve this goal
- How this policy could be integrated into the REVERTER roadmaps
- Replicable aspects (how this practice could be integrated into the roadmaps and implemented at the local level) – barriers and enablers.

7.2 Analysis of the Collected Data

The policies and practices mapped, generally include an element of active involvement of households, as the data collected has to inspire the development of REVERTER roadmaps for renovation of residential buildings.

The partners identified a total of 68 interesting policies, which are distributed by country, as presented in Table 34.

Table 34: Number of policies collected by country

Country	Policies
Bulgaria	12
Greece	10
Latvia	5
Portugal	16
Spain	12
Other countries	15
Total	68

The policies collected by type, topics and beneficiaries are presented in Table 35, Table 36 and Table 37.

Table 35: Policies collected by type

Type of the policies	Policies
Best practices and initiatives	28
Financial schemes	24
Legislative documents and regulations	10
Strategic document	4
Social incentives and tax reduction schemes	16

Table 36: Policies collected by topics

Topic of the policies	Policies
Deep renovation	7
Energy efficiency	42
Heating aids	5
Incentives	7
Renewables	7

Table 37: Policies collected by type of beneficiaries

Type of the beneficiaries	Policies
All households	35
Municipalities	1
Property owners	1
Vulnerable households	27
Not specified	4

In the strategic actions taken towards the European effort to fight energy poverty among households, all EU countries have introduced various policies and tools. This document is meant to present them in a systematic and synthesized manner to analyse how they might fit into the REVERTER project framework.

Financial schemes for energy efficiency, renovation and renewables in REVERTER countries and other EU countries

One such is the National scheme to support households in the field of energy from RES in the **Republic of Bulgaria** - the implementation of the investment aims to promote the decentralized production of energy from renewable sources, stimulate the consumption of ecologically clean energy, and reduce the consumption of solid fuels in the household sector. It does so by providing financing for the purchase of solar installations for domestic hot water supply (DHW) and the purchase of photovoltaic systems up to 10 kWp, including electrical energy storage systems. The total amount of the financial scheme is BGN 80 million, where each proposal can receive up to 100% of the value of the installation, but no more than BGN 1,960 for the purchase of solar installations for DHW, and up to 70% of the value of photovoltaic systems up to 10 kWp including the electrical energy storage systems, but not more than BGN 15,000.

Additionally, in the period 2023-2027, **Bulgaria** has introduced another financial scheme in support of sustainable energy renovation of residential buildings. It is meant to improve the energy characteristics of the national building stock by applying integrated energy-efficient measures. The criteria for the proposals in order to be approved require that the buildings reach energy consumption class minimum B after applying energy-saving measures; that the measures stimulate a minimum of 30% primary energy savings, implement resource efficiency, economic expediency, decarbonization through RES, sustainable construction process, reduce energy poverty by reducing energy costs, and ultimately, improve the conditions and quality of life of the population in the country through technological renewal and modernization of the building stock.

In the REVERTER project, both these schemes will be presented in detail to the municipality of Brezovo. Information about the scheme will also be included in the training program for the OSS and the ambassadors, who will give explanations to households: on financial and technical issues.
An important aspect to discuss with the national policy makers regarding these programs is expanding the scope of eligible applicants, since at the moment, only multi-family residential buildings are eligible for financing for renovation, and single- or two-family houses predominate in the territory of the Municipality of Brezovo.

In **Greece** in 2021, The "Exoikonomo 2021" programme began, financed under the framework of the National Recovery and Resilience Plan Greece 2.0 with funding from the European Union – NextGenerationEU. The "Exoikonomo 2021" is a residential energy upgrade program, which is the successor scheme of the "Exoikonomo kat' Oikon" and "Exoikonomo-Autonomo" programs, with a total budget of €632 million. The program concerns buildings that have a building permit or other legal document, they are used as a main residence and whose owners meet specific income criteria. The design of the program takes into account the integrated approach of energy-saving interventions in the domestic building sector and aims to (a) reduce the energy needs of buildings and pollutant emissions that contribute to the worsening of the greenhouse effect, (b) achieve cost savings for citizens, improving daily living conditions and comfort as well as their safety and health when using these buildings and (c) attain a cleaner environment. The program aims to improve the energy class of households by at least 3 energy classes (over 30% of primary energy saving). The total investment of the project will contribute to energy savings of at least 213 ktoe per year and to the energy renovation of at least 105,000 homes by 2025.

Within the REVERTER project it could be replicated and planned for regular implementation in the Athens area targeted for energy-poor households.

Latvia introduced a support program for the use of renewable energy resources in households in 2022. The support program envisages the provision of support for the replacement of fossil fuel (e.g. natural gas, diesel, coal) equipment with new equipment using renewable energy resources (biomass pellet boilers, heat pumps, solar collectors) or connection to a centralized heat supply system, as well as for the production of electricity from renewable energy resources (solar panels, wind generators) for household self-consumption. The purpose of the competition is to reduce greenhouse gas emissions and improve energy efficiency in households by supporting the purchase of heat energy or electricity generation equipment for installation in residential homes to ensure the production and supply of heat energy or electricity for household needs or the establishment of household connections to the centralized heat supply system.

Also in 2022, the **Latvian** ALTUM financial institution began a program for energy efficiency of private houses, that provided state support for the renovation of a private house and improvement of energy efficiency or installation of electricity production equipment (solar panels, wind generation). The overall goal of the policy is to reduce MFB heat energy consumption and CO_2 emissions reduction to achieve national goals for energy efficiency improvement in the building sector.

The Directorate General of Energy and Geology, ADENE in **Portugal** began a financial scheme in 2023, in support of Renewable Energy Communities and collective self-consumption. The objective of this program is to finance measures that promote the production of energy from renewable sources in Collective Self-Consumption and Renewable Energy Communities. It is intended that the supported measures can lead to, on average, at least a 30% reduction in primary energy consumption in the buildings, and reinforce the capacity of self-consumption and/or RECs in the residential, central public administration and services sectors by, at least, 93 MW.

Promoting Renewable Energy Communities is one of the top priorities of local governments in Portugal. There are several companies offering innovative energy services that include the establishment of REC together with energy efficiency improvements directed to vulnerable populations.

Another financial scheme in **Portugal** is IFRRU2020 - Financial Instrument for Urban Rehabilitation and Revitalisation from 2020, focused on energy efficiency, deep renovation, and renewables. It is a financial instrument that mobilises the funds approved by the Regional Operational Programmes of Portugal 2020, with the objectives of revitalising cities, supporting the physical revitalisation of the space dedicated to disadvantaged communities and supporting energy efficiency in housing. The fund is complemented with financing from the EIB and the Council of Europe Development Bank. The IFRRU 2020 provides loans at more favourable conditions than those available on the market, for the full rehabilitation of buildings, whether for housing or other activities, including the most appropriate integrated energy efficiency solutions within the scope of that rehabilitation. "The scheme thus aims to facilitate access to funding by promoting investments in the area of urban regeneration, improving the financing conditions, appropriate to the circumstances and specificities of the projects, and diversifying the supply of financing solutions on more favourable terms than those available in the market. When focusing on disadvantaged communities, it is also important to promote physical regeneration, associated with initiatives that contribute to economic stimulation and job creation, as fundamental elements for social inclusion and the fight against poverty.

When urban regeneration operations are implemented, integrated actions that provide greater energy efficiency can be complementarily supported, either through the adoption of passive systems or through the use of more efficient equipment or energy production for self-consumption.

The Metropolitan Housing Rehabilitation Plan (PMRH) in **Spain** has a planned horizon from 2020 to 2030. The plan promotes the rehabilitation of buildings and includes the renovation of facades and roofs, with the addition of insulation, the construction of new elevators and the updating of community facilities. With a budget of EUR 600’000’000, it takes into account instruments from various administrations, considering three types of financial aid for communities of owners:

1. Subsidy of 100% of the cost of the technical inspection and the energy efficiency and accessibility project (if applicable) with resources from the Metropolitan Consortium and the European ELENA program.
2. Subsidy of 35% of the cost of the energy efficiency work, with resources managed by the Catalan Energy Institute.
3. Financing of the amount of the work not subsidized, with soft credits of up to 15 years to the communities, through the Catalan Institute of Finance and the Housing Agency of Catalonia, the Official Crediting Bank. The Plan also provides for simplifying the administrative procedures to be able to carry out the works and obtain permits more quickly."

This works as a good roadmap example. The Housing Consortium of the Metropolitan Area of Barcelona has established a guide document specifying support tools, aids, etc. by area in order to develop a methodology to study and implement the plan. Additionally, KPIs and municipality analysis are included and can be used as examples in the activities set in the REVERTER project.

The Bank Gospodarstwa Krajowego in **Poland** planned for the period 2021-2030 the introduction of a Thermo-modernisation and Renovation Fund. The fund was established in place of the Thermo-modernisation Fund. The legal basis of the Fund is the Act of 21 November 2008 on supporting thermo-modernisation and renovation. The aim of the Fund is to provide financial aid to investors carrying out thermo-modernisation and renovation projects and to pay compensation to owners of residential buildings in which accommodation was provided. "Under this scheme, the applicants can get a grant for attic and wall insulations, heating controls upgrade, solar thermal solutions, solar PV panels, heat pump systems, and a Building Energy Rating (BER) after the energy-saving work is carried out. Essentially, this scheme provides grants to help upgrade the energy efficiency of a home to a BER rating of B2 or above.

The detailed description of the structure of the fund and the specific measures is very valuable for countries that have not developed funds for the building sector. In Central and Eastern Europe, the availability of funds is limited, as well as their size. Countries can use this example to compare the share of the population in energy poverty with target emissions and energy savings in the residential sector as a share of total savings.

Ireland has introduced many financial schemes, one of which is “Reduce Your Use” – the national campaign aiming to promote and encourage energy efficiency and highlight the range of supports that are available to households and businesses. The initial phase of the public information campaign began its run in May 2022, with ads running in print, on radio, and across social media. highlights how war and conflicts are affecting energy costs across Europe and how we need to be mindful of how we use energy in our daily lives. Energy efficiency advice within the campaign is provided by experts at the Sustainable Energy Authority of Ireland (SEAI). It is practical and evidenced-based, detailing what actions can help to save the most money and energy in four key areas:

- heating: Use of timers and thermostats to heat the home and hot water when needed and only to the temperature needed;
- appliances: Use of cookers, tumble dryers, washing machines, showers and kettles efficiently and where possible outside peak hours of 4-7 pm;
- travel: Avoiding the use of cars for short journeys; instead opt for walking, cycling or using public transport where available;
- driving: Driving at lower speeds, where safe and practical, to reduce fuel use.

The approach and organisation of the "Reduce Your Use" support is a good example of how to advise citizens to optimize their energy use and could be presented in the pilot OSSs as one of their consultation services.

The **Austrian** government, in 2022 introduced a national social incentive in the form of a financial scheme. Against the background of the current changes in the energy market, namely the massive increases in electricity and gas prices, the state of Lower Austria passed the Lower Austrian Electricity Price Discount Act (NÖ SPRG) in a state parliament session. On the basis of this law, depending on their size, households in Lower Austria are to be granted a corresponding relief amount as inflationary compensation for the increased cost of living and energy. With the blue and yellow electricity price discount, they relieve Lower Austria's households with around 250 million euros - they get between 169.58 euros (1-person household) and 457.07 euros (5-person households) - for each additional person, we help with 41.27 euros.

The **UK** has a similar scheme - Cold Weather Payment - The programme, implemented by the Department for Work and Pensions, provides financial assistance to certain households to cover their energy bills during cold weather in the winter period (November 1 - March 31). Cold weather is defined as a period when the average temperature has been recorded as, or is forecast to be, 0 degrees Celsius or below over seven consecutive days. The programme made 131,000 payments in the winter of 2016-2017, totalling an expenditure of £ 3.3 million in expenditures. Applicants can get Cold Weather Payments if they're getting pension credit, income support, income-based Jobseeker's Allowance, income-related Employment and Support Allowance, Universal Credit or support for Mortgage Interest.

Best practices and initiatives for energy efficiency, renovation and renewables in REVERTER countries and other EU countries

Regarding the best practices and initiatives, several have been identified from different countries – In **Bulgaria** for example, between 2016 and 2018, three energy efficiency campaigns were introduced, as practices that delivered sophisticated knowledge and a set of energy-saving devices to vulnerable households. In the course of the project, the team trained students from a local high school in order to build better energy skills among them and turn them into energy advisors of low-income households. All 3 campaigns improved knowledge and influenced more sustainable energy behaviour of the participating households. This resulted in decreased energy bills for households.

This example of social engagement is in some ways similar to activities within the REVERTER project and could be replicated and planned for regular implementation in the pilot municipalities. The developed training materials could be reviewed and used as good example for the REVERTER training programme.

More recently, in 2022 the capital's municipality (Sofia) performed a campaign for free replacement of wood and coal-based combustion plants with new fully automated and highly efficient installations based on pellet boilers and domestic heaters, and air-to-air heat pumps.

The goal was to replace old inefficient heating sources, that during the winter drastically contributed for the low air quality in densely populated areas such as cities.

This policy is implemented under the National programme for air quality improvement, but is applied only to large regional cities, which excludes small settlements. This is an important aspect to discuss with the authorities and a proposal to include small municipalities in the air quality improvement program, which mainly affects vulnerable consumers which use solid fuels for heating.

Closely to Bulgaria, another example of an energy initiative comes from **Greece**, where the Ministry of Environment and Energy introduced a policy measure with a 2021-2030 horizon that includes the design and implementation of targeted and innovative information and education actions at a central level. It targets households affected by energy poverty and professionals who will be involved in the implementation of the various technical measures. In the short term, the initiative aims to alleviate energy poverty and implement targeted information and training actions for affected households and professionals.

This practice can be of use in the defining of energy-poor households within the project and in the conduction of awareness-raising campaigns and training activities.

In 2020 **Spain** began an initiative, focused on the deep renovation of vulnerable households – the innovative project identifies energy vulnerability, through an intelligent tool for advanced analysis. In addition, based on a cross-sectional public service, unique in Europe, the initiative provides customized solutions adapted to the needs of citizens, improving their quality of life and thermal comfort, with emphasis on sustainability. The main goal of this initiative is to improve the living conditions of the citizens living in the most degraded areas of Madrid neighbourhoods and fight Hidden Energy Poverty (HEP) with a pilot project in its two most vulnerable areas: Las Margaritas and La Alhóndiga. The innovation of this initiative lies in understanding EP beyond monetary poverty.

The Spanish practice is an excellent example to inspire REVERTER activities. A representative from Getafe can be invited to further share practices, experiences and knowledge in order to support synergy between the practices.

In **Portugal**, the Energy Services Regulatory Authority (ERSE) has developed a competitive mechanism for promoting efficiency in electricity consumption called PPEC (Demand-side Electricity Efficiency Plan). In this plan, energy efficiency measures, promoted by suppliers, network operators, consumers energy agencies, etc, are evaluated and ranked by merit order, defined by a cost-benefit analysis. The end goal is to raise awareness, identify problems and solutions, and provide help without financing any equipment or renovation work. It brought together a multifaceted team of experts to develop an inclusive and comprehensive approach to tackling energy poverty, starting with the identification and mapping of hotspot regions for energy poverty vulnerability, followed by direct and in-person engagement with vulnerable consumers in selected regions to understand their situation and what can be done to improve it, and then conducting local actions in vulnerable homes for increasing their awareness and support them through energy efficiency strategies.

The implementation of the PPEC program provides good examples of promoting energy efficiency technologies and financial solutions to vulnerable consumers, namely regarding the achieved impact with different technologies and the strategies used to promote it.

In November 2017, the **UK** introduced another initiative more focused on a personal approach – the Energy café – a local community initiative providing energy advice and advocacy in a welcoming setting. People who attend them can receive tailored advice, information and support on a range of issues, including how to effectively engage in the energy market to reduce energy bills, how to deal with fuel debt, and how to reduce energy consumption and costs by cutting unnecessary energy use and loss from their properties. Energy cafés are physical spaces where people can get face-to-face energy advice - filling a gap that was created by the disappearance of such advice centres and the high-street presence of energy suppliers. These cafés have been located in a variety of places, including town centre shops, community cafés, city farms, food banks and village greens.

There is a potential for energy cafés to act as a patronage service – referring clients to a home visit service when vulnerable people present issues that cannot be resolved effectively through advice alone. The energy café can also be included in other local services of the local authorities and pilot OSSs.

Regulations and legislative documents in terms of EE, RES, energy poverty and vulnerable households

In **Greece** for example, a policy measure (M3) was introduced foreseeing the continuation of the following regulatory measures already in force, as well as their possible reinforcement in order to more effectively protect the affected households from the phenomenon of energy poverty. These measures include firstly the automatic transfer of vulnerable residential customers to the Universal Service regime in the event of delays in the repayment of energy bills provided that they meet the criteria for being defined as affected households. Secondly, the determination of a threshold of minimum consumption of energy products on an annual basis, below which the disconnection of the affected households is prohibited. The facilitation of repayment and adoption of a more flexible and favourable settlement framework for overdue debts of affected households in specific cases. And lastly, the limitation of the consumption of energy products with delays in the repayment of energy bills through smart meters.

In **Bulgaria**, the government introduced some post-COVID measure in the Law on Amendments and Additions to the Law on the State Budget of the Republic of Bulgaria in 2022 (supplementing the Law on the State Budget of the Republic of Bulgaria for 2022): DECREE No. 170:

- An exemption from excise duty (0% rate) on qualifying electricity (generally from renewable sources), liquefied petroleum gas, and natural gas until 30 June 2025);
- The introduction of a reduced VAT rate of 9% on central heating and natural gas supplies for one year;
- Support to farmers under national measures to compensate for the increased prices of energy carriers, feed, plant protection preparations, fuels and fertilizers.

In 2021, in **Portugal**, in order to promote the distribution, production and self-consumption of power from renewable energy sources, a new legal framework was developed (Decree-Law No 162/2019 of 25 October 2019), which is meant to enable the forming of energy communities. The legal establishment of these activities means to allow individuals, companies and other public and private entities to produce, consume, share, store and sell energy produced from renewable sources, so that they can be encouraged to actively participate in the energy transition.

The **Spanish** Government and Energy Marketers introduced a bill in 2022, meant to help vulnerable households with their energy expenses. Within the established requirements for classification, vulnerable consumers receive a 25% discount and severely vulnerable consumers – 40%. Exceptionally, until December 2023 vulnerable consumers can receive 65% and severely vulnerable – 80%. As for consumers at risk of social exclusion, because they are being attended by the social services of a regional or local administration that pays at least 50% of the bill, they would not have to face the electricity bill and, in case of temporary impossibility to face the payment, the electricity supply cannot be interrupted.

Additionally, from 2020 until 31/07/2021, the Ministry for the Ecological Transition and the Demographic Challenge in **Spain**, implemented PREE - Energy Renovation of Buildings – The objective of the PREE, also taking into account that only 0.3% of existing buildings have carried out interventions in energy rehabilitation, is to give a boost to the sustainability of existing buildings in the country through actions ranging from changes in the thermal envelope, to the replacement of thermal generation facilities with fossil fuels by thermal generation based on renewable sources such as biomass, geothermal energy, solar thermal, heat pumps, or renewable electricity generation for self-consumption and the incorporation of regulation and control technologies, as well as the improvement in energy efficiency in lighting. In addition, the program promotes the actions carried out by renewable energy communities or citizen energy communities, as included in the latest renewable energy and internal energy market directives.

The practice shows that it is crucial to have aids available for each pilot plan compiled to inform the public.

Strategic Documents

When it comes to national strategies, a few can be presented in this document – in **Bulgaria**, for example, between 2016 and 2020, a national program was adopted by Decision No. 796 of the

Council of Ministers - National Long-Term Investment Promotion Program For The Implementation Of Measures To Improve The Energy Performance Of Buildings From Public And Private National Housing And Commercial Building Fund 2016-2020. The document is strategic with the main objective of creating a sustainable model of energy efficiency management in the Republic of Bulgaria by implementing effective, integrated and sustainable development-oriented policies, flexible financial mechanisms and successful practices to reach a high national level of energy savings with care for people and the quality of their life, reduction of carbon emissions in the atmosphere and conservation of the country's energy resources.

A special highlight of the program is the section "From grant-in-aid to implementation of financial mechanisms for financing energy efficiency in the housing sector", which describes in detail and reasoned the benefits and negative effects of the practice of 100% grant-in-aid financing and identifies opportunities for a socially acceptable transition to more sustainable forms of stimulating building renovation.

In **Portugal**, a nationwide plan was introduced, with an execution period until 2026, which aims to implement a set of reforms and investments aimed at driving the country on the path to recovery, sustained economic growth and convergence with Europe over the next decade. Aligned with European climate targets, and committed to decarbonising the economy until 2050, six intervention components in strategic areas are designed in this program, one of which is component C13 - Energy Efficiency in Buildings. The objectives of C13 are to rehabilitate and make buildings more energy efficient, providing social, environmental and economic benefits for people and companies. The activities focus on co-financing the renovation of insulation, roofs, doors and windows, the incorporation of heat pumps, solar thermal installations and other RESs, as well as adaptation of fixed building elements such as shading, greenhouses and roofs or green façades, favouring natural base solutions.

Since there are several phases of implementation, this programme can be promoted in the OSS and replicated in the Municipality of Coimbra; the Coimbra Social Housing park is divided into dwellings owned by the Municipality and also dwellings owned by private landlords. The roadmaps are particularly useful for addressing private ownership.

Spain on the other hand developed a strategic plan with 4 main directions in the face of AXIS I - Improving knowledge of energy poverty; AXIS II – Improving the response to the current situation of energy poverty; AXIS III – Creating a structural change for the reduction of energy poverty; and AXIS IV – protection measures for consumers and social awareness. The goal of this strategy is to achieve a new sustainable energy model, fully decarbonized, aimed at the consumer and in which access to energy is configured as a citizen's right, it is necessary to establish a Global Strategy that integrates all the actions underway and planned in the different public policies to fight against energy poverty and guarantee the effective exercise of that right of all citizens to energy.

There are definitions and indicators within this strategic document that can be useful, such as survey methodology of how to get data to map the Spanish EP situation as well as an action plan to reduce energy poverty.

A complete analysis of the methodology described above was developed in an Excel tool.

8 Conclusions and Recommendations

8.1 Main Conclusions

Deliverable 2.1 presents a state-of-the-art review and assessment of several aspects related to EP, which are the grounds for REVERTER work, being the result of T.2.1-2.4, namely:

- T.2.1. Review and assessment of the state-of-the-art knowledge in EP, energy retrofits and road mapping
- T.2.2. Assessment and prioritisation of alternative energy-saving measures
- T.2.3. Review and assessment of renovation barriers and multiple benefits
- T.2.4. Assessment of policies, initiatives, strategies, etc. for the alleviation of EP and the promotion of deep renovation at national, regional and local levels

The drivers, definitions and indicators for energy poverty were reviewed. A plethora of scientific publications, studies, and technical reports providing insights into specific indicators for energy poverty and strategies to combat this issue are readily accessible. The magnitude of events cantered on energy poverty is substantial, and governments are actively formulating policies to ensure inclusivity. Nevertheless, the predicament persists and is exacerbated by the pressing demand for a transition to clean energy, placing more households in precarious situations. Measuring the number of households grappling with energy poverty proves challenging due to its multidimensional nature, temporal and spatial variability, and private characteristics. The literature reveals a divergence among experts regarding the optimal indicators and metrics for measuring energy poverty, given its complexity — a multifaceted, socially sensitive matter affecting various sectors such as energy, infrastructure, health, and mobility. Despite this divergence, experts unanimously acknowledge the importance of measurement in devising effective solutions to address the problem. Key gaps in indicators have been identified, encompassing issues like summer energy poverty, housing deficiencies or well-being, energy illiteracy, digital literacy, gender sensitivity (particularly gender bias in policy-making), resilience to climate change (evaluated in terms of environmental sustainability and technological advancement), resilience to vulnerabilities (measuring the ability to cope with adversity), transport poverty, and health-related impacts.

Various energy efficiency measures were assessed to identify the most appropriate set for reference buildings in each pilot region, considering both Multi-Family Buildings (MFB) and Single-Family Buildings (SFB). A methodology was then formulated to evaluate and prioritize alternative deep renovation packages for each reference building in every pilot area. This evaluation considered financial, technical, social, and environmental criteria, with a specific focus on utilizing Life Cycle Assessment (LCA) to pinpoint measures that decrease overall energy consumption and environmental impacts throughout the entire life cycle of the buildings. In Bulgaria, the evaluation of the SFB and MFB reveals that none of the DRPs exhibit a discernible advantage over the current building scenario, despite the positive environmental impacts. In contrast, for the public reference building the proposed solutions present similar financial life cycle costs to the existing building, but present a higher-level social impact. In Greece, for the SFB and the MFB, the best NPV is achieved with DRP1. However, from a societal viewpoint, DRP 3 for the SBF and DRP2 for the MFB present the best results, and DRP3 for the MFB present the best results from an environmental point of view. In Latvia, the best NPV is ensured with the baseline scenario. Hence, from both a private and societal perspective the economic performance of all DRPs is lagging behind the existing building situation. In Portugal for the SFB, DRP1 achieves the minimum NPV, and the best results from a societal viewpoint, but from an environmental perspective the most desirable alternative is DRP3. For the MFB DRP1 achieves not only the lowest NPV, but also the best societal and environmental results. From a policy-making point of view, the primary finding across the analysed reference buildings in the four REVERTER pilots is that undertaking deep renovations for residences is not economically advantageous for the majority of households. Therefore, the objectives of the EU's Renovation wave will not be achieved without appropriate financial incentives, predominantly in the form of subsidies targeting renovation investment costs. This imperative is particularly pronounced for vulnerable and low-income households, as highlighted in the relevant section, where substantial barriers arise due to their financial incapacity to cover investment costs and limited access to loan capital.

The Long-Term Renovation Strategies (LTRS) of 10 EU member states were analysed to identify the most essential aspects of the renovation roadmaps. All of the LTRS incorporate a monitoring scheme to ensure the effective implementation of renovation policies and measures, with the exception of Greece. Within the LTRS framework, comprehensive mapping and reporting of the main market and non-market barriers affecting building stock renovation have been conducted.

The examination of existing roadmaps has yielded the following policy recommendations, and crucial considerations for crafting effective renovation roadmaps:

- Clearly define the renovation target, specifying both absolute values (number of buildings) and the percentage relative to the total building stock.
- Establish a trajectory outlining how to reach the renovation target, including the identification of milestones.
- Identify the most cost-effective packages of energy efficiency interventions for building renovation.
- Estimate the necessary investments for implementing energy efficiency interventions required to achieve the specified renovation targets.
- Map and assess potential barriers, proposing suitable solutions for their effective mitigation.
- Identify the most effective policies and measures to mobilize necessary investments and address identified barriers.
- Establish an appropriate monitoring mechanism to assess the accomplishment of the designated renovation target.
- Consult with relevant stakeholders on the contents of the renovation roadmap, striving to reach a consensus.
- Design and implement early actions to kickstart the renovation roadmap.

The barriers to energy renovation as well as the benefits were identified and analysed. The barriers to renovation can be categorized into six general groups:

- Behavioural/Social barriers (e.g., demographic factors, disruptions during construction works, etc.)
- Financial barriers (e.g., limited access to capital, diseconomies of scale, etc.)
- Knowledge/Informative barriers (e.g., asymmetric information, lack of awareness of benefits, etc.)
- Organizational and Decision-Making barriers (e.g., split incentives between investors and society, lack of coordination, etc.)

- Regulatory barriers (e.g., inconsistent policies, institutional complexities, etc.)
- Technical barriers (e.g., absence of codes and standards, lack of technical capacity, etc.)

Beyond the reduction in consumption and energy bills, energy renovations yield various other advantages. These include indirect economic effects (e.g., job creation, macroeconomic impacts, enhanced energy security, etc.), social benefits (e.g., improvements in health and well-being, especially for vulnerable groups, elderly and children),), and environmental benefits (e.g., reduced greenhouse gas emissions and harmful pollutants) associated with building renovations. Similar to barriers, these benefits can manifest at different levels (individual, societal, etc.) and may vary based on factors such as country, building type, renovation measure, and ownership status. Identifying, quantifying, and monetizing these benefits are crucial to attracting more private and public funds for energy retrofit initiatives.

To comprehensively identify and categorize diverse policies and practices across European countries, an Excel tool was created to collect and further analyse various policy aspects, including size, scale, scope, objectives, budget, and more. A total of 68 policies were identified by the partners, not only from the pilot countries but also from other EU countries. Specifically, the identified policies spanned across the following countries: Bulgaria, Greece, Latvia, Portugal, Spain, the UK, France, Denmark, Poland, Ireland, Austria, and Italy. This approach was adopted to enable the analysis and potential replication of more good practices, thereby enhancing the extent of implementation in the roadmaps in T3.5.

8.2 Policy Recommendations

There is no single definition of Energy Poverty (EP) and there is no single indicator to measure it. The broad literature review carried out shows that whatever definition of EP is used as a starting point, they all refer to the inability to meet adequate energy expenses on the part of the household, a reality to which those households with low incomes are mainly exposed. No matter where people live or who they are, it is consensual that the first factor causing EP worldwide is a low level of household income. While one factor can be indicated as the main determinant of EP, there is no single nor simple solution to tackle this raising economic and social problem, which the pandemic and the economic crisis, following the Ukraine war and high inflation have emphasised by exacerbating the difference between the highest and lowest incomes in most of the EU countries (particularly in the Southern, Baltic and Eastern countries).

The percentage of the population self-reporting that they are unable to keep their home adequately warm is high in the Pilot countries. Conversely, based on existing surveys (REVERTER and other studies), many times, the percentage of the population unable to pay their utility bills on time due to financial difficulties seems to be less significant. It is therefore logical to suppose that this indicator is irrelevant because having no debts to public utilities does not give any indication of the effort people make to pay the bills. It also does not give any indication about the comfort levels they are living in. Most people make strong efforts to pay the electricity bill, because they fear being disconnected, but live with high restrictions on the consumption of goods, even basic goods, with a strong impact on comfort and health.

The Bulgarian, Greek, Latvian and Portuguese governments, mainly driven by the EU legislation, are currently developing national strategies for energy poverty mitigation, aiming to address these challenges and ensure access to affordable, reliable, and clean energy services for all citizens. Even though there are specific national particularities, the measures that are being considered are common to all countries (improving the energy efficiency of the building envelop and energy systems, expanding the use of renewable energy sources, promoting behavioural changes and awareness campaigns, and strengthening the social protection and support schemes for low-income and vulnerable households, such as social tariffs and financial assistance programs for vulnerable households). However, these are not widely known or used. There is no official concept or definition of EP and there is also a substantial lack of reliable and appropriate data and indicators to monitor and measure the extent and impact of energy poverty in the most affected countries. Harmonised collection of household data, through a dedicated survey on energy poverty and a harmonised household budget survey, is essential to collect robust and adequate data. To advance the measurement of EP at all levels: the European scale, national and local levels, the collection of quantitative and qualitative data must improve to help the implementation of policies that are able to deliver to the ground. Furthermore, there is a need to set a proper legal framework to ensure a multilevel approach to EP, including legislation, adequate financing and cooperation between local governments and entities.

Even though most of the technologies needed to renovate the buildings sector are known and already commercially available, the most effective improvements, building envelope measures, are still costly and may require government support to attain wide market uptake. The future challenges on buildings technology are not a technological development issue, but rather a concerted effort to facilitate enabling policy design and stakeholder engagement to support the implementation of strategic and effective mechanisms in accordance with national priorities.

One of the most important strategic tools to address these challenges has been promoted by the European Commission already in 2010 by the enforcement of the EPBD recast, requiring all new buildings to become “nearly zero energy” by 2020. Yet, in 2023, these still represent a very small percentage of the market today in most EU countries. The Directive is being revised again, coming up with more stringent rules and higher ambition, but buildings sector is extremely complex, and the market barriers speak louder, therefore, an integrated and comprehensive effort is needed to assist households overcoming the remaining barriers associated with higher initial prices, lack of awareness of technologies and their potential, and the split of incentives, between tenants and homeowners, clients, and utilities. Such concerted effort, around an integrated strategy, which uses the best available technology in combination with adequate strategies, ensuring that all available options are employed in an optimized approach, can overcome these barriers. However, this strategy requires exceptional effort and coordination among an oversized set of stakeholders, from policy makers to builders, technology developers, manufacturers, equipment installers, financial institutions, businesses, and users.

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