FleXible user-CEntric Energy poSitive houseS

Deliverable 5.2: Report on suitable energy efficiency schemes in the context of PEBs

LC-EEB-03-2019

New developments in plus energy houses (IA),

Proposal No. 870157

Title	Document Version
D5.2 Report on suitable energy efficiency schemes in the context of PEBs	1.0

Project Number	Project Acronym	Project Title
H2020-870157	EXCESS	FleXible user-CEntric Energy poSitive houseS

Contractual Delivery Date	Actual Delivery Date	Deliverable Type*-Security**
Dec 2023 (M52)	M52 (Dec 2023)	R-PU

*Type: P: Prototype; R: Report; D: Demonstrator; O: Other.

**Security Class: PU: Public; PP: Restricted to other programme participants (including the Commission); RE: Restricted to a group defined by the consortium (including the Commission); CO: Confidential, only for members of the consortium (including the Commission).

Responsible	Organisation	Contributing WP
Mia Ala-Juusela	VTT	WP5
Andreas Tuerk	JR	

Abstract

In this report, we a) present the potential funding that is available for PEBs, especially for the type of buildings that we have in the four demos and b) suggest which would be the most suitable funding sources for similar cases as we have in the four demos. This report starts with a short reminder of the background on the benefits of energy efficiency and renewable energy sources, and the European level legal framework. Then, the financing schemes available for PEBs are analysed, starting with short summary of general funding sources and the funding instruments available on European level. Then, a review and analysis of the technical and economic evidence on potential of PEB solutions is followed by a description of different ways of valuating energy efficiency and sustainability at large, as these are often intertwined in the rating tools. There are many different funding opportunities and schemes available for energy efficiency and renewable integration. The wide variety of schemes is creating challenges for the investors and house owners, as it is sometimes hard to find the right channel. Also, applying for funding from different providers may create challenges in the timing, as the decision making may have different lengths in different institutions. For PEBs, it is a major challenge that most of the funding schemes are meant to a certain technology. PEB solution often requires the use of several solutions in order to reach the PEB level. It would be better if the funding would rather take into account the final result.

Keywords
Funding schemes, financial support, financing for PEBs

Revision	Date	Description	Author (Organisation)
V0.1	26.01.2021	*ToC*	Mia Ala-Juusela (VTT)
V0.2	11.02.2021	*Finnish situation*	Mia Ala-Juusela (VTT)
V0.3	9.4.2021	*More content & details in TOC, roles, appr. chapter lengths*	Mia Ala-Juusela (VTT)
V0.4	9.9.2021	*Chapter contents from demo countries & EU level*	Hanne Siikavirta, Zarrin Fatima (VTT), Camilla Neumann (JR)
V0.5	24.10.2023	*Ch4 content*	Ilaria Marotta (JR),
V0.8	28.11.2023	*Updated contents for AUT, ES, BE, Ch2, Ch4*	Mia Ala-Juusela (VTT), Clemens Mayer, Ilaria Marotta (JR), Joaquin Villar (AEA), Koen Allaerts (VITO), Andreas Tuerk (JR)
V0.9	8.12.2023	*Finalised for internal review*	Mia Ala-Juusela (VTT)
V1.0	20.12.2023	*Finalised for submission based on comments from internal reviewers*	Mia Ala-Juusela (VTT), Clemens Mayer, Andreas Tuerk, Ilaria Marotta (JR)

This project has received funding from the
European Union's Horizon 2020 Research and Innovation Programme
under Grant Agreement № 870157.
More information available at https://positive-energy-buildings.eu/

Copyright Statement

EXECUTIVE SUMMARY

This report summarises the information about energy efficiency schemes that could be used for financing PEBs, as well as potential needs for developing them to better support the roll-out of PEBs. In this report, we a) present the potential funding that is available for PEBs, especially for the type of buildings and technologies that we have in the demos and b) suggest which would be the most suitable funding sources for similar cases as we have in the four demos. It is also relevant to look what would be the most efficient technologies to use now, or what should be developed further to come to better results. This leads to the recommendations for the most suitable funding sources.

This report starts with a short summary of the benefits of energy efficiency and renewable energy sources, and the European level legal framework. This is followed by an overview and analysis of the available financing schemes for PEBs, starting with short summary of general funding sources and the funding instruments available on European level. Finally, a review and analysis of the technical and economic evidence on potential of PEB solutions is followed by a description of different ways of valuating energy efficiency and sustainability at large, as these are often intertwined in the rating tools.

The benefits of PEBs include those related to energy efficiency, but also those related to the use of renewable energy sources. Energy efficiency leads to a reduction of both energy costs, vulnerability to energy and fuel price spikes, as well as operating and maintenance costs. In addition, it decreases greenhouse gas emissions and dependence on imports. It may also reduce negative effects on health and environmental risks. Renewable energy can e.g. generate new sources of growth, increase incomes, create jobs and improve welfare.

The legislation sets the scene for the PEBs and also partly for the funding, as the funding instruments are usually structured for supporting the legal framework. The key instruments on European level are the Energy Performance of Buildings Directive (EPBD) introduced in 2002 and its revisions in 2010, 2018 and 2023. EPBD sets the targets and minimum requirements for the energy efficiency of buildings and their systems. In 2018, the revision aimed at accelerating the cost-effective renovation of existing buildings. This was further supported by the Renovation Wave strategy, with priorities in tackling energy poverty and worst-performing buildings, renovation of public buildings, and decarbonisation of heating and cooling. The recast of EPBD as part of Fit-for-55 package set new requirements for new buildings and renovation, targeting zero emission starting from 2028. It also includes requirements to equip buildings with solar technology. Other elements in the EU-level legal framework that are relevant for PEBs include Energy Efficiency Directive (EED) and the Renewable Energy Directive (RED), which were also revised as part of Fit-for-55 package. The RePowerEU communication package launched in 2022 includes a number of strategies, action plans and recommendations to increase the capacity of renewable energy in the European Union. The realisation and detailed planning of these EU-level targets, strategies and directives are mostly left for the individual Member States, so the practices and emphases may vary in the individual countries.

A plethora of funding instruments are available on European and national level. Some of the funding opportunities are common and similar for all the countries, such as the own funds, loan or mortgage and crowdfunding. Most of the funding is offered for renovation.

The conclusion of our analysis is that there are many different funding opportunities and schemes available for energy efficiency and renewable integration. The wide variety of schemes is actually creating challenges for the investors and house owners, as it is sometimes hard to find the right channel. Also, applying for funding from different providers may create challenges in the timing, as the decision making may have different lengths in different institutions.

From the point of view on PEBs, it is a major challenge that most of the funding schemes are meant to a certain technology. PEB can be only achieved with different combination of technologies, and it requires the use of several solutions to reach the PEB level. It would be better if the funding would rather take into account the final result. However, this requires a common PEB definition as well as new ways of formulating the requirements for the funding, and potentially co-operation between the funding agencies.

Regarding the technical potential, there is a large variety of concepts and methods associated with the energy efficiency potential of buildings. Research on machine learning and artificial intelligence methods for the energy efficiency of the building stock has become more widespread, particularly in recent years. Concepts such as Building Information Modelling, Building Automation and Advanced Energy Management Systems have been increasingly combined over the last year with the concept of energy efficiency of the building stock. Among the research areas, the one on the building envelope and materials is the subject of considerable interest by the scientific community. Other sources of energy efficiency also include heat pumps, energy storage systems and integration with renewable energy sources, in particular with solar photovoltaic. The aspects that have gained less attention include life-cycle assessment in connection with building renovation, and the social impact of energy efficiency measures is most often limited to the reduction in energy bills and the alleviation of energy poverty, while less attention is paid to thermal comfort and the effects on occupant well-being.

Regarding the economic potential, from the analysis of the data available in DEEP platform related to the energy efficiency investments in 2557 projects, it seems that interventions on the HVAC system and on the building envelope achieve the greatest annual energy cost savings but lead to higher LCOE. On building envelope, the smallest avoidance costs (LCOE) are gained by shading measures, followed by insulation and efficiency of the building roof and vertical envelope. Regarding the building type, the greatest avoided costs occur in the case of detached single family dwellings, followed by office buildings. On the other end, the least avoidance costs occurred in projects addressing educational buildings and multi-family buildings with 1-4 storeys.

There is evidence that energy efficiency and other environmental rating systems affect the value of the building, on increasing rate, although there are also studies not showing a very clear connection, and the effect still seems to be relatively modest. The existence of several rating tools and the way they use the data is creating some confusion, and also some mistrust to the rating systems, created by this confusion. International efforts are however put in standardisation of the different evaluation methods and increased data availability for comparison. Once a common understanding of the rating systems has been gained, these could be used for the development of the funding schemes, so that the more sustainable (and energy efficient) solutions would receive better funding terms than the less sustainable.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

ANESE	National Association of ESCOs
ARA	the Housing Finance and Development Center
BESS	Battery Energy Storage
BIM	Building Information Modeling
BIPV	Building-Integrated Photovoltaic
BREEAM	Building Research Establishment Environmental Assessment Method
CEF	Connecting Europe Facility
CEN	European Committee for Standardization
CF	Cohesion Fund
CIW	Co-Innovation Workshop
CSRD	Corporate Sustainability Reporting Directive
CTP	Climate Target Plan
DEEP	De-risking Energy Efficiency Platform
DHW	Domestic Hot Water
EAFRD	European agricultural fund for rural development
EED	Energy Efficiency Directive
EEEF	European Energy Efficiency Fund
EEFIG	Energy Efficiency Financial Institutions Group
EEOs	Energy Efficiency Obligations
EFRAG	European Financial Reporting Advisory Group
EFSI	European Fund for Strategic Investments
EIB	European Investment Bank
ELENA	European Local Energy Assistance
ELY-keskus	Elinkeino-, liikenne- ja ympäristökeskus; Centre for Economic Development, Transport and the Environment
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificates
ERDF	European Regional Development Fund
ESCOs	Energy Service COmpanies
ESF+	European Social Fund Plus
ESG	Environmental, Social Governance
ESRS	European Sustainability Reporting Standards

EUGBS	EU Green Bond Standard
EVO	Efficiency Valuation Organization
GDP	Gross Domestic Production
GHG	greenhouse gas
HVAC	Heating, Ventilation and Air-Conditioning
IAQ	Indoor Air Quality
IEA	International Energy Agency
IPMVP	International Performance Measurement and Verification Protocol
IRENA	International Renewable Energy Agency
KPC	Kommunalkredit Public Consulting
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCOE	Levelized Cost of Energy
LEED	Leadership in Energy and Environmental Design
MPC	Model Predictive Control
MuniFin	Municipality Finance Plc, Kuntarahoitus
NECP	National Energy and Climate Plan
NIB	Nordic Investment Bank
NOI	Net Operating Income
nZEB	nearly Zero Energy Buildings
OBF	On-bill financing
PACE	Property Assessment Clean Energy
PEB	Positive Energy Building
PRTR	Recovery, Transformation and Resilience Plan
RDP	Rural Development Programmes
RED	Renewable Energy Directive
RES	Renewable Energy Source(s)
RRF	Recovery and Resiliency Plan
SME	Small and Medium-sized Enterprise
SOFC	Solid-Oxide Fuel Cells
SYK	the University Properties of Finland Ltd
TES	Thermal Energy Storage
VALERI	Valuation of Energy related investments
VES	Virtual Energy Storage

1 Introduction

1.1 Purpose of the document

This report summarises the information about energy efficiency schemes that could be used for financing the PEBs, and also presents potential needs for developing and improving them to better support the roll-out of PEBs. In this report, we a) present the potential funding that is available for PEBs, especially for the type of buildings and technologies that we have in the demos and b) suggest which would be the most suitable funding sources for similar cases as we have in the four demos. It is also relevant to look what would be the most efficient technologies to use now, or what should be developed further to come to better results. This leads to the recommendations for the most suitable funding sources and changes that would be needed to facilitate wide roll-out of PEBs. It all starts by looking at the legal framework at European level, as the success of the funding schemes is highly dependent on and supported by the legal framework.

Benefits and financial risks of the different financing schemes were evaluated in relation to the demo cases and discussed with local stakeholders in the second Co-Innovation Workshops (CIWs) in each country (T6.3). The outcomes of benefits and financial risks assessment will be used for investigating opportunities with other sources of mid- and long-term funding during the third Co-Innovation Workshops of T6.3. The report will also feed in the replication planning (T6.5).

Furthermore, the report outlines the technical and economic potential of energy efficiency measures as well as the valuation of energy efficiency as these aspects are crucial for the definition of accurate and meaningful funding schemes.

VTT and JR identified the available funding sources, demo related policy stakeholders (e.g. national energy ministries that would cover operating costs), local energy administrations, umbrella associations, public or private energy efficiency programmes or initiatives or from energy providers, which have obligations in the context of the Energy Efficiency Directive. The national partners in Belgium (VITO) and Spain (CENER & AEA) helped in collecting the material and checking the content of the relevant chapters. PI delivered the reports of the co-innovation workshops (CIWs, in T6.3).

1.2 Scope of the document

This document describes the available funding alternatives for energy efficiency measures and the installation of renewable technology for all building types. The document covers four European countries of varying climatic zones including Finland, Austria, Belgium and Spain and explores the existing funding opportunities for building owners. It also presents the underlying legal framework on European and national level and gives an overview of the technical and economic potential of the energy efficiency and renewable installations.

1.3 Structure of the document

The document is structured into seven Chapters. After this introduction, this report starts with a short reminder of the background on the benefits of energy efficiency and renewable energy sources (Chapter 2), and the European level legal framework (Chapter 3). Then, the financing schemes available for PEBs are analysed (Chapter 4), starting with a short summary of general funding sources and the funding instruments available on European level, followed by an analysis of

the demo countries. This is followed by a review and analysis of the technical and economic potential of energy efficiency and renewable energy measures for PEB solutions (Chapter 5). Chapter 6 describes different ways of valuating energy efficiency and sustainability at large, as these are often intertwined in the rating tools. Finally, Chapter 7 outlines our main conclusions.

2 Benefits of energy efficiency and renewable energy sources

This chapter outlines the multiple benefits of energy efficiency measures and renewable energy installations. An analysis of the of the multiple benefits of energy efficiency and RES is very important as it helps to understand the economic savings and the environmental and social impact of these measures and thereby supports the definition of accurate and meaningful funding schemes.

Globally, energy efficiency is increasingly understood as a key component of net zero energy policy (IEA, 2023). At the same time, there is considerable evidence showing that many energy efficiency opportunities are not pursued in several economic sectors (Graham et al 2013, IEA 2015).

Today, it starts to be general knowledge that energy efficiency has multiple benefits. Energy efficient buildings deliver the same or better service at reduced cost and with lower environmental impact. The IEA (2014) lists several impacts of energy efficiency in the form of 'intangible benefits' (Figure 1).

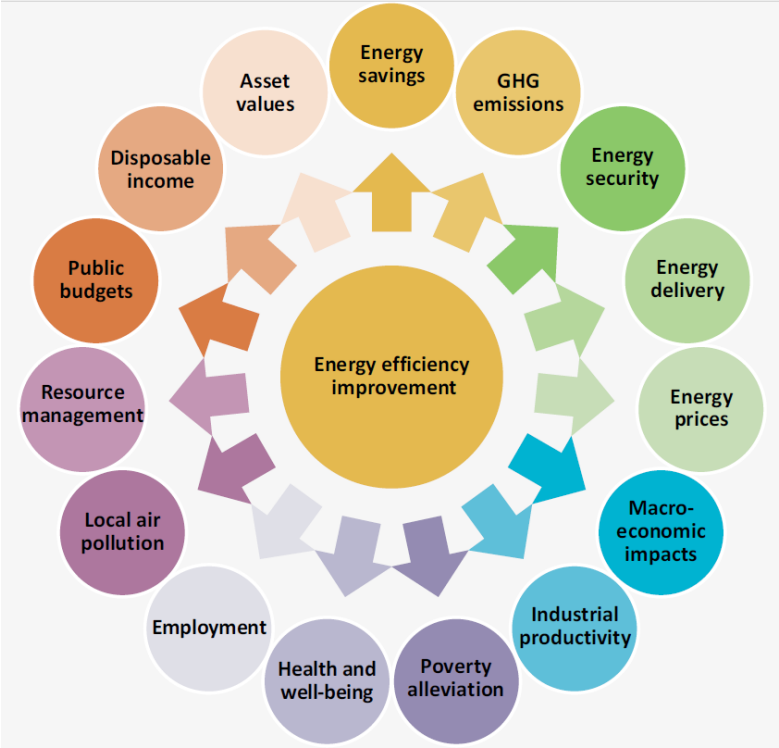

Figure 1: Multiple benefits of energy efficiency (IEA, 2014)

This is supported by the findings in IMPAWATT, an EU funded Horizon2020 project, that energy efficiency leads to reduction of both energy costs, vulnerability to energy and fuel price spikes, as well as operating and maintenance costs while creating a stronger image and improving branding. In addition, it decreases greenhouse gas emissions, dependence on imports and end users may greatly benefit from profit generated from subsidies. Moreover, an energy efficiency strategy supports the EU and national targets set in the Member States. (IMPAWATT 2019)

In strategic terms, in addition to several cost benefits, energy efficiency can increase value through better quality of products and design. It may also reduce negative effects on health and environmental risks, for example an insulated steam pipe decreases the risk for employees to get burned (Graham et al 2013). These strategic benefits are summarised in Figure 2.

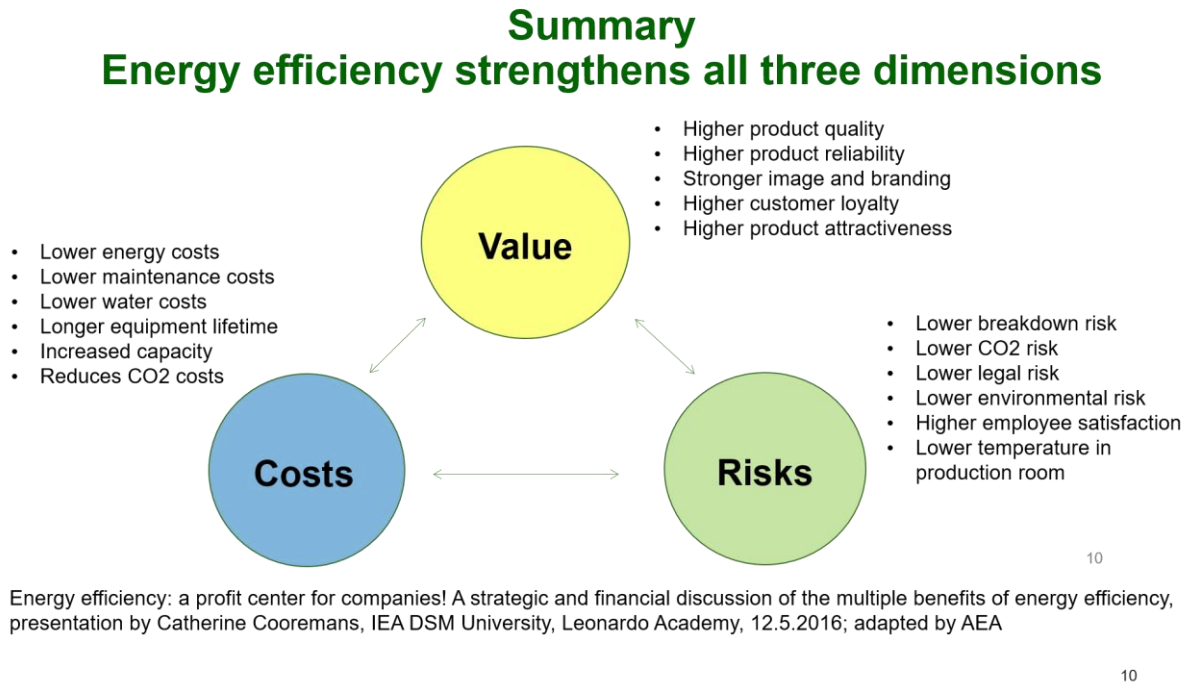

Figure 2: Summary of energy efficiency benefits (credit: IMPAWATT)

In the context of PEBs, it is worth widening the view towards renewable energies, which are an essential part of PEBs. The arguments used for the benefits of renewable energy installations are very much the same as those made by the energy efficiency community. A report by IRENA (2016), discussing the economic benefits of renewable energy focused on four macroeconomic variables - GDP, employment, welfare and trade. It concluded that:

> *"Scaling up renewable energy can generate new sources of growth, increase incomes, create jobs and improve welfare. Going forward, holistic, adaptable frameworks that capture and measure the multiple impacts of renewable energy deployment can tip the balance in favour of low-carbon investments. Policy makers responsible for taking today's critical investment decisions need more complete analysis and evidence of the broad impacts of their choices."* (IRENA 2016:80)

Therefore, in this report, the benefits and financing options for renewable energy solutions are also looked at, as well as the potential of financing for other elements enabling the realisation of the PEB concept, like energy flexibility and storages.

3 Legal framework in Europe

The legislation sets the scene for the PEBs and also partly for the funding, as the funding instruments are usually structured for supporting the legal framework. A report by the European Commission (2022) gives a thorough description on the evolution of financing practices for energy efficiency in buildings, SMEs and in industry. In this report, policy recommendations are given, supported by indications they have on the financial side: "*new mechanisms to de-risk renovation investments, a faster deal flow from concept to bankable projects, and new capacity within financial institutions to identify, evaluate and implement energy efficiency transactions. A variety of new business models, innovations and tailored tools are required in each buildings segment. The main issue is improving the energy efficiency of existing buildings, as new buildings will be built with nearly zero energy needs from 2021.*"

Economidou et al. (2020) describe the path towards the current EU-level legal framework for EU energy efficiency policies for new and existing buildings:

The first cohesive European legal act related to energy performance of buildings was the **Energy Performance of Buildings Directive (EPBD)** introduced in 2002. A re-cast version of EPBD was given in 2010 and it was amended in 2018 and 2023. The EPBD in 2002 introduced e.g. minimum energy performance requirements in buildings, energy performance certification and regular inspections and assessment of efficiency of boilers and air-conditioning systems. **EPBD recast in 2010** strengthened some provisions in the original EPBD. It also introduced the cost-optimal methodology as the guiding principle for setting building energy requirements, energy performance requirements for technical building systems (heating, hot water, ventilation, cooling, air conditioning) and the concept of ''nearly zero-energy buildings" (NZEBs). EU Commission Recommendation 2016/1318 include benchmarks for the energy performance of NZEBs for different climatic zones. According to the reviewed studies on energy performance optimization reaching the NZEBs target in new buildings appears to be feasible. NZEB renovation is challenging and there are different technical, financial, social, political and institutional barriers. The **EPBD revision in 2018** introduced amendments that aim at accelerating the cost-effective renovation of existing buildings, with the aim of a decarbonized building stock by 2050 and the mobilization of investments to reach this goal. The revision also supported electro-mobility diffusion and introduces new provisions to enhance smart technologies and technical building systems, including building automation.

In 2020 the Commission published the **Renovation Wave** strategy as a follow-up to the **Green Deal** presented in 2019 (European Commission, 2020a and 2023a). The Renovation Wave is a strategic communication with the aim to double annual energy renovation rates in the next ten years and renovate 35 million buildings in Europe by 2030. Together with a very ambitious decarbonisation of heating this should enable to cut direct building sector greenhouse-gas emissions by 60% until 2030 (based on 2015 levels) as laid down in the Climate Target Plan 2030 (CTP). The three priorities in the Renovation Wave are tackling energy poverty and worst-performing buildings, renovation of public buildings, and decarbonisation of heating and cooling. Finance via NextGenerationEU and other EU and private funds is mentioned as one of the ways to tackle the barriers. The initiative builds on the national long-term building renovation strategies that are part of building-related aspects of each EU country's National Energy and Climate Plans (NECPs). Decision makers are encouraged to make strong long term renovation strategies and to also introduce greater financial and technical assistance to fund subnational renovation programs and citizen hubs to support the emergence of

innovative financing schemes and improved data collection to inform policy making and monitor their impacts (ICLEI, 2021).

In beginning of 2023 the European Commission decided of a new revision to EPBD, as part of the **Fit-for-55** package. **The recast of EPBD** will bring new requirements for new buildings and renovation. Its main objectives are to substantially reduce greenhouse gas (GHG) emissions and energy consumption in the EU building sector by 2030 and make it climate neutral by 2050. It also aims to increase the rate of renovations of energy-inefficient buildings and improve information on energy performance.

According to the recast, the requirement for new buildings is to fulfil the zero emission target starting from 2028 (public buildings from 2026). This is "*a building with very high energy performance in line with the energy efficiency first principle, where the very low amount of energy required is fully covered by energy from the building itself or from locally produced renewables*." The zero emissions building would replace nearly Zero Energy Buildings (nZEB) as the standard for all new buildings from 2027 and for all renovated buildings from 2030. All new buildings should be equipped with solar technologies by 2028, where technically suitable and economically feasible, while residential buildings undergoing major renovation have until 2032 to comply. Residential buildings would have to achieve at least energy performance class E by 2030, and D by 2033. Non-residential and public buildings would have to achieve the same classes by 2027 and 2030 respectively.

In addition to EPBD there are also other elements in the EU-level legal framework that are relevant for PEBs such as the **Energy Efficiency Directive (EED)** and the **Renewable Energy Directive (RED)**, which were also revised as part of Fit-for-55 package. The EED recast targets to make buildings more energy efficient and boost the use of renewable energies in buildings. In addition to the new headline target to double the existing share of renewable energy sources, the revised RED introduces a strong policy framework that will facilitate electrification in different sectors, with new increased sector-specific targets for renewables in heating and cooling, transport, industry, buildings and district heating/cooling, but also with a framework promoting electric vehicles and smart recharging.

In 2022, the European Commission launched the **REPower EU** communication with the aim to reduce the EU's dependency on Russian fossil fuel imports. The REPower EU plan encourages Member States to find the quickest and cheapest ways to address the current energy crisis. The package includes a number of strategies, action plans and recommendations to increase the capacity of renewable energy (e.g. solar PV and heat pump capacity should be doubled) in the European Union and therefore also affects the renovation of residential buildings.

The realisation and detailed planning of these EU-level targets, strategies and directives are mostly left for the individual Member States, so the practices and emphases may vary in the individual countries.

4 Existing financing frameworks

In this chapter, synergies with energy efficiency (EE) investments (renovation subsidies, ESCO models, financing instruments via dedicated funds) are investigated, especially in relation to the demonstration cases.

In general, it is recommended for funding schemes to be transparent, independently managed, be able to engage local finance partners, cater to diverse stakeholder and address various building types (Streimikiene & Balezentis, 2019; Réfabert, 2020). Furthermore, there is no one-size-fits-all financial solution (Bertoldi et al, 2021). It is possible that end users find an energy renovation solution by combining both public and private funding opportunities (Bertoldi et al, 2021; Stirano et al, 2019; Economidou et al, 2019).

Despite the evidence of the wide range of benefits of energy efficiency and use of renewable energy sources, the investment cost and the related energy savings are considered to be the most important aspects in convincing companies, in particular SMEs, and building owners to pursue energy efficiency projects. Although sufficient knowledge during the planning phase is a significant barrier, the willingness to exploit the potential of an innovative financial scheme combined with national/regional funding might attract SMEs to enter the energy efficiency market. In addition, the quantitative and structured information generated by financial models supports in stakeholders' awareness and knowledge rising as they may wish to investigate different financing patterns and assess the potential risks and the related benefits, such as return on investment. (NewBEE, 2014)

The high investment cost is also a large barrier for improving energy efficiency or adding renewable energy technology. To overcome the "upfront cost" barrier, several financial instruments have been developed or adapted to make energy efficiency easier. Each instrument has unique characteristics that make it applicable for a specific situation. Considering the economical aspect, the financial models are supposed to meet several needs and conflicts in the owner-user structure and the owner-provider-structure, to find a compromise. There are many elements to take into account both technical and non-technical, at different geographical levels; legislation and fiscal framework plays an important part in the creation of new business and financial models as well as their organisational aspects (NewBEE, 2014).

Financial instruments can be divided in different ways. At its simplest, an investment can be financed with, for example, equity, a bank loan, a hire purchase agreement and various financing service models. There are also various subsidies available, such as state energy subsidies, which can be used both for investments in energy efficiency and renewable energy and e.g. for energy audits (in Finland).

In the following, the generally available means to finance energy efficiency and renewable energy investments are presented. Then, the analysis drills down from European level to national level in the four demo countries. If regional, city of other local level funding is available, this is also presented in the country chapters. The country chapters also include the analysis of the available funding opportunities in relation to the demo case in that country and how the funding schemes could be further developed to better support the similar types of PEB projects.

4.1 General funding opportunities

Some of the funding opportunities are common and similar for all the countries, such as the own funds and loan or mortgage. These are very briefly handled in the following. The tax reductions or credits may differ from country to country, and they are described in the country chapters. Other options include for example grants and subsidies available on the European and national level, which are presented in the following chapters.

Own resources: The use of own resources is often the simplest solution, making it possible to avoid the financial expenses (no interest rate, no fees, and no charges) and keep the decision-making power completely in own hands. This option is however limited to those building owners which have good financial resources available. It may also compete with other investment opportunities, which could have more important return on investment. The benefit is that the savings start to be immediately realised.

Loan/mortgage: This is the most widely available resource and provide the initial capital outlay. The loan is paid back over a time period and the lender bears the risk of lending the amount of money. The main consideration for the lending institutions is the credit risk. Energy Efficiency loans are often unsecured because it is difficult to use the energy efficiency investment as collateral. Also, it is not common to use the annual energy cost savings as collateral to secure the loan in the loaning opportunity, but this approach is used in the Energy Performance Contracting. However, in some cases, banks may issue a special loan such as refurbishment or green loans.

Property Assessment Clean Energy (PACE): This alternative has been piloted in Europe and successfully implemented in the US. The benefit of these loans is that they are not linked to home or building owners but rather to the building itself, which enables transfer of ownership including the financial repayment obligations. This particular model has been structured around bonds provided by municipalities with repayments made through property taxation over a period of 15-20 years (Bertoldi 2021, Stirano 2019, Economidou 2019). The adoption of PACE is currently at hold in Europe due to regulatory issues. (Bertoldi, 2021; EuroPACE, 2018).

On-bill financing (OBF): OBF schemes aim to lower the initial investment cost burden of energy renovations and address split incentives issue (Bertoldi, 2021). OBF allows utilities (or other parties) to act as a cushion to the impact of initial investment costs for home or building owners, either via an on-bill loan or on-bill tariff structure (Economidou, 2019).

Revolving funds: These funds capture some of the savings linked with energy efficiency measures and re-invest these into further projects. The Estonian Kredex Credit and Export Guarantee Fund has had considerable impact and could be considered for further replication (Economidou, 2019).

Energy Efficiency Funds*:* several international funds exist, often bringing together public and private investment, to mobilize energy renovations. Key players include the European Energy Efficiency Fund (EEEF), the SUSI Energy Efficiency Fund and the Renewable Resources and Energy Efficiency (R2E2) Fund (Stirano, 2019).

Grants: This may be awarded by public or private institutions and do not need to be repaid. The grant may be provided for specific energy efficient equipment and may be tied to energy performance, and it does not need to be repaid (IEA, 2015; NewBEE, 2014).

Subsidies/incentives: The basic purpose of the subsidy is to reduce the market price of an item below its cost of production. The most commonly known method for quantifying consumption

subsidies is “the price-gap approach”. Incentives on the other hand may be supplemental reward for encouraging particular behaviour (IEA, 2015; NewBEE, 2014).

Tax reductions, tax credits: This option depends on the country’s taxation policy. For example, in this model some individuals may receive tax credit for new energy efficient equipment. The eligibility for this benefit is usually set (IEA, 2015; NewBEE, 2014).

ESCOs/EPC/Third Party financing: ESCOs (Energy Service COmpanies) are described as energy solution providers, who also offer services, such as installation of equipment in the user’s facility. The associated cost of the service is paid for with savings acquired from reduced energy costs. The EPC, on the other hand, may be claimed as a contract between an ESCO and its client that includes an energy efficiency investment in the client’s facilities, the performance of which is somehow guaranteed by the ESCO and with financial consequences also residing for the ESCO (NewBEE, 2014).

With ***Energy Service Agreements***, service providers apply energy efficiency measures and guarantee certain savings over a time period. If technologies are installed as part of an energy service agreement, they remain in the ownership of the service provider and will be removed or must be purchased by building owners once the agreed service period ends. With such agreements, the provider is a third party rather than an ESCO. However, these agreements are less suitable for deep renovation and because of high transaction costs, they are generally only applied in larger buildings and blocks (Stirano, 2019).

Energy Efficiency Obligations (EEOs): Energy savings may be achieved by establishing EEOs under which energy providers are required to meet cumulative end-use energy savings targets in a given timeframe (BPIE, 2019). EEOs are considered difficult to apply in apartment buildings with multiple owners due to the fact that reaching consensus on renovation work could be time consuming. Nonetheless, ESCOs could be further pushed to deliver a certain percentage of energy savings and thus this will increase EEOs (IEA, 2015). This approach may also be combined with White certificate schemes (WhC) as being done in Denmark, France and Italy. (Streimikiene & Balezentis, 2019)

White certificate schemes: The basic principle of this option is that a regulatory authority imposes energy efficiency obligations on certain parties, such as electricity, gas suppliers or ESCOs, who are obliged to demonstrate they have achieved a certain amount of energy savings each year. When energy savings are achieved and certified, each unit of saved energy (usually 1 toe) generates a tradable title called white certificate (the WhC). (NewBEE, 2014)

Value of building: An improvement in Energy Performance Certificate has been said to improve the building’s market value and rent. This has been observed on both the US level and European level. Although this can’t be regarded strictly a funding opportunity, it is listed here due to its financial character, which may affect the decision making of the building owner. This subject is addressed separately in Chapter 6.

Urban filling: Infill projects offer many housing companies an alternative to partially finance large renovation projects. By selling a part of their plot, or by constructing additional new dwellings, they are able to earn extra income. This is done together with the municipal authorities in order to utilize the existing but unused building right or adjusting the plan to grant additional building rights for the plot. (Nykänen et al, 2013)

Synergies with other major refurbishments: It could be that certain refurbishments are very costly, for example the application of insulating panels require the use of scaffolding structures. In such a

case, where the building renovation is mandatory, the high auxiliary costs can be combined with similar projects to avoid the high cost burden. (NewBEE, 2014)

Aggregation of customers: In a similar manner when producing more units decreases the total cost of production, more customers requiring energy improvements could bring more economic benefits. This implies that more customers (i.e. building owners) increase the "purchasing (market) power", which could decrease for example the price of equipment and the installation cost. (NewBEE 2014)

Crowdfunding is a new form of business finance where majority of the providers have entered the market within the last ten years. Crowdfunding refers to an open request to the general public to collect funds for a specific project. It can include sponsorship or investment. This financing alternative has gathered wide popularity as a means of financing renewable energy projects, among other things. (Bergman et al, 2021; Ziegler et al, 2019)

4.2 European level

Over the recent years, there has been an increase in the availability of both private and public financial instruments to support energy renovations (BPIE 2016). It may also be made possible if European and national actors support this process by developing guidelines on ESG / sustainable investing, in line with the EU taxonomy for sustainable activities, and by facilitating capacity building on climate-risk in the financial industry (Vitali Roscini et al, 2020).

It is estimated that the achievement of strengthened greenhouse gas emissions reduction target for 2030 of at least 55% increases annual investments related to energy production and use in 2021-2030 by around € 350 billion per year. Investments are needed both from the public and private sectors. Around one third of these additional investments is needed in the transport and residential sectors (Climate Action, 2020).

Energy efficiency is an essential component for actions to achieve the increased GHG emissions reduction target, with the building sector as one of the areas requiring further efforts. Only 1% of buildings undergo energy efficient renovation every year. Deep renovations that reduce energy consumption by at least 60% are carried out only in 0.2% of the building stock per year (European Commission, 2020c). However, energy efficient building renovations can be expensive, and owners may not have the means to finance them. Technical solutions utilised in NZEBs may be expensive and request a high investment. Access to finance may be limited and payback periods for renovation may in some cases be long.

In support of the latest policy packages that were presented above, the European Commission is fostering the use of EU funds for the investment in energy efficiency of buildings and has been further developing financial instruments. The main sources of funding for energy efficiency and renewables are presented below, although they may also provide funding for other purposes.

4.2.1 Financial instruments

Various forums and guides are available to support the implementation of investments. A comprehensive guide for funding opportunities for municipalities on climate and energy measures has been developed by **Covenant of Mayors** (2023), providing information on a number of financial instruments. Similarly, various financial instruments are also available for other sectors. For example, the **Energy Efficiency Financial Institutions Group (EEFIG)**, set up by the EU and the UN, provides a wealth of information on energy efficiency financing, describing the evolution of financing practices for energy efficiency in buildings, SMEs and in industry, with a plethora of examples from

different member countries (European Commission, 2022). The **De-risking Energy Efficiency Platform (DEEP)** has done a comparison of different energy efficiency investments (see more in Chapter 5.2). The aim of the DEEP databank is to improve the understanding of the risks and benefits of energy efficiency investments. Additional information on investments, financing and business models internationally can be found, among other things, in the International Energy Agency's **IEA report "Energy Efficiency 2019"** (IEA, 2019).

The EU's recovery instrument **NextGenerationEU** will make available significant resources that can also be used to kick-start renovation for recovery. The centerpiece of NextGenerationEU is the **Recovery and Resilience Facility** - an instrument that offers grants and loans to support reforms and investments in the EU Member States for a total of €723.8 billion in current prices. In the Annual Sustainable Growth Strategy 2021, the Commission has proposed the **European Flagships Renovate and Power Up** for coordinated intervention by all Member States (European Commission, 2020d). To sustain the implementation of these Flagships, the Commission will complement the Guidance to Member States on the preparation of Recovery and Resiliency Plans with tailor-made guidance to each Member State in the context of the individual assessment of their National Energy and Climate Plans (NECPs) and Long-term Renovation Strategies.

The **Just Transition Fund**'s purpose is to alleviate the socio-economic costs triggered by climate transition, supporting the economic diversification and reconversion of the territories concerned. This means backing productive investments in small and medium-sized enterprises, the creation of new firms, research and innovation, environmental rehabilitation, clean energy, up- and reskilling of workers, job-search assistance and active inclusion of jobseekers' programmes, as well as the transformation of existing carbon-intensive installations when these investments lead to substantial emission cuts and job protection. It is expected to mobilise close to €30 billion in investments. Member States may transfer to the JTF additional resources from their national allocations under the European **Regional Development Fund (ERDF)** and the **European Social Fund Plus (ESF+).**

The Modernisation Fund is a dedicated funding programme to support the 10 lower-income EU Member States in their transition to climate neutrality by helping to modernise their energy systems and improve energy efficiency. The beneficiary Member States are Bulgaria, Croatia, Czechia, Estonia, Hungary, Latvia, Lithuania, Poland, Romania and Slovakia. It will support investments in generation and use of energy from renewable sources; energy efficiency; energy storage; modernisation of energy networks; and just transition in carbon-dependent regions (redeployment, re-skilling and upskilling of workers, education, job-seeking initiatives and start-ups).

European Investment Bank (EIB) will step up its support for the aggregation of building renovation projects into portfolios and the provision of tailored financial support in the context of its **European Initiative for Building Renovation**. The Commission will work in cooperation with the Member States, the EIB and market participants to facilitate the implementation of rules for combining EU programmes and instruments, national funds and private funds for renovation projects.

The **Connecting Europe Facility** (CEF) aims at supporting the development of high performing, sustainable and efficiently interconnected trans-European networks in the fields of transport, energy and digital services. The key benefits sought include the enhancement Europe's energy security while enabling wider use of renewables, and facilitating cross-border interaction between public administrations, businesses and citizens. One of the key priorities of CEF is enabling and strengthening the synergies between the three sectors: transport, energy, digital.

Some funding to support energy efficiency and renewable sources implementation is available through **European Regional Development Fund (ERDF)** and **Cohesion Fund (CF)**. The **ERDF** provides funding to public and private bodies in all EU regions to reduce economic, social and territorial disparities. ERDF finances programmes as shared responsibility between the European Commission and national and regional authorities in Member States (European Commission, 2023b). The **Cohesion Fund (CF)** provides support to EU countries with a gross national income per inhabitant below 90% of the EU average. CF funds capital-intensive environmental and transport investments, which could also include renewable installations.

European agricultural fund for rural development (EAFRD) & rural development funds: EU countries implement EAFRD funding through rural development programmes (RDPs). In these programs, some funding is available for energy efficiency improvement and renewables. These programs are co-financed by national budgets and are developed on either a national or regional basis (European Commission, 2023c).

4.2.2 Measures for stimulating sustainable financing in the private sector

Commission is looking into additional standards and labels for sustainable financial products, such as green mortgages, green loans and green bonds within the **EU Renewed Sustainable Finance Strategy.** The aim is to make sure that energy and resource efficiency lending products are offered more widely and are more visible to consumers.

There is, however, also a need to further unlock private financing. **European Fund for Strategic Investments (EFSI)** (2015-2020) aimed to overcome the investment gap in the European Union (EU) by mobilising private financing for strategic investments which the market couldn't finance alone. It aimed to support strategic investments in infrastructure as well as risk finance for small businesses. The expectation to support €500 billion in investment was finally reached and exceeded. In 2022 **InvestEU** took over as the new long-term financing programme of the European Union, building on the success of EFSI.

The EU Commission has also developed the **EU Taxonomy**, with technical screening criteria for the buildings sector. The aim is to direct private capital towards sustainable investments in energy renovation, relying on Energy Performance Certificates and nearly zero-energy building standards. As part of the forthcoming EPBD revision, the Commission will also consider introducing a 'deep renovation' standard, to enable anchoring significant private financing to transparent, measurable and genuinely "green" investments.

InvestEU acts as a single EU-level investment support programme complementing other EU funding sources. It consists of three components: the InvestEU Fund, the InvestEU Advisory Hub and the InvestEU Portal. It provides technical assistance and financing backed by an EU budget guarantee to unlock private investments building on the experience of the EFSI. There will be dedicated financial products for energy renovation of buildings targeting the residential sector and focus on social and affordable housing, public buildings, schools and hospitals, SMEs and support for ESCOs to mainstream energy performance contracting. Drawing on the experience gained with earlier initiatives the Commission will also work to facilitate means for a Member State to transfer part of the funding available under cohesion policy to the Member State compartment of InvestEU. The €26.2 billion EU budget guarantee backs the investments of financial partners (the "implementing partners"), increasing their risk-bearing capacity and thus allowing to mobilise at least €372 billion in additional investment. (European Union, 2023)

4.2.3 Capacity building and research

Capacity building and technical assistance is often required for preparing a good renovation project. It is suggested that EU can play a stronger role also in these activities. Current example is **ELENA (European Local Energy Assistance),** which funds the preparations and background research of local operators' own investment programmes striving to prevent climate change. The most central investment programmes supported by ELENA are focused on urban and regional energy efficiency of buildings and public transport as well as the use of renewable sources of energy.

Based on lessons learnt from the ELENA facility and other programmes and facilities the Commission aims at simplifying and reinforcing technical assistance, with a priority objective to reach a larger pool of beneficiaries. It is proposed that strengthened financing for the ELENA facility would come from the **InvestEU** advisory hub and possibly from other European programmes. The Commission and EIB aim at helping Member States to design national or local programmes replicating the ELENA model and to reward fast implementation and high energy performance using following financing streams: cohesion policy funds (as a stand-alone support or as a part of a financial instrument operation), the Member State compartment of InvestEU, or the Recovery and Resilience Facility. There are also various capacity building sources.

Horizon Europe will support e.g. research and innovation on energy technologies, sustainability and circularity of materials and systems for construction. In the Horizon Europe Programme implementation, the Commission is considering a Public-Private Partnership on People-centric Sustainable Built Environment (Built4People) and a dedicated Mission on Climate-Neutral and Smart Cities.

LIFE programme is the EU's funding instrument for the environment and climate action. It has four sub-programmes, including those on Climate change mitigation and adaptation and Clean energy transition. (CINEA, 2023)

The **Innovation Fund** is the EU fund for climate policy, with a focus on energy and industry. It aims to bring to the market solutions to decarbonise European industry and support its transition to climate neutrality while fostering its competitiveness. (European Commission, 2023d)

One of the priority areas of **European Social Fund + (ESF+)** is reskilling and upskilling people for the transition to a green and digital economy.

4.3 Finland

4.3.1 Funding for energy efficiency or RES in buildings

In Finland, a good source for information about available funding is the state-owned sustainable development company Motiva. Its main aim is to provide "*the public sector, businesses, municipalities and consumers with information, solutions and services that allow them to make resource-efficient, effective and sustainable choices*". As one of the activities, they have recently opened a web-service that provides companies and municipalities information about available funding sources for energy efficiency improvements and renovation. In November 2023, it lists 20 different sources of funding, for different stages of the projects, provided by national and EU-level institutions (e.g. Housing Finance and Development Center ARA, Business Finland, Finnvera, Municipal financing, different banks, EU).

On Motiva's site (https://www.motiva.fi/ratkaisut/energiatehokkuuden_rahoitus), there is also a good amount of information of funding for consumers and housing companies about funding for

energy efficiency improvements (in Finnish). Less information is available about funding for renewables.

In 2020 a Finnish expert reported about the effect of incentives to the energy efficiency improvement: "*Incentives also have an important leverage effect on business and municipalities. Since 2008, a total of well over EUR 160 million in energy support has been granted to more than 4,200 projects, of which energy efficiency investments account for more than 90%. Within the same time period, in Energy Contract operation with more than 30 000 energy efficiency improvement measures an annual energy saving effect of 23 TWh has been reached, which corresponds to more than half a million annual average Finnish carbon footprint*." (Laitila 2020)

Many of the funding instruments or organisations in Finland offer funding for new buildings and renovation, as well as renewable installations. These include the following:

- Household deduction
- Purchasing as a service/leasing
- Green bonds
- Municipal financing
- Housing Finance and Development Center ARA
- Energy subsidies
- Business Finland
- Finland's recovery and resiliency plan (RRF)
- Nordic Investment Bank
- Grant for giving up oil heating in a detached house
- Other sources

Household deduction

One opportunity available for consumers for funding energy efficiency renovations or RES installations are the household deductions. The household deduction is a form of tax relief, which is given for buying services for the households. It applies only to the portion of the work, not to supplies or design work. The maximum household deduction is EUR 2,250 per person and 40 % of the costs. The deductible is 100 euros per year per person. (Finnish Tax Administration 2023.)

There has been discussion raised about the equality of this instrument, as it is only applicable to situations where the house owner buys the services, and thus mainly for single family houses. In Finland, the apartments are usually organised under housing companies, who are typically responsible for the parts of the building affecting the energy efficiency and possibilities to use renewable energy.

Purchasing as a service/ Leasing financing

A new service has been developed for housing companies by a service provider and bank where the energy renovation is compensated according to the leasing model with a monthly fee. In this model, the bank finances the energy renovation and the service provider conducts the planning, implementation and follow-up of the renovation. This means that housing association does not have to tie up equity to the project as done before, which supports more energy renovations to pursued. There are currently several providers for the leasing services.

Green bonds

Green bonds are gaining interest also in Finland. Currently green bonds are offered by Ålandsbanken, S-pankki and MuniFin. One successful experiment was done in 2018 by SYK, the University Properties of Finland Ltd, (SYK 2018) which is presented below as an example of how the eligibility rules for green bonds could be defined.

SYK is a nationwide owner and developer of higher education campuses outside of the Helsinki metropolitan area. Altogether SYK owns 1.1 million square meters of space. SYK is owned by the Government of Finland and ten Finnish universities. In 2018 SYK defined a funding instrument called Green bonds that promote the transition to low carbon and climate resilient growth. Eligible projects for the funding were evaluated and selected by SYK's Green Bond Committee. The eligible projects were selected among the following:

- New properties or major renovation of properties that have or will have a BREEAM certification with a certification level of at least Very Good, and an energy use that is at least 15% lower than that required by the Finnish national building code.
- Existing buildings with BREEAM In-use certification (two parts out of three: Asset and Building Management) with a certification level of at least Very Good
- Energy efficiency projects leading to a reduction of energy use of at least 25%.
- Technical solutions utilizing renewable energy of solar, geothermal or wind power to satisfy the energy needs of properties.
- Clean transportation infrastructure for electric vehicles.

It is clearly stated in the Green Bonds framework that: "*SYK's Green Bonds will not finance fossil fuel generation projects*". Based on the overall assessment of the project types and governance and transparency considerations, SYK's Green Bond Framework received a Medium green shading from external evaluators (second best on the scale, CICERO 2018). The SYK Green Bond funded several successful projects (SYK 2020), and it was planned that a new program would be launched in 2020, but so far it seems to be on hold.

Municipal financing

Municipality Finance Plc, or MuniFin (Kuntarahoitus), is a credit institution owned by the municipalities, the government of Finland and Keva, a public sector pension fund. It is specialised in the financing and financial risk management of the Finnish public sector, offering lending exclusively to Finnish municipalities, their majority-owned companies, and non-profit housing companies.

As one of its funding instruments, MuniFin offers Green funding or Green bonds, which set strict requirements for the projects accepted for funding. The Green Bond Framework, running since 2016, was updated in 2022, to better address environmental challenges as well as to enhance transparency for investors and stakeholders, e.g. related to the criteria for the eligibility. The areas in the new framework cover buildings, transportation, renewable energy and water and wastewater management. The EU Taxonomy as well as the requirements of the proposed European Green Bond Standard (EU GBS) were considered when defining eligibility criteria and overall framework structure for the updated framework from. The examples of eligibility criteria include e.g. energy class A in new buildings, at least 30% reduction in energy efficiency for renovations, renewable energy sources and waste heat. (MuniFin 2023)

Housing Finance and Development Center ARA

In Finland, there is a specific organisation, the Housing Finance and Development Center ARA, which is responsible for implementing the state's housing policy. Although ARA does not provide actual energy subsidies, some of the housing and construction-related loans and grants provided by ARA are relevant for the PEBs, e.g. the interest subsidy loans for the new production, renovation and acquisition of housing or the guarantee loans for the construction of rental houses and the renovation of housing companies. The repair allowances offered by ARA for the elderly and the disabled could also be useful for funding part of a comprehensive renovation that also includes e.g. RES installations. ARA also provides support to residential properties for the construction of electric car charging infrastructure. Each year, the Parliament decides the amount and weighting of the loan approved by ARA. The application period for ARA funding is continuous. Unfortunately, the current Finnish Government has suggested to stop the funding for many of the ARA funding instruments in the coming budget, so it seems that this funding will not be available in the (near) future.

In addition, ARA has development money in use every year, which is also allocated to projects that promote energy efficiency (e.g. the Monitoring of Energy Efficient Model Solutions and the Resident Perspective study, Pesola et al 2016).

Energy subsidies for energy efficiency improvements were granted by ARA until the end of 2022. The purpose of this was to promote the development of new and innovative solutions to transform the energy system into a low-carbon one. The support was meant for companies and communities of all sizes, for example municipalities, parishes and foundations. Energy support was meant for investment or exploration projects that encourage energy saving or support efficient energy production or use.

Energy subsidies that were available in 2020-22 included subsidies for investment projects and new technology projects. For investment projects the following subsidies were available:

- 20% for companies and entities that have signed energy efficiency agreements.
- 25% when using the ESCO service.
- 15% for non-energy efficiency companies and entities when using the ESCO service.
- Projects involving new technologies could also receive increased support on a case-by-case basis (20-40%) for companies and municipalities not covered by energy efficiency agreements.

For new technology projects, energy support of up to 40% was provided for investments in renewable energy sources as well new energy technologies.

Business Finland

The Finnish Government pays the financial incentives for companies mainly through Business Finland, where the incentives have been centralized in the last few years. The Smart Energy Finland program (in 2017-2021) supported internationalization and exports for companies to develop and adopt smart energy solutions (Business Finland 2023). Approximately, hundred million euros were granted by the Program and the priority were SMEs and growth-oriented companies. Focus segments were waste-to-value, bioenergy, biofuels, smart grids, district energy, hydrogen, power-to-X and batteries. The program covered 40% of costs for large companies and 50% for SMEs. There was funding available for both individual companies and business ecosystems. HYBGEO, the sister project of EXCESS, was one of the projects funded by Smart Energy Finland program.

Business Finland also grants 20% investment for solar or heat production projects for large companies while also providing low-interest loans to companies. Moreover, the Finnish government

pays 40-60% of energy audit costs for SMEs whereas large companies have a statutory obligation to do energy-audit every four years.

Finland's recovery and resiliency plan (RRF)

The reforms and investment in Finland's plan are helping it become more sustainable, resilient and better prepared for the challenges and opportunities offered by the green transition and digital transition. Total value of the plan amounts to 1,822M€ which is almost completely financed by the RRF. Funding for the Sustainable Growth Programme for Finland will come mainly from the EU Recovery Plan 'Next Generation EU'. The plan consists of:

- 37 investment streams and 18 reforms
- 50.1% of the plan will support climate objectives
- 29.6% of the plan will foster the digital transition

The funds would be allocated as follows:

- speeding up permit procedures in a manner compatible with the regional government reform, EUR 32 million
- R&D and pilot projects relating to clean energy and material flows, EUR 40 million
- investments in the clean transition, EUR 55 million.

All measures have to be implemented within a tight time frame, as the Regulation establishing the Recovery and Resilience Facility requires all milestones and targets within the national plans to be completed by August 2026.

Nordic Investment Bank *also* provides funding that can be used in Finland. This funding is available for projects on energy efficiency and renewable energy.

Grant for giving up oil heating in a detached house

One of the funding sources that are especially relevant for renewables is the grant for giving up oil heating in a detached house, which was launched in 2020, although it can also be used for changing to other than renewable heating sources (e.g. district heating). Centre for Economic Development, Transport and the Environment offers a grant for the owners of detached houses to switch from oil heating to another form of heating. The grant is EUR 4,000 when the detached house is converted to district heating, ground heat or an air-to-water heat pump. Other forms of heating are assisted with EUR 2,500. A grant may be awarded for costs incurred after 1.6.2020. By November 2023, more than 32 000 applications had been received, and almost 26 000 houses had received a positive response. The processing time was approximately 6 months. This grant is removed from the Government's budget starting from 2024, but the grants are continued to be distributed as long as the current allowance lasts, but not after August 2025. (ELY-keskus 2023)

Other potential sources

Electricity Feed-in Tariff started in Finland in 2011 and it will continue until 2030. In this, the Finnish government will pay the difference between the target price defined by the law and the market price for the producer. In 2018, the Finnish government paid 255,8 million euros for Feed-in Tariffs, although the feed-in tariffs have been criticized for being too generous and inefficient.

On the other hand, *White Certificates and On Bill Financing* system are less widely used since Finland had already developed its own certificates and incentives systems before the development of the other systems. In addition, the Finnish market could be also a market too small for White Certificates.

4.3.2 Relevant funding sources for the Finnish demo

The Finnish demo is a new construction, so the renovation related financing is not relevant in this case. The housing company's company loan is a green loan. The condition for the loan was that it must meet certain green criteria, which it of course easily does. The conditions for the loan were a bit more beneficial than in normal case, but the main benefit of the green status was being able to get the loan in first place.

Hitas system is not a funding instrument in its strict meaning, but as it is very relevant for the Finnish demo case, it is worth presenting here. It is a system for regulating the price and quality of apartments in Helsinki, Finland. The idea is to provide affordable owner-occupied apartments to the citizens in Helsinki. Apartments within the Hitas system are set a maximum selling price already when the lot is signed over for construction, and this maximum selling price may not be exceeded even when selling the apartment afterwards. The system includes approximately 18 000 apartments in Helsinki, situated on lots rented from the city. This is the main benefit for the construction company, making it easier to agree on the renting of nearby lots for free market price construction.

4.3.3 Recommendations on improved funding schemes for the Finnish demo

In the second CIW in Finland, the participants recognised several points that will help in finding funding for PEBs, grouped in the following clusters:

- Practical examples and peer support
- Attention to long term financial effects
- Clear communication
- Create stimulus for increasing energy efficiency

Additional ideas, on how to improve the financing for energy renovation is also provided through events such as Finland's *Sustainable Energy Investment Forum* in 2020 and 2021 (European Commission 2020d, Motiva 2021). The purpose of the events was to promote dialogue amongst key stakeholders on the energy efficiency funding opportunities available and how they are available to different actors. Moreover, stakeholders also identified common objectives and development needs related to the current policy framework and business practices. Often energy renovations are not undertaken due to reasons such as lack of knowledge about opportunities, perspectives and risks. However, with the introduction of national programs and directives, a positive change could happen in the future. The need for additional capacity building, especially on the residential sector was underlined in the discussions.

Finland has just recently finalised its ***long-term renovation strategy*** in accordance with the EPBD. (Kauppinen 2020) It concerns residential and service buildings completed by the beginning of 2020 (in total 1.4 million buildings). The aim in the strategy is to reduce CO_2 emissions from buildings by 90% from the beginning of 2020 by 2050. The strategy presents cost-effective ways to reach the targets, to make the existing building stock highly energy efficient and low carbon by 2050. It also includes examples of cost-effective renovation measures and their financing. These include the sources mentioned above: own funds, loans and household deduction for house owners, Green bonds, EIB, NIB. The strategy also mentions the challenges that short-term funding schemes may create: they may disturb the market, raise the price levels and lead to hasty decisions on the

renovations. Long-term schemes would also allow more time for the planning and implementation, leading to better solutions. Therefore, it is recommended that the financial incentives should be long lasting and predictable. They should also include funding for planning of renovations. The public funding should be allocated also to projects that develop new solutions to the market.

4.4 Austria

Even though GHG emissions from buildings have decreased over the past decades in Austria, there is still a high savings potential in this sector. Building related targets and policy measures are outlined in the Integrated National Energy and Climate Plan for Austria (NECP, Federal Ministry Republic of Austria, 2019). According to the NECP, Austria foresees funding schemes for thermal renovation of buildings, renewable heating, rooftop solar panels, as well as small-scale storage programs. Conventional incentives are usually given in the form of investment grants, annuity subsidies or special credit conditions. Many incentives for private households are offered from the housing subsidies authorities or other institutions at the federal state level. At the federal level, incentives are processed by the KPC (Kommunalkredit Public Consulting).

In 2023, the Austrian Government published an agenda for green financing intending to mobilize private capital and to move financing streams towards sustainable projects. The goal is to identify green finance instruments, to advance investment reforms, which enable a transition towards a low emission and efficient economy. It further aims to provide a sustainable, seminal and secure investment environment and to prevent negative "Lock-in effects". This plays an important part in reaching the climate and energy goals. (Federal Ministry Republic of Austria, 2023)

4.4.1 Funding for energy efficiency or RES in buildings

The Austrian long-term renovation strategy (OIB, 2020), the National Energy and Climate plan (Federal Ministry Republic of Austria, 2019) and the Recovery and Resilience Plan (European Commission, 2023f) of Austria define the basic policies, targets and measures related to the renovation of buildings. This section outlines all nationwide incentives for the cost-efficient renovation of buildings.

- Heating system replacement ("Raus aus Öl und Gas")
- Renovation bonus ("Sanierungsbonus")
- Clean heating for everyone ("Sauber Heizen für Alle)
- Heating system replacement ("Raus aus Öl und Gas")
- Heating optimization for multi-storey residential buildings ("Heizungsoptimierung im mehrgeschossigen Wohnbau")
- Thermal component activation ("Bauteilaktivierung")

Heating system replacement („Raus aus Öl und Gas") for one-two-family houses
The funding campaign "Raus aus Öl und Gas" for private individuals in one or two family houses, is part of the nationwide renovation offensive by the Federal Ministry for Climate Protection, Environment, Energy, Mobility, Innovation and Technology. This funding scheme supports the switch from fossil-fueled space heating (oil, gas, coal) to new climate-friendly heating systems. Applications for funding can be submitted by (co-)owners, building permit holders or tenants of a single-/two-family house or terraced house. The funding amounts up to 7.500 € and is limited to 50% of the

eligible cost. Eligible costs include costs for materials, (de)assembling, planning and disposal. (KPC, 2023a)

Clean heating for everyone ("Sauber Heizen für alle)

The funding scheme "Sauber Heizen für alle" supports low-income households in switching from fossil-fueled space heating to climate friendly heating systems. The "Clean Heating for All" funding is financed by the federal government and implemented together with the federal states ("Länder") of Austria. The funding is made available exclusively to private low-income individuals. The funding scheme targets low-income households of the two lowest income deciles (EUROSTAT data from Nov 2022) which corresponds a monthly income below 1.554€ for single person household. In any case, valid confirmation of receipt of social assistance or the existence of the GIS exemption are considered proof of social need. If necessary, other benefits/exemptions – such as housing allowance – can also serve as proof. (KPC, 2023b)

Renovation bonus („Sanierungsbonus")

The funding scheme "Sanierungsbonus" is a renovation subsidy for provide individuals in one or two family houses or terraced houses. The funding scheme supports thermal renovations in private residential buildings that are more than 20 years old. Comprehensive renovations that comply with the "Klimaaktiv" standard as well as partial renovations that lead to a reduction in heating requirements by at least 40% are eligible for funding. Applications for funding can be submitted by (co-)owners, building permit holders or tenants of a single-/two- family house or terraced house. The height of the subsidy depends on the renovation activity and varies between 3000€ and 14000€. (KPC, 2023c)

Heating system replacement („Raus aus Öl und Gas") for multi-storey residential buildings

The funding scheme for boiler replacement ("Raus aus Öl und Gas") is also available for multi-storey residential buildings. Similar to the funding scheme above, it supports the switch from fossil-fueled room heating to climate-friendly heating systems. Applicants for funding can be submitted by building owners or their authorized representative (e.g. the property management company) on behalf of the owner of a multi-story residential building or a terraced house complex with at least three residential units/terraced houses. Tenants and owners of individual apartments can also apply for funding if they bear the cost of the change and if the new heating system is centralized. (KPC, 2023d)

Heating optimization in multi-storey residential buildings ("Heizungsoptimierung im mehrgeschossigen Wohnbau")

This funding scheme supports the review and optimization of the existing heat supply in conjunction with investment measures to implement hydraulic balancing in multi-storey residential buildings. Applications for funding can be submitted by building owners or their authorized representatives (e.g. the property management on behalf of the owners). Consulting services for the preparation of a hydraulic balancing (heating optimization), the implementation as well as the associated investment costs and final digitalization measures are supported. Only projects in which both advice and investment measures have been carried out can be funded. (KPC, 2023e)

Renovation bonus („Sanierungsbonus") for multi-storey residential buildings

This funding scheme supports the thermal building renovation of multi-storey residential buildings. Thermal renovation in private residential buildings for multi-storey buildings that are older than 20 years is funded. Comprehensive renovation according to the klimaaktiv standard and individual component renovation of windows are eligible for funding. In addition, green roofs and facades on buildings in the town center are also supported. Either with simultaneous comprehensive renovation

according to the klimaaktiv standard or with existing buildings that have already been renovated, provided they meet the requirements of the comprehensive renovation to the klimaaktiv standard. Applications for funding can be submitted by building owners or their authorized representative (e.g. the property management company) on behalf of the owner of a multi-story residential building with at least three residential units. Private apartment owners can submit an application for funding for the renovation of individual window components. (KPC, 2023f)

Investment subsidy Photovoltaic

The Austrian federal government established an investment grant for photovoltaics and power storage. This funding scheme supports the construction or expansion of PV systems and, in connection with this, new electricity storage systems built at the same time in the calendar year 2023. Investment grants are a one-off grant for the PV and electricity storage system. For PV systems, each individual kWp, and for electricity storage, each individual kWh is supported with a specific funding rate (€/kWp or €/kWh).

Applications for the granting of investment grants for PV systems and electricity storage can be submitted to the respective funding calls. The following funding rates applied to investment funding for photovoltaic systems and electricity storage:

- Category A (0.01 – 10 kWp): 285 euros per kWp
- Category B (> 10 – 20 kWp): 250 euros per kWp
- Category C (> 20 – 100 kWp): 160 euros per kWp (maximum)
- Category D (> 100 – 1000 kWp): 140 euros per kWp (maximum)
- Storage: 200 euros per kWh (maximum 50 kWh net capacity eligible for funding)

Thermal component activation (“Bauteilaktivierung”)

This funding scheme aims to optimize renewable energy usage and energy flexibility through thermal component activation and is of particular importance for the multifunctional façade in the Austrian demo. The program sees itself as a source of inspiration for the innovative planning of thermal component activation, in that the Climate and Energy Fund specifically supports planning services for entire heat supply concepts with component activation as heat storage. Funding can be awarded to property developers whose headquarters and location of the project is in Austria. The program is primarily aimed at new residential buildings with at least 5 residential units, but innovative renovations of multi-story residential buildings are also generally possible. Natural and legal persons who build subsidized and/or privately financed projects with predominantly residential use are eligible to submit applications. The subject of the funding is a planning service for the development of overall solutions for the thermal conditioning (summer and winter) of multi-story residential buildings with optimized use of renewable energy based on the use of the flexibility option of “thermal component activation” as heat storage. (KPC, 2023g)

The buildings to which the developed heat supply concepts are applied must, among other things, meet the following requirements:

- More than 50% of the usable space is used for residential purposes
- Buildings with five or more apartments
- The activated building masses are the only system for room temperature control (except for temporarily operated additional heating systems in lower-level rooms)
- Heating load < 25 W/m² in exposed rooms

Plans for construction projects can be submitted in one of the following categories:

- Use of locally generated renewable energy

- Use of renewable electricity from generation peaks from the grid
- Flexibility options in micro, local and district heating networks

The funding for the planning service for each individual project is as follows:

- Flat rate between 40,000 and 85,000 euros depending on the size of the multi-storey building
- Bonus for participation in scientific monitoring
- Bonus for building renovation projects
- Bonus for projects with a special contribution to the circular economy

Energy-efficient constructed new building incentive ("Neubau in energieeffizienter Bauweise")
The "Energy-efficient constructed new building" incentive is aimed at company buildings that achieve higher requirements than stated in the OIB-Richtlinie (Austrian regulations for construction). Newly built buildings that reduce the heating demand by at least 15% compared to the OIB Richtlinie are entitled to incentives of 30% of the additional investment costs. (KPC, 2023h)

The climate initiative of the Federal Ministry of agriculture, regions and tourisms "klimaaktiv" has introduced national sustainability building standards based on the location, energy and supply, building materials and constructions as well as comfort and health and labeling them as klimaaktiv BRONZE, klimaaktiv SILBER and klimaaktiv GOLD (klimaaktiv, 2023a). Several regional financing schemes take these standards into account as criteria for financing. The Carinthian housing subsidies, for example, increase if a higher klimaaktiv standard is reached. For new rental flats subsidies increase to 8% if klimaaktiv SILBER and to 10% if klimaaktiv GOLD is reached. For new private homes, a bonus is advertised, if the house reaches klimaaktiv standards 180€/m^2 (klimaaktiv SILBER) and 200€/m^2 (klimaaktiv GOLD) are received. Within the housing subsidies regulation, also different requirements and bonuses are mentioned such as a prohibition of fossil fuels, prevention of summer heat, bicycle parking or e-mobility. (klimaaktiv, 2023b)

4.4.2 Relevant funding sources for the Austrian demo

The funding sources were discussed with a group of Austrian stakeholders in a co-innovation workshop. After plenary discussions and smaller group exercises, several essential points of attention were brought forward by stakeholders. Those included for example a call to realise direct, indirect and alternative sources of financing for PEBs to allow for a larger roll out. In addition, stakeholder saw that the new/revised EU directives related to energy efficient buildings have a lot of interesting aspects that could support the roll out of energy efficient buildings, but some aspects, such as the need for an overarching vision/goal that still allows flexibility, while ensuring control.

For the technologies that are used in the Austrian demo case, following funding schemes are applicable:

- Investment subsidy Photovoltaic
- Renovation bonus („Sanierungsbonus") for multi-storey residential buildings
- Thermal component activation
- Heating system replacement

Although the funding schemes "renovation bonus for multi-storey residential buildings" and "Heating system replacement" would be suitable for the technologies that are used in the Austrian demo, the demo owners cannot apply for those subsidies as the building was not used as residential building before the renovation started (former fodder silo).

Earlier work in the EXCESS project showed that renovation to PEB level with multifunctional façade elements is more expensive than a traditional deep renovation with standard façade insulation. This leads to the conclusion that more funding is needed to boost the usage of high efficient multifunctional façade elements. As the multifunctional façade elements are not yet produced in a fully automated mass production, funding for improving manufacturing processes of such elements could reduce the production cost and close the price gap to standard insulation materials.

In conclusion it can be said that there are several funding mechanisms available for the renovation of a building to PEB standard. However, there is no funding mechanism available that directly aims for the achievement of PEB standard. Each funding mechanisms has its own eligibility criteria. In order to incentivise the creation of PEBs, a simplified funding scheme should be defined that incentivises entire technology packages needed for PEB realisation. A good example is the approach tested in Germany called "serial renovation", which is intended to integrate new technical possibilities for the industrial prefabrication of technology packages (prefabricated façades or roof elements) as well as the possibilities of digitalisation into renovation processes.

4.5 Belgium

Belgium has introduced BEN (nearly energy-neutral) credits for houses that comply with the NZEB principles. For a newly built residential house in 2021 this means at least E30 standards and renewable energy production of at least 15 kwh/m^2/year must be reached. Several banks offer financial benefits for energy efficiency measures in newly built and renovated houses. (Vlaanderen. 2023a)

4.5.1 Funding for energy efficiency improvement (renovation)

A renovation credit, more precisely an interest subsidy for renovation loans in combination with a mortgage, is granted for houses to transfer a single-family home from label E/F to A/B/C and for apartments from D/E/F to A/B over the timespan of 5 years starting 2021. The renovation credit must be used for renovation, demolition and reconstruction of the house. It is possible to borrow up to 60 000 euros. For level B it is 45 000€ and label C it is 30 000€. (Vlaanderen, 2023b) The renovation credit is similar for apartments (Table 1).

Table 1: Overview of renovation credit rate discounts

EPC label before renovation	EPC label after renovation	Maximum credit	Discount/subsidy on the interest rate	Estimation of total benefit for a loan period of 20 years
House with EPC label E or F	Minimal EPC-label D	20.000 euro	-2%	4.369 euro
	Minimal EPC-label C	30.000 euro	-2,5%	8.173 euro
	Minimal EPC-label B	45.000 euro	-3%	14.678 euro
	EPC-label A	60.000 euro	-3,5%	22.781 euro
Apartment with EPC label E or F	Minimal EPC-label D	10.000 euro	-2%	2.184 euro
	Minimal EPC-label C	20.000 euro	-2,5%	5.448 euro
	Minimal EPC-label B	30.000 euro	-3%	9.785 euro
	Minimal EPC-label A	45.000 euro	-3,5%	17.086 euro

Starting 2019, an energy loan (at 0% interest rate for the social target group) and (at 1% interest rate for certain non-commercial legal entities and cooperative companies, such as schools, hospitals, non-profit organizations) with a maximum of 15 000 € over a period of 10 years has been introduced to finance energy efficient measures, such as replacement of an old boiler to a newer condensing one (Vlaanderen, 2023c). An energy loan+ (up to 60 000€) is granted after inheritance or donation of a non-energy-efficient home (level E/F for houses or D/E/F for apartments) interest free. If A level is reached 60 000€, B level 45 000€ and C level 30 000€ can be borrowed interest free. In comparison to the renovation credit, the loan is interest free from the start and does not use an interest subsidy. (Vlaanderen, 2023d)

Further, the Flemish government started to support renovation projects for emergency housing (people who buy a house without the means for adequate renovation) with interest free credit lines (max. 1 800 000€/project) for PCSWs and public social welfare contractors for providing interest free loans (max. 30 000€/home). (Vlaanderen, 2023e)

Fluvius, the Flemish grid operator, offers grants for energy efficiency measures in existing residential buildings, such as ventilation systems, heat pumps, heat pump boilers, solar water heaters, solar panels, and insulation improvements. Protected customers further receive a discount coupon for an energy efficient (level C or better) washing machine / refrigerator (150 €). (Fluvius, 2023; Vlaanderen, 2023f)

Small companies have the opportunity to reduce their taxable profit with an increased investment deduction for energy saving investments in industrial processes. Measures which can be categorized under the following categories are eligible:

- Reduction of energy losses
- Recuperation of waste energy
- Improving energetic efficiency
- Energetic valorization of biomass and waste streams
- Using renewable energy
- Sustainable transport (railroad or water-bound transport)

4.5.2 Funding for renewables

There is a general call for projects using green heat, residual heat and heat networks. In the context of the federal COVID recovery plan, this framework will be extended (Kabinet van de staatssecretaris voor Relance en Strategische Investeringen, 2021).

Renewable heat and electricity production is facilitated from the Flemish Government with a premium for micro CHP (<10 kW for biogas systems), a call for green and residential heat, a call for biomethane, and for green electricity. The call for green electricity includes new solar panels with an inverter power greater than 40 kW up to and including 2 MW, new wind turbines on land with a turbine power greater than 10 kW up to and including 300 kW. (Vlaanderen, 2023g)

For certain residential installations, the DSO (Fluvius) grants a premium for installing a heat pump, a heat pump boiler, a solar boiler and the installation of PV panels. For larger installations, there is a renewable energy certificate system installed in the Flemish region for the following renewable energy sources:

- Biomass
- Biogas
- Solar (project specific)
- Wind (> 300kW)

For each MWh of renewable electricity, a certificate is granted taking into account a correction factor ('bandingfactor') which is updated on a regular basis.

4.5.3 Funding for smart technology and digitalisation

There is an increasing demand for digitalization, smart control and energy flexibility to support the electricity grid. Therefore, with the COVID recovery plan, the federal government will also support investments in home battery systems, smart control of heat pumps and electric boilers. This will build further on the existing framework for these technologies.

4.5.4 Funding for all types of buildings, new and existing

New homes have to follow the legal energy standard (the E-level). A newly built building which scores significantly better than the minimum requirements is eligible for a reduction of the property tax, and under certain conditions further receives a premium from the grid operator Fluvius. Reduction of the property tax for energy-efficient buildings:

- Only for new construction, rebuilding and 'full renovation'
- Discount of 50% or 100% depending on the energy standard reached

The funding mechanisms for renovation are being updated also under the incentive of the COVID recovery plan.

4.5.5 Relevant funding sources for the Belgian demo

Subsidies used at Belgian demo side:

- Premium from the network operator for the installation of a heat pump boiler in existing homes and recent new-build homes (Distribution network operator)
- Premium for photovoltaic solar panels (commissioning in 2021) (Distribution network operator)
- Interest free loan for energy efficiency measures which score better than the minimum EPB requirements

4.5.6 Positive Energy Buildings and Social Housing - recommendations on improved funding schemes for the Belgian demo

The Flemish society for social housing provides interest free loans for social housing companies to cover a part of the investment costs for renewable energy technologies in new-built and renovation projects (VMSW, 2022). The following technologies are considered:

Table 2: Flemish Society for Social Housing – overview of simulation table for renewable energy technologies

Technology	Single family house	Apartment
PV installation	1.6 €/KW_p (max 6.400€)	1.6 €/KW_p (max 4.200€)
Solar thermal system	4.900€	3.700€
ASHP	3.200€	2.700€
GSHP	4.800€	3.200€

If the investment for the technology exceeds the tariffs according to the simulation table, the social housing company can receive a loan for the remaining costs. However, the interest rate is higher than the commercial tariffs. Therefore, subsidy mechanisms of 40 to 50% are required to be able to install the equipment at competitive tariffs. This can make it challenging to invest in more expensive renewable energy technologies such as heat pumps and geothermal energy systems for social housing projects.

In a co-innovation workshop organised by EXCESS project, stakeholders discussed in groups how PEBs and other innovative projects could be implemented in social housing. Several issues were addressed including accessing to finance, changing business models and regulation, and sharing knowledge and best practices within the sector.

4.6 Spain

The Integrated National Energy and Climate Plan (NECP) for Spain describes measures for energy efficiency in existing buildings in the residential sector and in service sector buildings that are financed mainly by the Recovery Plan trough different programs, such as the PREE or PREE 5000 programs, as well as other programs financing the integration of renewable energies in buildings (European Commission, 2020e).

Measures aim at reducing the energy consumption of existing residential buildings through energy upgrade activities that enable improvement of the building's energy rating. According to the NECP investments in thermal envelope (facade, roofs and walls) are prioritised over improving the thermal installations for heating and/or air conditioning to reduce thermal demand in order to avoid investments into oversized heating and/or air-conditioning equipment.

Also, the measures for service sector buildings aim at reducing the energy consumption in existing buildings used for services, owned publicly or privately, through energy upgrade activities that will improve their energy rating.

4.6.1 Funding for energy efficiency improvement (renovation)

PREE Programme – Promoting energy rehabilitation and reducing final energy consumption and CO2 emissions in the building stock (IDAE, 2023a)

The PREE programme was approved by the Spanish Government on 4th August 2020. The Spanish building stock currently consumes 30 % of the final energy. However, it has an important potential for saving and incorporating renewable energies. Thus, the objective of the PREE, taking into account, in addition, that only 0.3 % of the existing buildings have carried out interventions in energy rehabilitation, is to give a boost to the sustainability of the existing buildings in Spain, through actions that range from changes in the thermal envelope, to the replacement of thermal generation facilities with fuels of fossil origin by thermal generation based on renewable sources such as biomass, geothermal, solar thermal, heat pump, 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 Programme aims to promote the actions carried out by renewable energy communities or citizen energy communities, as set out in the latest renewable energy and internal energy market directives.

A remarkable aspect of the PREE, in addition to its positive effects on improving energy efficiency and the environment, is its social reach, since special attention is given to the granting of aid to carry out rehabilitation measures in those buildings that welcome vulnerable groups and affected by energy poverty.

PREE is a continuation of the programmes PAREER-CRECE and PAREER II, carried out between October 2013 and December 2018 and which had a joint budget of 404 million euros, allowing the energy rehabilitation of some 80.000 homes in Spain.

PREE budget allocation has become 402.5 M€, which will be managed by the Autonomous Communities, including Andalusia, through the Andalusian Energy Agency. The recipients of the programme are natural or legal persons, public or private. The eligible actions correspond to three typologies:

1. Improvement of thermal envelope

2. Improving the energy efficiency of thermal installations, such as:

- Replacement of conventional energy by solar thermal energy.
- Replacement of conventional energy by geothermal energy.
- Replacement of conventional energy by biomass in thermal installations.
- Improving the energy efficiency of generation subsystems not previously included, such as the heat pump.
- Improvement of the energy efficiency of distribution, regulation, control and emission subsystems of thermal installations.

3. Improvement of lighting installations

In order to qualify for the programme, the actions for which aid is requested must justify the reduction of final energy consumption and carbon dioxide emissions compared to their starting situation, using one of the calculation methods included in Directive 2012/27/EU2. Likewise, buildings must have been built before 2007, and must improve the total energy rating of the building by at least one letter, measured in the scale of carbon dioxide emissions (kg CO_2/m² year), with respect to the initial energy rating of the building.

On the other hand, the eligible actions will be actions in complete buildings of the following uses:

- Single-family buildings.
- Buildings of collective residential typology of housing;
- Buildings for any other use (administrative, sanitary, teaching, cultural, etc.).
- Exceptionally, in view of the building typology or climatic characteristics, the autonomous communities and cities of Ceuta and Melilla may allow in their calls to consider eligible actions on one or more dwellings or premises of the same building, considered individually or on parts of a building.

Eligible actions will not be carried out in newly built buildings, which involve an extension that increases the area or volume built, which entails a change in the use of buildings.

The amount of the basic aid provided for in the PREE programme for actions in complete buildings will be for all types of action of 35 % of the eligible cost, except in the case of energy efficiency improvements in lighting installations, where the aid will be 15%. In the case of renovations in individual dwellings or premises within buildings, this percentage will be 25% and 15%, respectively, being able to count on additional aid depending on the use of the building and, if the criteria of energy efficiency, social criteria or criteria for integrated actions are met. About social criteria, the Royal Decree establishes that actions carried out in housing buildings that have been definitively classified under a public protection regime and in residential buildings located in the Urban or Rural Regeneration and Renovation Areas will be entitled to additional aid.

Likewise, they will be entitled to additional aid for improving energy efficiency, actions that raise the energy rating of the building to obtain an energy class “A” or “B”, on the CO_2 scale, or increase the starting energy rating by two letters.

In addition, integrated actions will be eligible for additional support; that is to say those that combine two or more typologies simultaneously, one of them being on the thermal envelope that implies a decrease in demand of 30% in air conditioning, combined with another action, or on the thermal installation that involves at least the replacement of 60% of the power of the existing thermal generation; or on lighting, in the case of buildings of different use than the house, which involves the renovation of more than 25% of the illuminated surface.

In any case, the condition of integrated action could also be met when always acting on the thermal envelope and in addition, one of the other types of action is replaced by the realisation of a solar photovoltaic installation or other renewable electricity generation technology, with or without accumulation, intended for the self-consumption of the building when its installed capacity is at least 10% of the contracted electrical power.

Buildings rehabilitated by renewable energy communities or citizen energy communities will also be eligible for integrated additional support.

Therefore, by means of additional aid, the basic aid may be increased by up to 15% if it meets the social criterion, up to 15% if the action reaches energy class A and up to 20% if the integrated policy criterion is met.

The total amount of aid shall, however, be limited to the maximum amount resulting from the application of State aid rules.

PREE 5000 programme

The **PREE 5000 programme** (IDAE, 2023b) was approved by the Government of Spain on August 2021 by **Royal Decree 691/2021 regulating the** subsidies to be granted to energy rehabilitation actions in existing buildings, in implementation of the Energy Rehabilitation Programme for existing buildings in municipalities of demographic challenge (PREE 5000 Programme), included in the Regeneration and Demographic Challenge Programme of the Urban Rehabilitation and Regeneration Plan of the Recovery, Transformation and Resilience Plan, as well as its direct concession to the Autonomous Communities.

The inefficiency of the current building stock affects in particular the so-called demographic challenge municipalities, where there are around 6,827 municipalities with up to 5,000 inhabitants, which account for 5.7 million people, 12% of the total population. In the last decade, they have lost eight out of ten population, so that, together, these municipalities and nuclei have 410.000 fewer people than they were ten years ago. In municipalities and towns with less than 1,000 inhabitants, depopulation reaches 86 % of the almost 5,000 municipalities, which have lost more than 200.000 inhabitants in the last decade. In these municipalities, secondary and empty housing accounts for 44%, 15 points more than in the national average, and 30 % of homes are before 1960. In addition, in municipalities and towns with less than 5,000 inhabitants, 9.7% of homes are in a ruinous, bad or deficient state, almost three points more than in the national average; 24.4% of empty dwellings are in a ruinous, bad or deficient state, which, in absolute terms, amounts to 410.225 homes.

Thus, the objective of the PREE 5000, is to give a boost to the sustainability of the building in the municipalities of demographic challenge in our country, through actions that range from changes in the thermal envelope, to the replacement of thermal generation facilities with fuels of fossil origin by thermal generation based on renewable sources such as biomass, geothermal, solar thermal or heat pump and the incorporation of regulation and control technologies, as well as the improvement in energy efficiency in lighting. In this programme one can obtain a better incentive (10% additional)

if to renovation a photovoltaic system is added. This action is called “actuaciones integrada” because combine the improvement of thermal envelope with PV.

The initial budget allocation of EUR 50.000.000 €, is to be managed by the Autonomous Communities, including Andalusia, through the Andalusian Energy Agency.

Sustainable Construction Program of Andalusia. EPA

The Incentives Program for Sustainable Energy Development of Andalusia 2020 “Andalucía es más” (Andalusia is more), funded by ERDF of the 2014-2020 programme and managed by the Andalusian Energy Agency, which offers a specific line of incentives, named Sustainable CONSTRUCTION, endowed with a budget of EUR 180 million. With 38 different types of actions, it is aimed at investments of savings, energy efficiency, use of renewable energies and energy infrastructure in buildings, for private or public use, located in the Autonomous Community of Andalusia, that help society to improve the conditions in which they use energy, with special attention to disadvantaged groups. Work is currently under way on a new ERDF-funded programme of the 2021-2027 programme.

Regarding the energy efficiency, there are financing schemes based on the EIB funds (see e.g. MITECO, 2023).

ANESE, National Association of ESCOs, is a benchmark for investment in energy saving and efficiency. It is a non-profit business platform that aims to structure the ESCO market, a new business model with great business opportunity (ANESE, 2023).

4.6.2 Funding for renewables

Public funding for residential and service sector buildings seems to cover also renewables, such as:

Incentive programmes for the implementation of installations linked to self-consumption and storage, with renewable energy sources (EERR), as well as the implementation of renewable thermal systems in the residential sector, within the framework of the Recovery, Transformation and Resilience Plan (PRTR)

On 2nd June 2021, the Spanish Government approved Royal Decree 477/2021 approving the direct grant by Spanish regions and the cities of Ceuta and Melilla of aid for the implementation of various incentive programmes linked to self-consumption and storage, with renewable energy sources, as well as the implementation of renewable thermal systems in the residential sector, within the framework of the Recovery, Transformation and Resilience Plan.

The budget allocation is 660 million euros from the Recovery and Resilience Facility, which can be extended to 1,320 million euros, which will be managed by the Autonomous Communities, including Andalusia, through the Andalusian Energy Agency.

Renewable generation actions include new photovoltaic and wind installations for self-consumption, which may carry associated storage facilities. The incorporation of storage facilities in existing renewable self-consumption facilities is also considered as eligible actions.

Eligible actions also include solar thermal, biomass, geothermal, hydrothermal or aerothermal technologies (except air-to-air technologies) for air conditioning or domestic hot water in homes.

Residential sector

- Self-consumption Photovoltaic installation: 300-EUR 600/kWp

- Self-consumption wind installation: EUR 650-2,900/kW
- Incorporation of self-consumption storage: 140 – EUR 490/kWh

Government and third sector

- Self-consumption Photovoltaic installation: EUR 500-1,000/kWp
- Self-consumption wind installation: EUR 1.150-4.100/kW
- Incorporation of self-consumption storage: 140 – EUR 490/kWh
- Aerothermal installations: EUR 500/kW (EUR 3.000/housing)
- Thermal Solar Installation: 450-EUR 900/kW (550-EUR 1.800/housing)
- Biomass: EUR 250/kW (2,500-EUR 3.000/housing)
- Geothermal or hydrothermal installations: 1,600-EUR 2.250/kW (9,000 – EUR 13.500/housing)

Publicly owned housing and third sector

- Aerothermal installations: EUR 650/kW (EUR 3.900/housing)
- Thermal Solar Installation: 650-EUR 950/kW (820 – EUR 1.850/housing)
- Biomass: EUR 350/kW (3,500-EUR 4.200/housing)
- Geothermal or hydrothermal installations: 1,700-EUR 2.250/kW (9.550 – EUR 13.500/housing)

Royal Decree 1124/2021 of 21 December 2021 approving the direct grant by autonomous communities and the cities of Ceuta and Melilla of aid for the implementation of incentive programmes for the implementation of thermal renewable energy installations in different sectors of the economy, within the framework of the Recovery, Transformation and Resilience Plan (PRTR)

On December 2021, the Government of Spain approved Royal Decree 1124/2021 of 21 December 2021 approving the direct grant to the autonomous communities and the cities of Ceuta and Melilla of aid for the implementation of incentive programmes for the deployment of renewable thermal energy installations in different sectors of the economy, within the framework of the Recovery, Transformation and Resilience Plan.

- **Incentive programme 1**: Realisation of thermal renewable energy installations in the industrial, agricultural, services and other sectors of the economy, including the residential sector.
- **Incentive programme 2**: Realisation of renewable thermal energy installations in non-residential buildings, establishments and public sector infrastructure.

The budget allocation is 150 million euros from the Recovery and Resilience Facility, which will be managed by the Autonomous Communities, including Andalusia, through the Andalusian Energy Agency.

The renewable thermal technologies included are solar thermal, biomass, geothermal, hydrothermal or aerothermal. For the purposes of the RD are also considered eligible actions, the microgrids of district heat or cold, for which the maximum aid to be received will correspond to the first MW of power of the production plant or the first MW of exchange power.

The Sustainable Construction Program of Andalusia (presented above) is also relevant funding source for renewable installations.

Regarding the financing strategies from the Government towards the private initiatives in RES. There is a bidding process to empower the investments in RES during the 5 years 2020-2025 (MITECO, 2019).

Different banks also offer in their portfolio of financing lines the goal to promote renewable energies.

4.6.3 Funding for all types of buildings, new and existing

All funding described above concerns existing buildings. No aid is provided for new buildings, as they have to comply with the regulations in force at national level, which obliges them to be net zero-energy buildings.

4.6.4 Relevant funding sources for the Spanish demo

The aid described at national level applies throughout the territory of Spain. Therefore, for the building of the Spanish demo, and in the case of a rehabilitation, the aid programs described would be applicable, provided that the solutions to be implemented are market-based. As for aid with ERDF, they are regional competences, so it would be in this case, the Government of Castilla y León is responsible for subsidising the project with regional funds, as defined in its operational programme that must be approved by the European Commission.

As an outcome of a European Project, Enerinvest, a platform focused on financing sustainable projects was created. Although the tool is not available anymore, the Enerinvest team wrote a guide on financing sustainable of projects which still includes many relevant points, both regarding financing, but also generally the planning, legal aspects and benefits (Enerinvest 2018).

4.6.5 Recommendations on improved funding schemes for the Spanish demo

The participants in the second CIW in Spain recognised several points that will help in finding funding for PEBs, grouped in the following clusters:

Empowerment: Self-funding; Create a positive district; Critical mass (more PEBs)

Funding mechanisms: Service provider company; Create a platform for PEBs agents

Communication and visibility: Disseminate information on PEBs; Community contest; Holistic public funding (considering benefits and comfort)

Legal measures and normative framework: Adequate, clear and coherent legal and institutional framework; Simplification of procedures; More economic incentives for PEBs foreseen in Spanish legislation, Economic incentives to the final buyer (CO_2 markets, Personal Income Tax); Social criteria for PEBs funding (for low-income citizens).

5 Technical evidence of potential energy efficiency

The buildings sector is a major consumer of energy and contributes to 39% of CO_2 emissions globally (IEA & UN, 2019). Therefore, for sustainable development and energy transition goals to be achieved, energy efficiency solutions are needed to reduce the energy consumption and carbon footprint of buildings and improve interaction with energy networks (IEA 2019b and 2019c; Ceglia et al, 2022; Campos and Marín-González, 2020). A comprehensive understanding of the technical energy efficiency potential is very important for the design of funding schemes. Therefore, this chapter outlines the basics characteristics of energy efficiency measures in the building sector, as well as the economic potential of energy efficiency.

This chapter focuses on potential energy efficiency solutions for the built environment and discusses research trends, methodological and conceptual gaps and opportunities. It also briefly presents the potential economic effects of the different technology choices.

5.1 State of the art on energy efficiency in innovative building concepts

This section discusses the state of the art on energy efficiency in PEBs and other innovative building concepts from which lessons learned can be transposed to PEBs. In this regard, a collection of scientific articles was made using the Scopus database. Figure 3 shows the authors' keywords co-occurrence map, while Figure 4 illustrates the density map of the main authors' keywords co-occurrence.

According to Figure 3, there is a large variety of concepts and methods associated with the energy efficiency potential of buildings. As can be seen in both Figures, research on machine learning and artificial intelligence methods for the energy efficiency of the building stock has become more widespread, particularly in recent years (from 2020) and requires greater research efforts. Concepts such as Building Information Modeling (BIM), Building Automation and Advanced Energy Management Systems have been increasingly combined over the last years with the concept of energy efficiency of the building stock.

Among the research areas, the one on the building envelope and materials is the subject of considerable interest by the scientific community. Other sources of energy efficiency also include heat pumps, energy storage systems and integration with renewable energy sources, in particular with solar photovoltaic.

Energy efficiency measures are also studied in the context of energy flexible buildings. In particular the joint application and interaction of flexibility and demand response techniques, combined with energy efficiency strategies of HVAC systems and the building envelope, were discussed.

As for the sustainability of energy efficiency actions, Figure 3 shows how aspects linked to economic sustainability ("cost-effective assessment", "techno-economic analysis", etc.), environmental ("life cycle assessment (LCA) ", "circular economy") and social ("fuel poverty", "energy poverty", "energy justice", "Indoor Air Quality", "behavioural change", "collaborative governance" etc.), have been investigated.

However, as emerges from Figure 4, the integration of life cycle assessment approaches in building renovation is limited to only a few studies. Furthermore, most research evaluates the social impact

of energy efficiency measures by calculating the reduction in energy bills and the alleviation of energy poverty, while less attention is paid to thermal comfort and the effects on occupant well-being.

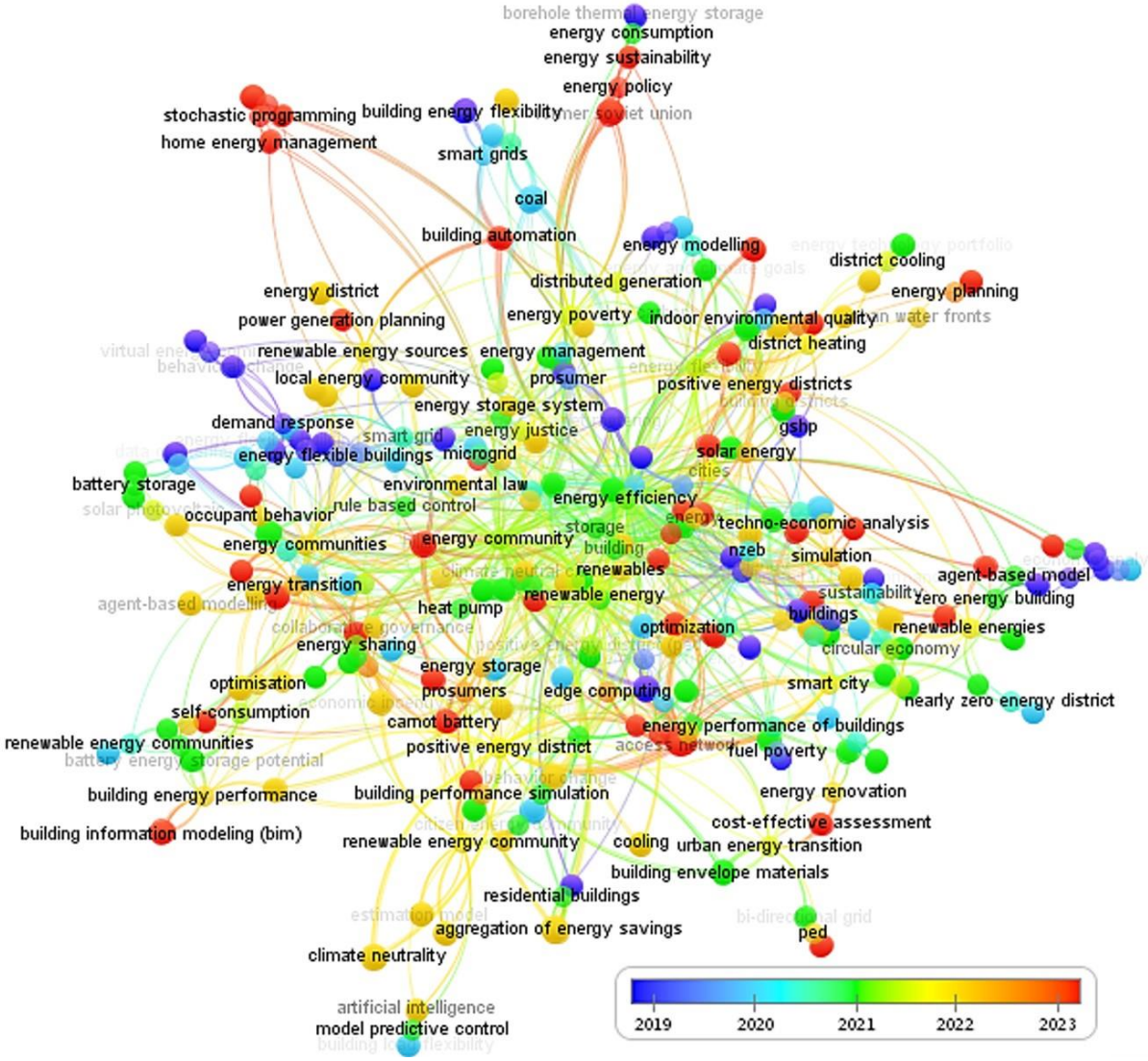

Figure 3: Authors' keywords co-occurrence – Links and temporal distribution

Regarding the building simulation environment, Energyplus, Designbuilder and TRNSYS are the most used. On the other hand, MATLAB is widely used for mathematical programming, although recent developments are also based on the use of Python in combination with TRNSYS, e.g. in Model Predictive Control (MPC) applications (Drgoňa, J. et al 2020). It should be noted that obtaining robust building models, appropriately calibrated based on data, is a central point for the development of reliable energy scenarios.

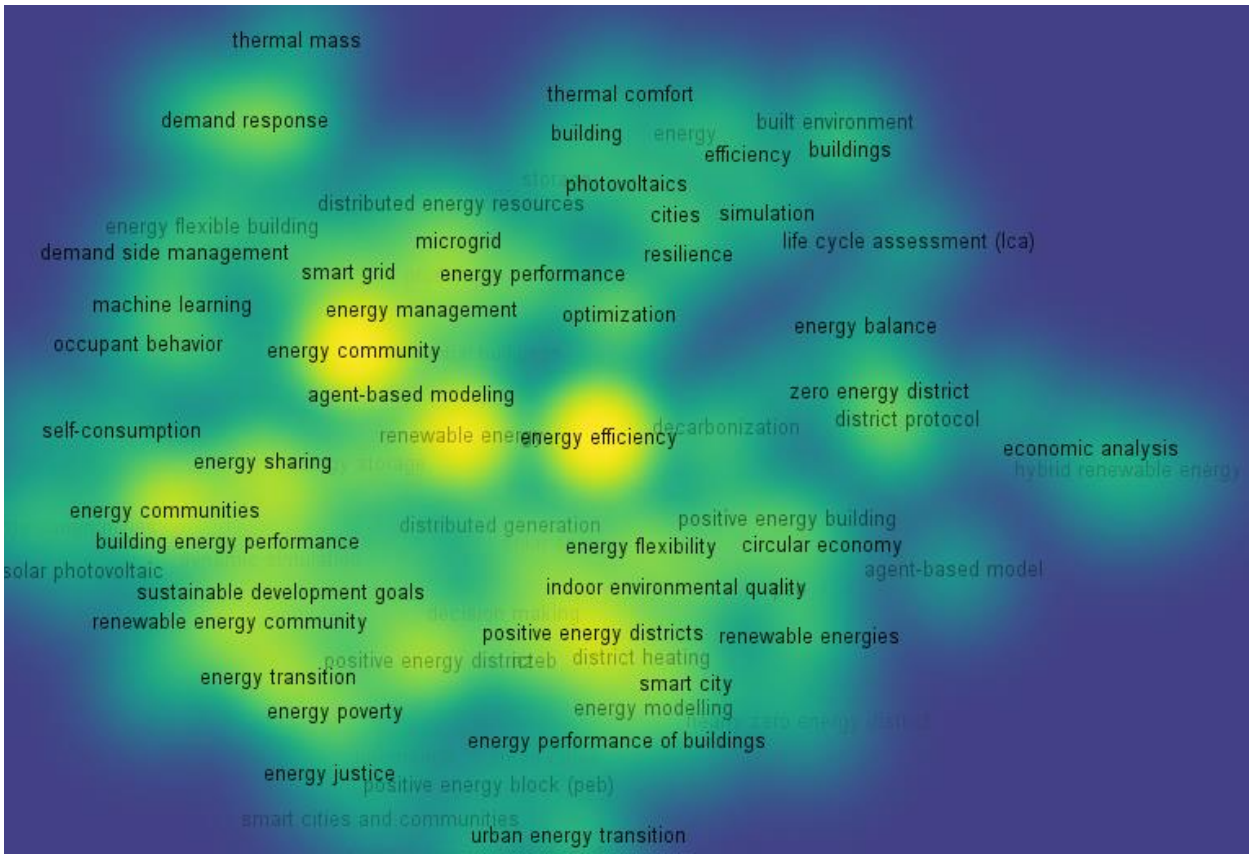

Figure 4: Density map of the main authors' keywords co-occurrence. A greater intensity of yellow corresponds to areas of greater research intensity. Conversely, the predominance of blue tones represents keywords associated with a greater lack of literature studies.

5.1.1 Building envelope and passive solutions

The building envelope plays a predominant role in reducing the energy demand of the building stock at several latitudes. For hot and arid climates, some authors find that wall insulation reduces energy consumption, mostly due to space cooling, by about 40%, and CO_2 emissions by 32% (Rakhshan & Friess, 2017). Furthermore, the use of low-cost reflective materials for walls and roofs, low-emissivity glazing and shading systems is recommended. Even in cold climates, deep renovation leads to significant energy savings (Felius et al 2020). As an example, Felius et al. (2020) and Bruck et al. (2022) delve into its effects on achieving a positive and net zero energy balance, respectively. The results show that the renovation of the building envelope in cold climates is of primary importance for energy efficiency, by contributing approximately 63-70% to the reduction of energy consumption with improvement in energy flexibility and interaction with the energy grid.

As for the Mediterranean climate, two districts were modelled and simulated in non-steady state by Guarino et al. (2023) Marotta et al. (2023). More in specific, authors assess the potential for achieving a positive energy balance, respectively, in a group of non-residential buildings in Spain and in Italy. In both studies, building envelope insulation scenarios are modelled and evaluated in terms of energy efficiency, economic impact and environmental performance. As a result, the renovation determines a 47% reduction in the overall energy consumption for space heating, with an increase in energy requirements for space cooling of about 3%. The LCA approach highlights a non-negligible share of embodied emissions compared to use phase emissions. On the same line, the findings by

Marotta et al. (2023) indicate that the joint action of building insulation, integration of solar energy and energy flexibility reduces operational emissions from 33.37 tons CO_{2eq}/y to 19.52 tons CO_{2eq}/y.

In Méndez Echenagucia et al. (2015) multi-objective optimization is used in the early stages of building design. However, for sustainable solutions to be achieved, the optimization should also take into account cost variables, emissions and thermal comfort (Kumar et al, 2020), as well as the life cycle perspective (Marotta et al. 2021).

In addition, other techniques are used to improve building performance with a focus on thermal mass. Among these Trombe/mass wall, thermally activated buildings and use of Phase Change Materials (PCM). A large margin of energy saving and an acceptable level of thermal comfort is due to the incorporation of PCMs in building envelopes (Nada et al, 2019; Afolabi et al, 2019). The IEA/SHC Task 42 Compact Thermal Energy Storage, recommends the use of PCMs especially in case of overheating during summer (Rommel, 2016). Furthermore, Al-Yasiri and Szabó (2021) highlight that most research concerns hot climates, while data in different climatic conditions are limited.

Other technologies are also attracting growing interest. These mainly include the integration of Building-Integrated Photovoltaic (BIPV) modules into the building envelope. Feng et al (2019) emphasize the potential of BIPV systems to achieve zero or positive energy balances, especially when coupled with natural ventilation during summer conditions.

A key figure for energy efficiency is the exploitation of passive solutions. Other passive measures include natural ventilation and free cooling and natural light-oriented design (Chel and Kaushik, 2018), movable shading devices (Pellegrino et al 2015) and behavioural changes, largely overlooked (Ruparathna et al, 2016). Among the new technologies, there is the use of thermochromic windows capable of modulating internal solar radiation by acting on the optical properties of the glass surfaces (Aburas et al, 2019). The potential of such devices in hot climates is high (Cannavale et al, 2020), however, knowledge on the performance of visual and thermal comfort in buildings is limited.

Green walls can also contribute equally to improving energy efficiency in buildings, with an improvement in Indoor Air Quality (IAQ): 11.7%–40% reduction of NO_2, and 42%–60% of PM_{10} according to Jayasooriya et al (2017). These solutions also contribute positively to the mitigation of Urban Heat Islands (HI), resulting in an expected decrease in urban temperature of about 1.4 °C (Manso et al, 2021).

In recent years the concept of energy efficiency has been associated with that of eco-design, especially considering the significant embodied impacts of high-performance buildings (Gustavsson and Joelsson, 2010; Assiego De Larriva et al, 2015; Sabnis, 2015; Wiik et al, 2018). In this context, and LCA approaches can help to identify sustainable materials to avoid shifting the impacts from the operational phase to the other phases of the building's life cycle.

5.1.2 Energy layout and sustainability performance

Several studies and experiences of Horizon H2020 urban projects combine the replacement and energy efficiency of heating and cooling systems, DHW production with the integration of renewable energy sources. Overall, solar photovoltaic and heat pumps are the most common technologies. Besides BIPV systems, PV are usually installed on the roof of buildings or on parking areas (Guarino et al, 2023; Wang et al, 2019). Geothermal heat pumps are also used in some NZEBs. As an example in Todorović et al. (2019), semi-transparent photovoltaic windows power geothermal heat pumps for space heating.

In addition, some studies highlight the potential for energy efficiency of multi-generation, waste heat recovery and smart control strategies (Piacentino et al, 2019; Pomianowski et al, 2020). Other authors highlight the positive role of Fourth Generation District Heating (4GDH) or Cooling networks in the integration of renewable sources and efficiency of heat pumps due to the lower temperature of the network (Lake et al, 2017).

Furthermore, trigeneration with hydrogen fuel cells can also improve the environmental impact of urban areas and increase energy efficiency. For example, in Fong and Lee (2014), an energy scenario based on the use of a SOFC and absorption chillers achieved a reduction in CO_2 emissions by 50% and overall system efficiency by 75%.

Regarding the energy efficiency of HVAC systems, there are some machine learning applications on fault detection and diagnosis. Other experiences focus on forecasting building demand and learning the energy behavior of occupants. On this line, limitations could include the lack of data to train and validate the model and the limited transferability of the model to other case-studies (Hong et al, 2020).

As for the sustainability performance of building-HVAC systems, it is often evaluated in terms of technical-economic feasibility. Some studies focused on the environmental impacts of energy scenarios, mostly considering the operational CO_2 emissions while other significant impacts on the environment are neglected (Marotta et al, 2021; Röck et al, 2021). Future research is necessary on overcoming environmental hotspots, aimed at extending the results to other impact categories (e.g. environmental pollution, eutrophication, land use etc.) and other life cycle phases. In this context, there is a growing interest in energy efficiency approaches guided by LCA (Marotta et al, 2021), or by LCA and BIM (Najjar et al, 2019) or integrated with LCC in order to also minimize costs. More in general, for buildings to be energy efficient and sustainable, a multi-criteria approach that also take socio-economic and environmental issues into account is needed (Marotta et al, 2021; Hafez et al, 2023).

5.1.3 Energy management and energy flexibility

As discussed in several directives and International Energy Agency (IEA) reports, efficient buildings should rely on flexible control and Demand-Side Management in to improve the contemporaneity between load and generation and provide ancillary services to the grid (IEA & UN, 2019 and 2020; IEA, 2019b; European Commission, 2023a). The combination of energy efficiency and energy flexibility strategies is another key figure for the PEBs to be sustainable, especially in the case of high population density (Erba and Pagliano 2021).

There are several sources of potential flexibility: energy storage devices, electric vehicles, Domestic Hot Water (DHW), movable loads, etc. (Tang et al, 2021; Li et al, 2022). Some authors studied the flexible control of the air-conditioning system, by exploiting the building thermal mass (Péan et al, 2019; Marotta et al, 2021; Clauß et al 2017; Majdalani et al, 2020); and of TES and BESS systems (Marotta et al, 2021; Salpakari and Lund, 2016; Fitzpatrick et al. 2020; Rehman et al, 2021). As an example, the flexibility offered by the thermal mass of buildings is also studied in Marotta et al (2023) and Fambri et al (2023), for renewable or positive energy communities. The virtual energy storage (VES), based on the thermal inertia of buildings, is also compared with traditional storage batteries and studied from a technical-economic point of view by Fambri et al (2023) and also from an environmental perspective by Marotta et al (2023). Buildings are modeled through a second-order thermal resistor-capacitor equivalent model in Fambri et al (2023) and in TRNSYS environment

in (Marotta et al, 2023). The results demonstrated that the VES solution improves self-consumption by 10%-17% and reduces CO_{2eq} of about 2.11 tons CO_{2eq}/y.

Tonnelato et al. (2022) delve into the flexible operation of Ground Source Heat Pumps. TRNSYS and MATLAB are used in order to define a proper Model Predictive Control (MPC) framework.

Overall, although there are experiences on flexibility in NZEBs and PEBs, research is mainly based on the use of energy storage systems, such as BESS and TES. Other potential sources, such as the flexibility offered by the thermal mass of buildings, require further attention in the PEBs and PEDs context. In this regard, the risk of negative effects on peak loads (rebound effects) and thermal comfort conditions of the occupants should be considered (Li et al, 2022). On the other hand, there is a need for detailed building models.

Furthermore, future research could be oriented towards the analysis of the flexibility potential and sustainability of innovative and emerging technologies for the clean energy generation, such as fuel cells (e.g. considering cogeneration layouts, wastewater as input fuel), etc.

Finally, most of the research is focused on the technical feasibility and economic profitability of flexibility approaches, while the environmental dimension requires further attention. In addition, given the interdependence between social, environmental, economic sustainability and energy innovation, some socio-economic aspects of flexibility should be explored, such as citizens' involvement in flexibility practices, social acceptance, influence on energy poverty, etc.

5.2 Economic potential of energy efficiency

This section discusses some results and evidence from real case-studies on energy efficiency in buildings. For this purpose, data from the De-risking Energy Efficiency Platform (DEEP, 2023) is used. As mentioned in the previous chapters, DEEP is an open-source database for energy efficiency investments performance monitoring and benchmarking. DEEP is based on market evidence and investment track records and includes almost 38,000 energy efficiency projects in the civil and industrial sectors.

Available project data on the economic potential of energy efficiency strategies in buildings were selected and analysed. Figure 4 depicts the Levelized Cost of Energy (LCOE) /Avoidance Cost per energy efficiency measure. For each type of measure on the abscissa, the values between the 75 percentile and the 25 percentile (on the total number of reference projects) are plotted (box plot). In addition, the horizontal trend line indicates the median value.

Interventions on the HVAC system and on the building envelope achieve the greatest energy cost savings but, as shown in Figure 4, correspond to higher LCOE.

Considering the building fabric measures, data from 2557 projects are collected. These strategies include the insulation and renovation of the exterior (vertical) walls, roof and floor of buildings; the installation of shading devices and the replacement of windows with efficient glazing and frames.

As per results, the median value of avoidance cost of building fabric measures is equal to 2.53 c€/kWh, while the maximum and minimum values are respectively 5.77 and 1.46 c€/kWh. The

average Payback Time is equal to 10.26 years, while the maximum and minimum values are equal to 15.73 years and 5.25 years.

From the analysis of data at a disaggregated level it emerges that the greatest LCOE are due to the replacement of windows, with a median value of 5.35 c€/kWh. This is followed by the insulation and efficiency of the building roof and vertical envelope and by the shading measures with a median value of avoidance cost equal to 3.24 c€/kWh, 2.29 c€/kWh and 1.84 c€/kWh respectively.

As for the energy efficiency of the HVAC plant, data from 4539 projects are collected. Overall, the median value of avoidance cost is equal to 1.96 c€/kWh, while the maximum and minimum values are respectively about 5 and 0.6 c€/kWh. The average Payback Time is equal to 7.86 years, while the maximum and minimum values are equal to 10.87 and 5.61 years.

Measures relating to the lighting, heating and cooling systems respectively achieve Levelized Cost of Energy (median value) equal to 1.52, 0.84 and 1 c€/kWh with corresponding Payback Times equal to 2.22, 1.78 and 1.5 years.

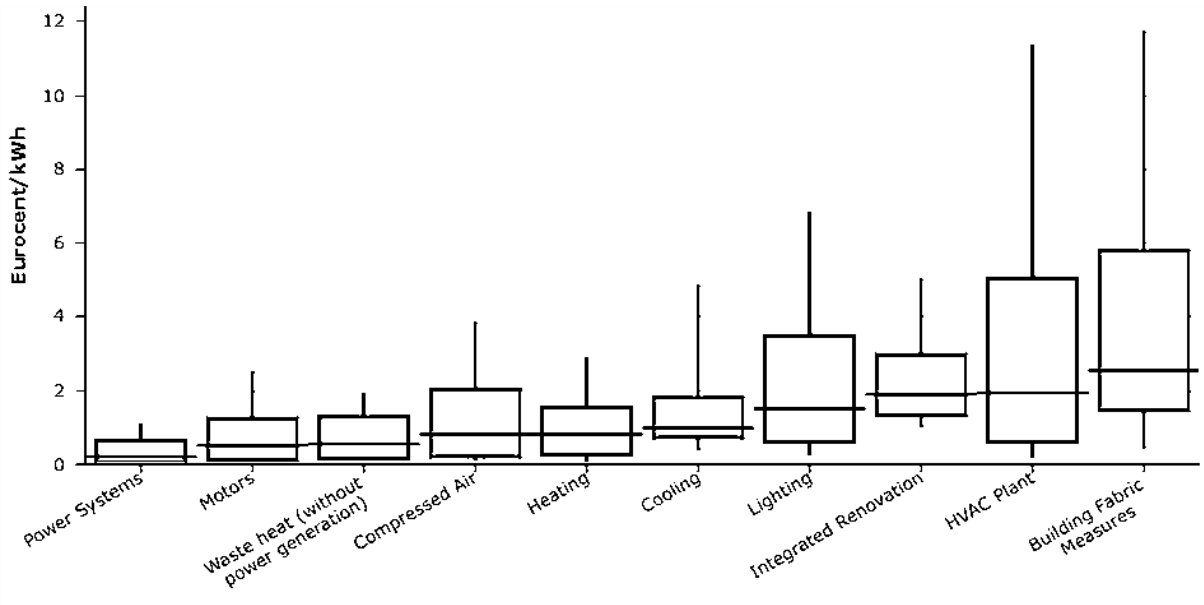

Figure 4: Levelized Cost of Energy (LCOE) per measure. (DEEP, 2023)

Figure 5 illustrates the profile of the Levelized Cost of Energy (LCOE) per building type. As visible, the greatest avoidance costs occur in the case of detached single family dwellings (median value: 6.61 c€/kWh, max: 11.89 c€/kWh, min: 4.15 c€/kWh), corresponding to 725 in the DEEP platform, followed by office buildings according to the 312 projects analyzed (median value: 3,74 c€/kWh, max: 8.78 c€/kWh, min: 1.24 c€/kWh). On the other end, the least avoidance costs occured in projects addressing educational buildings and multi-family buildings with 1-4 storeys.

The present analysis is limited due to the lack of further data available in DEEP platform relating to the technical description of the specific measures and projects which does not allow further investigations on the correlations between variables.

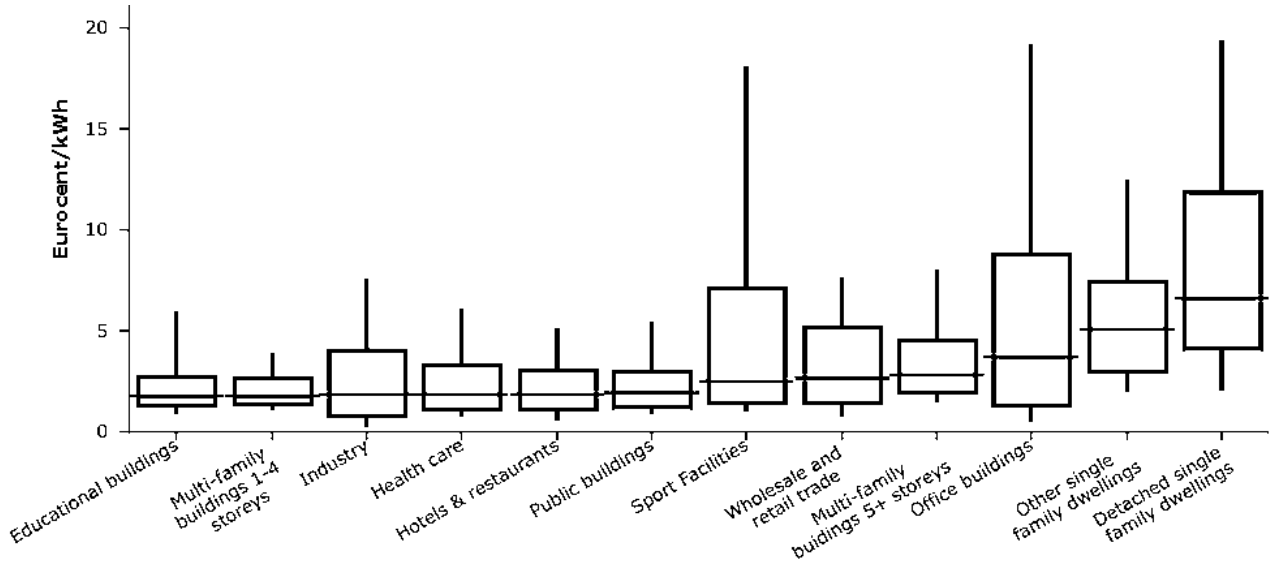

Figure 5: Levelized Cost of Energy (LCOE) per building type. (DEEP, 2023)

6 Valuating energy efficiency

The different ways of valuating energy efficiency and their connection to the funding sources are introduced in this chapter. There are several guidelines and tools available both on international and European level to support the investors and financing organisations in evaluating the value of energy efficiency improvements and the related risks. In many cases, the energy efficiency improvements are included in the evaluation protocols' sustainability and environmental scope.

International Performance Measurement and Verification Protocol (IPMVP) was created for measuring and verifying efficiency investments to facilitate a scaled-up global engagement into energy efficiency. It is owned and maintained by Efficiency Valuation Organization (EVO®), a non-profit organization whose products and services are intended to help the users engineer and invest in energy efficiency projects. It is intended to be a living document that includes methodologies and procedures that enable the protocol to evolve and adapt to changing market conditions and new technologies. (EVO, 2023)

In 2021, the European Commission adopted a proposal for a **Corporate Sustainability Reporting Directive (CSRD)** to extend the existing non-financial reporting requirements in the EU significantly. On 5th January 2023, the CSRD entered into force. This new directive modernises and strengthens the rules concerning the social and environmental information that companies have to report. A broader set of large companies, as well as listed SMEs, will now be required to report on sustainability, increasing the number of in-scope companies from around 10,000 to around 50,000. The first companies will have to apply the new rules for the first time in the 2024 financial year, for reports published in 2025. (European Commission, 2023e)

The new directive introduces more detailed reporting requirements, included in the new mandatory European Sustainability Reporting Standards (ESRS) that is currently developed by the European Financial Reporting Advisory Group (EFRAG). The standards will be tailored to EU policies, while building on and contributing to international standardisation initiatives. The companies are required to digitalize the reported information in order to make it machine readable and accessible through a single access point. The new rules will ensure that investors and other stakeholders have access to the information they need to assess the impact of companies on people and the environment and for investors to assess financial risks and opportunities arising from climate change and other sustainability issues. It is also expected that harmonising the information to be provided will reduce the reporting costs for companies over the medium to long term. (European Commission, 2023e)

The European Committee for Standardization (CEN) published in 2022 a new **standard EN 17463 'Valuation of Energy related investments (VALERI)'** (CENELEC, 2022). This standard, intended to support decision-making on energy related investments, complies with the requirements of the Energy Efficiency Directive (2018/2002/UE) and with the performance assessment of the financial institutions completing the framework for a material reporting and monitoring of the value generated by "green" investments. It includes references on risk assessment aligning the economic evaluation with the analysis required by the Non-Financial Reporting Directive (2014/95/EU) and the framework of EU Taxonomy.

There is also evidence that **certification schemes (e.g. LEEDS, BREEAM)** can help in improving the energy efficiency of the building (Eichholtz et al, 2019). Although points in these rating systems are awarded from variety of qualities, energy is a significant part of e.g. LEED rating, accounting for up to 33 points out of the possible 110 (U.S. Green Building Council, 2023). There is also evidence that energy rating can be monetized in the rent: A review of scientific articles indicated that 27 papers

found a positive correlation between green building certifications and rents (Zhu et al, 2018). This is also supported by the studies by Cloutier et al (2017), who tested the impact of LEED or ENERGY STAR® certification status on several financial variables. Their correlation analysis indicated that "green" properties had higher occupancy, higher market value, net operating income (NOI) and rent per square foot, and lower operating expenses and rent concessions per square foot. One interesting way of valuating ESG rating is presented by Clayton et al (2019), showing that while the ESG rating alone can reduce the energy use (and consequently, the costs) the ESG-related tenant awareness and engagement programs play crucial roles in reducing energy consumption.

Somewhat contradictory findings are presented by Broberg et al (2019), who studied the effects that **energy performance certificates (EPC)** had on Swedish house owners' willingness to invest on energy efficiency improvements. They found that the EPCs seemed to have no or a very minor effect on these investments, but the reason might have been more on the house-owners unfamiliarity to the EPC. In Norway, the situation was better, according to a study by Khazal and Sønstebø (2020). They found that EPC labelled dwellings had a premium compared with non-labelled dwellings, and that the premium was also increasing with a higher EPC-label. Professionals (real-estate agents) assigned higher rents compared with non-professionals (homeowners). In their later analysis (2023), they found that improving the energy efficiency of the dwelling with one letter on the EPC rating seems to have similar effects for both rental and sales objects, with a price impact of about 0.8-1.0%.

The ESG (Environmental, Social Governance) rating can also be used for insights about how energy efficiency is valuated, as in that rating, the E is often weighted higher than the other two subjects. The good news is that (according to KPMG 2022) sustainability reporting has grown steadily: 96% of the world's top 250 companies (= G250[1]) are providing some form of sustainability reporting. The challenge is that there is contradictory evidence on the impact of ESG rating to profit and in general, the unclarity of the message given by the rating. An overwhelming focus of the ratings also seems to be on sustainability risk and not on impact (GRI, 2022). One big issue is also the variety of ways for producing the scores, and the data used for these (KPMG, 2020; Brounen and Marcato, 2018). The diverse range of reporting standards currently used around the world makes comparison across companies and markets challenging, but there are global efforts to align the metrics. Also, the reporting of the environmental risks in 2022 was mostly in form of narrative description of the potential risks. Only 4% of G250 companies provided financial quantification of potential risks. (KPMG, 2022)

The increased understanding of the potential value of energy efficiency, and its potential to reduce the risks for investments has motivated the development of green loans, and other financing instruments that give better terms for greener investments, so-called green tagging. The problem here is the same as in ESG rating: the lack and unclarity of data. Here, initiatives like the DEEP platform will help, providing benchmarking data using and comparing the energy performance and payback period, in case of DEEP for 38 000 European energy efficiency projects. (DEEP, 2023)

Another guideline offered for especially financial institutions to scale up their deployment of capital into energy efficiency is the Energy Efficiency Financial Institutions Group, EEFIG toolkit, taking a wide view on the value and risks that energy efficiency can bring to the project. It will help financial institutions better understand the nature of energy efficiency investments and therefore better evaluate both their value and the risks. The idea is to provide a common framework for

[1] World's 250 largest companies by revenue based on the 2021 Fortune 500 ranking (KPMG 2022)

evaluating energy efficiency investments and analysing the risks. On the other hand, with the help of the tool the developers and owners of energy efficiency projects will be able to develop projects in a way that better addresses the needs of financial institutions. Finally, the aim is to foster a common language between project developers, project owners and financial institutions. (EEFIG, 2023)

One barrier for the valuation is that, while the benefits of energy efficiency and renewable installations are known and appreciated, the income is generated too slowly for the taste of the investors (RenOnBill, 2022). New business models could possibly mitigate this barrier.

7 Conclusions

This report starts with a short reminder of the background on the benefits of energy efficiency and renewable energy sources, and the European level legal framework. Next, the financing schemes available for PEBs are analysed, starting with short summary of general funding sources and the funding instruments available on European level. Then, a review and analysis of the technical and economic evidence on potential of PEB solutions is followed by a description of different ways of valuating energy efficiency and sustainability at large, as these are often intertwined in the rating tools.

The benefits of PEBs include those related to energy efficiency, but also those related to the use of renewable energy sources. Energy efficiency leads to reduction of both energy costs, vulnerability to energy and fuel price spikes, as well as operating and maintenance costs. In addition, it decreases greenhouse gas emissions and dependence on imports. It may also reduce negative effects on health and environmental risks. Renewable energy can e.g. generate new sources of growth, increase incomes, create jobs and improve welfare.

The legislation sets the scene for the PEBs and also partly for the funding, as the funding instruments are usually structured for supporting the legal framework. The key instruments on European level are the Energy Performance of Buildings Directive (EPBD) introduced in 2002 and its revisions in 2010, 2018 and 2023. EPBD sets the targets and minimum requirements for the energy efficiency of buildings and their systems. This was further supported by the Renovation Wave strategy, with priorities in tackling energy poverty and worst-performing buildings, renovation of public buildings, and decarbonisation of heating and cooling. The recast of EPBD as part of Fit-for-55 package set new requirements for new buildings and renovation, targeting the zero emission starting from 2028. It also includes requirements to equip buildings with solar technology. Other elements in the EU-level legal framework that are relevant for PEBs include Energy Efficiency Directive (EED) and the Renewable Energy Directive (RED), which were also revised as part of Fit-for-55 package. The RePowerEU communication package launched in 2022 includes a number of strategies, action plans and recommendations to increase the capacity of renewable energy in the European Union. The realisation and detailed planning of these EU-level targets, strategies and directives are mostly left for the individual Member States, so the practices and emphases may vary in the individual countries.

Regarding the technical potential, there is a large variety of concepts and methods associated with the energy efficiency potential of buildings. Research on machine learning and artificial intelligence methods for the energy efficiency of the building stock has become more widespread, particularly in recent years. Concepts such as Building Information Modelling (BIM), Building Automation and Advanced Energy Management Systems have been increasingly combined over the last year with the concept of energy efficiency of the building stock. Among the research areas, the one on the building envelope and materials is the subject of considerable interest by the scientific community. Other sources of energy efficiency also include heat pumps, energy storage systems and integration with renewable energy sources, in particular with solar photovoltaic. The aspects that have gained less attention include life-cycle assessment in connection with building renovation, and the social impact of energy efficiency measures is most often limited to the reduction in energy bills and the

alleviation of energy poverty, while less attention is paid to thermal comfort and the effects on occupant well-being.

Regarding the economic potential, from the analysis of the data available in DEEP platform related to the energy efficiency investments in 2557 projects, it seems that interventions on the HVAC system and on the building envelope achieve the greatest annual energy cost savings but lead to higher LCOE. On building envelope, the smallest avoidance costs (LCOE) are gained by shading measures, followed by insulation and efficiency of the building roof and vertical envelope. Regarding the building type, the greatest avoidance costs occur in the case of detached single family dwellings, followed by office buildings. On the other end, the least avoidance costs occurred in projects addressing educational buildings and multi-family buildings with 1-4 storeys.

There is evidence that energy efficiency and other environmental rating systems affect the value of the building, on increasing rate, although there are also studies not showing a very clear connection, and the effect still seems to be relatively modest. The existence of several rating tools and the way they use the data is creating some confusion, and also some mistrust to the rating systems, created by this confusion. International efforts are however put in standardisation of the different evaluation methods and increased data availability for comparison. Once a common understanding of the rating systems has been gained, these could be used for the development of the funding schemes, so that the more sustainable (and energy efficient) solutions would receive better funding terms than the less sustainable.

A plethora of funding instruments are available on European and national level. Some of the funding opportunities are common and similar for all the countries, such as the own funds, loan or mortgage and crowdfunding. Most of the funding is offered for renovation. As conclusion of our analysis is that there are many different funding opportunities and schemes available for energy efficiency and renewable integration. The wide variety of schemes is actually creating challenges for the investors and house owners, as it is sometimes hard to find the right channel. Also, applying for funding from different providers may create challenges in the timing, as the decision making may have different lengths in different institutions.

From the point of view on PEBs, it is a major challenge that most of the funding schemes are meant to a certain technology. PEB solution can be achieved with different combination of technologies, and it requires the use of several solutions to reach the PEB level. A more holistic approach incentivising technical systems or modular technology packages, such as being tested for prefabricated facades in Germany will be key to accelerate the implementation of PEB technologies.

This requires new ways of formulating the requirements for the funding, and potentially co-operation between the funding agencies. But also funding schemes that specifically target district level renovations may be of high importance. More holistic funding may require the consideration of new target groups, such as service providers, building renovation aggregators or energy communities. Finally additional criteria for obtaining funds, such as social criteria for low-income citizens next to above mentioned sustainability criteria may play an increasing role to mainstream the PED concept.

8 References

Aburas, M.; Soebarto, V.; Williamson, T.; Liang, R.; Ebendorff-Heidepriem, H. and Wu, Y. 2019. Thermochromic smart window technologies for building application: A review. Appl. Energy **255**, 113522 (2019).

Afolabi, L. O.; Ariff, Z.M.; Megat-Yusoff, P.S.M.; Al-Kayiem, H.H.; Arogundade, A.I. and Afolabi-Owolabi, O.T. 2019. Red-mud geopolymer composite encapsulated phase change material for thermal comfort in built-sector. Sol. Energy **181**, 464–474 (2019).

Al-Yasiri, Q. & Szabó, M. 2021. Incorporation of phase change materials into building envelope for thermal comfort and energy saving: A comprehensive analysis. J. Build. Eng. **36**, 102122 (2021).

ANESE. 2023. National Association of Energy Service Companies. https://www.anese.es/en/home/

Assiego De Larriva, R., Calleja Rodríguez, G., Cejudo López, J. M., Raugei, M. & Fullana I Palmer, P. 2014. A decision-making LCA for energy refurbishment of buildings: Conditions of comfort. Energy Build. **70**, 333–342 (2014).

Bergmann, A.; Burton, B. and Klaes, M. 2021. European perceptions on crowdfunding for renewables: Positivity and pragmatism, Ecological Economics, Volume 179, 2021, 106852, ISSN 0921-8009, https://doi.org/10.1016/j.ecolecon.2020.106852. (https://www.sciencedirect.com/science/article/pii/S0921800919318130)

Bertoldi, P., Economidou, M., Palermo, V., Boza-Kiss, B. & Todeschi, V. 2021. How to finance energy renovation of residential buildings: Review of current and emerging financing instruments in the EU. Wiley Interdiscip. Rev. Energy Environ. 10, (2021).

Broberga, T.; Egüeza, A. and Kažkauskas, A. 2019. Effects of energy performance certificates on investment: A quasi-natural experiment approach

Brounen, D. and Marcato, G. 2018. Sustainable Insights in Public Real Estate Performance: ESG Scores and Effects in REIT Markets. Available at: https://buildings.lbl.gov/sites/default/files/ESG%20measures%20FinalVersion.pdf

Bruck, A., Diaz Ruano, S. & Auer, H. 2022. Values and implications of building envelope retrofitting for residential Positive Energy Districts. Energy Build. **275**, 112493 (2022).

Buildings Performance Institute Europe (BPIE). 2019. Building renovation in the Clean Energy Package: implications at local, national and EU levels. (2019). doi:10.36548/jiip.2019.1

Buildings Performance Institute Europe (BPIE). 2020. Building Renovation Strategies Under the Spotlight Delivering the Energy Efficiency Directive Article 4 -.

Business Finland. 2023. Even smarter energy. Available at: https://www.businessfinland.fi/en/for-finnish-customers/services/programs/ended-programs/smart-energy-finland#about Accessed 4.12.2023

Campos, I. & Marín-González, E. 2020. People in transitions: Energy citizenship, prosumerism and social movements in Europe. Energy Res. Soc. Sci. **69**, 101718 (2020).

Cannavale, A., Ayr, U., Fiorito, F. & Martellotta, F. Smart Electrochromic Windows to Enhance Building Energy Efficiency and Visual Comfort. Energies **13**, 1449 (2020).

Ceglia, F., Marrasso, E., Pallotta, G., Roselli, C. & Sasso, M. 2022. The State of the Art of Smart Energy Communities: A Systematic Review of Strengths and Limits. Energies **15**, (2022).

CENELEC. 2022. The "Valuation of energy related investments" is now a standard supporting the energy transition. Available at: https://www.cencenelec.eu/news-and-events/news/2022/eninthespotlight/2022-01-24-valuation-of-energy-related-investments/

Chel, A. & Kaushik, G. 2018. Renewable energy technologies for sustainable development of energy efficient building. Alex. Eng. J. **57**, 655–669 (2018).

CICERO. 2018. 'Second Opinion' on SYK's Green Bond Framework. Available at: https://sykoy.fi/wp-content/uploads/SYK-Second-Opinion-11-July-2018.pdf

CINEA (European Climate, Infrastructure and Environment Executive Agency). 2023. LIFE Programme. https://cinea.ec.europa.eu/life_en

Clauß, J., Finck, C., Vogler-finck, P. & Beagon, P. 2017. Control strategies for building energy systems to unlock demand side flexibility – A review. 15th Int. Conf. Int. Build. Perform. 611–620 (2017).

Clayton, J.; Devine, A. and Holtermans, R. 2019. Beyond Environmental Building Certification: The Impact of Environmental Interventions on Commercial Real Estate Operations. https://buildings.lbl.gov/sites/default/files/ClaytonDevineHoltermans_RERI-LBNL_FINAL_04302019.pdf

Cloutier, D.; Hosseini, F. and White, A. 2017. Utilizing Commercial Real Estate Owner and Investor Data to Analyze the Financial Performance of Energy Efficient, High-Performance Office Buildings (lbl.gov)

Covenant of Mayors - Europe. 2023. Financing opportunities. https://eu-mayors.ec.europa.eu/en/resources/funding_guide

DEEP.ec.europa.eu. 2023. De-risking Energy Efficiency Platform - View Charts - Buildings. https://deep.ec.europa.eu/viewcharts/buildings/

Drgoňa, J. et al. 2020. All you need to know about model predictive control for buildings. Annu. Rev. Control **50**, 190–232 (2020).

Economidou, M.; Todeschi, V. & Bertoldi, P. 2019. Accelerating energy renovation investments in buildings - Financial and fiscal instruments across the EU. doi:10.2760/086805.

Economidou, M.; Todeschi, V.; Bertoldi, P. D'Agostino, D.; Zangheri, P.; and Castellazzi, L. 2020. Review of 50 years of EU energy efficiency policies for buildings. Energy and Buildings, Volume 225, 15 October 2020.

EEFIG (Energy Efficiency Financial Institutions Group). 2023. The EEFIG underwriting toolkit. https://valueandrisk.eefig.eu/valueandriskappraisal

Eichholtz, P., Holtermans, R., Kok, N., & Yönder, E. 2019. Environmental performance and the cost of debt: Evidence from commercial mortgages and REIT bonds. Journal of Banking and Finance.

ELY-keskus (Elinkeino-, liikenne- ja ympäristökeskus; Centre for Economic Development, Transport and the Environment) 2023. Avustus pientalon öljylämmityksestä luopumiseksi. https://www.ely-keskus.fi/oljylammityksen-vaihtajalle (In Finnish)

Enerinvest. 2018. Guía para la financiación de proyectos de energía sostenible (Guideline on RES projects financing) (In Spanish). https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiC78K3-7bvAhUT3IUKHfeRCMAQFjABegQIFRAD&url=https%3A%2F%2Fwww.ecoserveis.net%2Fwp-content%2Fuploads%2F2019%2F04%2Fguia-para-la-financiacion-de-proyectos-de-energia-sostenible-2a-edicion.pdf&usg=AOvVaw26hsl75ismlmWZ-EUn7BNp

Erba, S. & Pagliano, L. 2021. Combining Sufficiency, Efficiency and Flexibility to Achieve Positive Energy Districts Targets. Energ. 2021 Vol 14 Page 4697 **14**, 4697 (2021).

Erkkilä, R. 2020. Kuntarahoitus. CO2 - Yhdessä vähemmän. (CO2 - Together less) (In Finnish). Presentation in SEI Forum. Available at: https://keskisuomi.fi/wp-content/uploads/sites/3/2020/12/Keski-Suomi_Vihrea%CC%88n-rahoituksen-mahdollisuudet22042020.pdf

EuroPACE. 2018. Europace Readiness Assessment: Legal and Fiscal Analysis of the EU-28.

European Commission. 2018. Recast, E. (2018). Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency. (2018).

European Commission. 2020a. A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. Renovation Wave Communication (europa.eu)

European Commission. 2020b. Kick-starting the journey towards a climate-neutral Europe by 2050 EU Climate Action Progress Report 2020. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0777

European Commission. 2020c. NextGenerationEU: Commission presents next steps for €672.5 billion Recovery and Resilience Facility in 2021 Annual Sustainable Growth Strategy. Available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1658

European Commission. 2020d. National roundtable on financing energy efficiency in Finland; 29 September 2020 Helsinki – Finland. Available at https://www.motiva.fi/ratkaisut/energiatehokkuuden_rahoitus/tilaisuudet_ja_tapahtumat/sei_forum_finland_2020

European Commission. 2020e. Integrated National Energy and Climate Plan 2021-2030 of Spain. https://energy.ec.europa.eu/system/files/2020-06/es_final_necp_main_en_0.pdf

European Commission. 2023a. The European Green Deal; Striving to be the first climate-neutral continent. Available at: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en

European Commission. 2023b. European Regional Development Fund. https://ec.europa.eu/regional_policy/en/funding/erdf/

European Commission. 2023c. Rural development. https://ec.europa.eu/info/food-farming-fisheries/key-policies/common-agricultural-policy/rural-development_en

European Commission. 2023d. Innovation Fund - Deploying innovative net-zero technologies for climate neutrality. https://ec.europa.eu/clima/policies/innovation-fund_en

European Commission. 2023e. Corporate sustainability reporting. Available at: https://finance.ec.europa.eu/capital-markets-union-and-financial-markets/company-reporting-and-auditing/company-reporting/corporate-sustainability-reporting_en

European Commission. 2023f. Austria's recovery and resilience plan. https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility/country-pages/austrias-recovery-and-resilience-plan_en

European Commission. Directorate-General for Energy. 2022. Report on the evolution of financing practices for energy efficiency in buildings, SME's and in industry – Final report, Publications Office of the European Union, 2022, https://data.europa.eu/doi/10.2833/509481

European Parliament. 2023. Energy performance of buildings: climate neutrality by 2050; Press Releases. Available at: https://www.europarl.europa.eu/news/en/press-room/20230206IPR72112/energy-performance-of-buildings-climate-neutrality-by-2050

European Union. 2023. InvestEU Programme. https://investeu.europa.eu/investeu-programme_en

EVO – Efficiency Valuation Organisation. 2023. International Performance Measurement and Verification Protocol (IPMVP). Available at: https://evo-world.org/en/products-services-mainmenu-en/protocols/ipmvp

Fambri, G., Marocco, P., Badami, M. & Tsagkrasoulis, D. 2023. The flexibility of virtual energy storage based on the thermal inertia of buildings in renewable energy communities: A techno-economic analysis and comparison with the electric battery solution. J. Energy Storage **73**, 109083 (2023).

Federal Ministry Republic of Austria. 2019. Integrated National Energy and Climate Plan for Austria 2021-2030. https://energy.ec.europa.eu/system/files/2020-03/at_final_necp_main_en_0.pdf

Federal Ministry Republic of Austria. 2023. Green Finance in Austria. https://www.bmk.gv.at/en/green-finance.html

Felius, L. C., Dessen, F. & Hrynyszyn, B. D. 2020. Retrofitting towards energy-efficient homes in European cold climates: a review. Energy Effic. **13**, 101–125 (2020).

Feng, W. et al. A review of net zero energy buildings in hot and humid climates: Experience learned from 34 case study buildings. Renew. Sustain. Energy Rev. **114**, 109303 (2019).

Finnish Tax Administration. 2023. Household deduction. Available at: https://www.vero.fi/henkiloasiakkaat/verokortti-ja-veroilmoitus/vahennykset/kotitalousvahennys/ (In Finnish)

Fitzpatrick, P.; D'Ettorre, F.; De Rosa, M.; Yadack, M.; Eicker, U. and Finn, D.P. 2020. Influence of electricity prices on energy flexibility of integrated hybrid heat pump and thermal storage systems in a residential building. Energy Build. **223**, 110142 (2020).

Fluvius. 2023. Premies voor huishoudelijke klanten. (In Flamish) https://www.fluvius.be/nl/thema/premies/premies-voor-huishoudelijke-klanten

Fong, K. F. & Lee, C. K. 2014. Investigation on zero grid-electricity design strategies of solid oxide fuel cell trigeneration system for high-rise building in hot and humid climate. Appl. Energy **114**, 426–433 (2014).

Graham, P., Laustsen, J., Ürge-Vorsatz, D. 2013. Going deep in energy consumption in buildings: How to achieve the best case scenario for deep savings in building energy consumption, European Council for an Energy Efficient Economy Summer Study, Pres'que Ile de Giens, France.

GRI (Global Reporting Initiative). 2022. Demystifying ESG raters and rankers. Available at: https://www.globalreporting.org/news/news-center/demystifying-esg-raters-and-rankers/

Guarino, F.; Rincione, R.; Mateu, C.; Teixidó, M.; Cabeza, L.F. and Cellura, M. 2023. Renovation assessment of building districts: Case studies and implications to the positive energy districts definition. Energy Build. **296**, 113414 (2023).

Gustavsson, L. & Joelsson, A. 2010. Life cycle primary energy analysis of residential buildings. Energy Build. **42**, 210–220 (2010).

Hafez, F. S. et al. Energy Efficiency in Sustainable Buildings: A Systematic Review with Taxonomy, Challenges, Motivations, Methodological Aspects, Recommendations, and Pathways for Future Research. Energy Strategy Rev. **45**, 101013 (2023).

Hong, T., Wang, Z., Luo, X. & Zhang, W. 2020. State-of-the-art on research and applications of machine learning in the building life cycle. Energy Build. **212**, 109831 (2020).

ICLEI. 2021. Note with policy recommendations. Deliverable 6.5 from Triple-Areno project. https://triplea-reno.eu/wp-content/uploads/2022/01/Note-with-policy-recommendations.pdf

IDAE. 2023a. Programa PREE. Rehabilitación Energética de Edificios. (In Spanish) https://www.idae.es/ayudas-y-financiacion/para-la-rehabilitacion-de-edificios/convocatorias-cerradas/programa-pree

IDAE. 2023b. PREE 5000. Rehabilitación Energética de Edificios en Municipios de Reto Demográfico. (In Spanish) https://www.idae.es/ayudas-y-financiacion/para-la-rehabilitacion-de-edificios/programa-pree-5000-rehabilitacion

IEA & UN (International Energy Agency & UN Environment Programme). 2019. Global Status Report for Buildings and Construction: Towards a zero-emission, efficient and resilient buildings and construction sector.

IEA & UN (International Energy Agency & UN Environment Programme). 2020. GlobalABC Roadmap for Buildings and Construction.

IEA (International Energy Agency). 2014. Capturing the multiple benefits of energy efficiency. International Energy Agency, Paris.

IEA (International Energy Agency). 2015. Accelerating energy efficiency in small and medium-sized enterprises: Powering SMEs to accelerate economic growth. International Energy Agency, Paris.

IEA (International Energy Agency). 2019a. Energy Efficiency 2019. The authoritative tracker of global energy efficiency trends. https://www.iea.org/reports/energy-efficiency-2019

IEA (International Energy Agency). 2019b. World Energy Outlook 2019-GlobalABC Regional Roadmap for Buildings and Construction in Asia 2020-2050. (2019) doi:10.1787/CAF32F3B-EN.

IEA (International Energy Agency). 2019c. Perspectives for the Clean Energy Transition - The Critical Role of Buildings.

IEA (International Energy Agency). 2023. Net Zero Roadmap 2023 Update – A Global Pathway to Keep the 1.5 °C Goal in Reach.

IMPAWATT. 2019. Benefits of energy efficiency Factsheet. Available at https://eu.impawatt.com/energyEfficiency

IRENA, 2016. Renewable energy benefits: Measuring the economics. International Renewable Energy Agency, Available at: https://www.irena.org/publications/2016/Jan/Renewable-Energy-Benefits-Measuring-the-Economics.

Jayasooriya, V. M., Ng, A. W. M., Muthukumaran, S. & Perera, B. J. C. 2017. Green infrastructure practices for improvement of urban air quality. Urban For. Urban Green. **21**, 34–47 (2017).

Kabinet van de staatssecretaris voor Relance en Strategische Investeringen. 2021. Nationaal Plan voor Herstel en Veerkracht. (In Flamish)

Kauppinen, J. 2020. Suomen pitkän aikavälin korjausrakentamisen strategia (Finland's long-term renovation strategy). (In Finnish) https://ym.fi/korjausrakentamisen-strategia

Khazal, A., & Sønstebø, O. J. 2020. Valuation of energy performance certificates in the rental market – Professionals vs. non-professionals. Energy Policy, Volume 147, 2020, 111830, ISSN 0301-4215, https://doi.org/10.1016/j.enpol.2020.111830.

Khazal, A., & Sønstebø, O.J. 2023. Energy Efficiency Premium Issues and Revealing the Pure Label Effect. The Energy Journal, 44, 33 - 54. https://doi.org/10.5547/01956574.44.1.akha

klimaaktiv. 2023a. KLIMAAKTIV BASISKRITERIEN 2020. (In German) https://www.klimaaktiv.at/dam/jcr:bac0c0f6-dd3d-4487-a9ef-270dd8448ea9/20230824_Brosch%C3%BCre%20Basiskriterien%202020_bf.pdf

klimaaktiv. 2023b. Wohnbauförderung Kärnten 2022: Erhöhte Förderungen für klimaaktiv Gebäude! (In German) https://www.klimaaktiv.at/bauen-sanieren/wohngebaeude/erhoehte-foerderung-kaernten-2021.html

KPC (Kommunalkredit Public Consulting). 2023a. Informationsblatt raus aus Öl und Gas für Private. (In German) https://www.umweltfoerderung.at/fileadmin/user_upload/umweltfoerderung/private/TGS_Priv_2023/Infoblatt_raus_aus_Oel_2023_2024_EFH.pdf

KPC (Kommunalkredit Public Consulting). 2023b. „Sauber Heizen für Alle“ für Private 2023. (In German) https://www.umweltfoerderung.at/privatpersonen/sauber-heizen-fuer-alle-2023/unterkategorie-ein-und-zweifamilienhaus

KPC (Kommunalkredit Public Consulting). 2023c. Sanierungsbonus für Private 2023/2024 Ein-/Zweifamilienhaus/Reihenhaus. (In German) https://www.umweltfoerderung.at/fileadmin/user_upload/umweltfoerderung/private/TGS_Priv_2023/Infoblatt_Sanierungsscheck_2023_2024_EFH.pdf

KPC (Kommunalkredit Public Consulting). 2023d. Kesseltausch Mehrgeschossiger Wohnbau. (In German) https://www.umweltfoerderung.at/privatpersonen/kesseltausch-mehrgeschossiger-wohnbau

KPC (Kommunalkredit Public Consulting). 2023e. Heizungsoptimierung im mehrgeschossigen Wohnbau. (In German) https://www.umweltfoerderung.at/privatpersonen/heizungsoptimierung-mgw/unterkategorie-mehrgeschossiger-wohnbau

KPC (Kommunalkredit Public Consulting). 2023f. Sanierungsbonus Mehrgeschossiger Wohnbau 2023/2024. (In German) https://www.umweltfoerderung.at/privatpersonen/sanierungsscheck-mehrgeschossiger-wohnbau-2023/2024/unterkategorie-mehrgeschossiger-wohnbau

KPC (Kommunalkredit Public Consulting). 2023g. Bauteilaktivierung. (In German) https://www.umweltfoerderung.at/privatpersonen/bauteilaktivierung/unterkategorie-altantraege

KPC (Kommunalkredit Public Consulting). 2023h. Neubau in energieeffizienter Bauweise. (In German) https://www.umweltfoerderung.at/fileadmin/user_upload/umweltfoerderung/betriebe/SUN_Betriebe/UFI_Standardfall_Infoblatt_NEH_NEUBAU.pdf

KPMG. 2020. Sustainable investing: fast-forwarding its evolution. https://assets.kpmg.com/content/dam/kpmg/xx/pdf/2020/02/sustainable-investing.pdf

Kumar, D., Alam, M., Zou, P. X. W., Sanjayan, J. G. & Memon, R. A. 2020. Comparative analysis of building insulation material properties and performance. Renew. Sustain. Energy Rev. **131**, 110038 (2020).

Laitila, P. 2020. Vähähiilisyyttä ei saavuteta ilman energiatehokkuusinvestointeja. (Low carbon is not achieved without energy efficiency investments). (In Finnish) Available at: https://kumppaniblogit.uusisuomi.fi/vieraskyna/motiva-vahahiilisyytta-ei-saavuteta-ilman-energiatehokkuusinvestointeja

Lake, A., Rezaie, B. & Beyerlein, S. 2017. Review of district heating and cooling systems for a sustainable future. Renew. Sustain. Energy Rev. **67**, 417–425 (2017).

Li, R.; Satchwell, A.J.; Finn, D.; Haunstrup Christensen, T.; Kummert, M.; Le Dréau, J.; Amaral Lopes, L.; Madsen, H.; Salom, J.; Henze, G. and Wittchen, K. 2022. Ten questions concerning energy flexibility in buildings. **223**, (2022).

Majdalani, N., Aelenei, D., Lopes, R. A. & Silva, C. A. S. The potential of energy flexibility of space heating and cooling in Portugal. Util. Policy **66**, 101086 (2020).

Manso, M., Teotónio, I., Silva, C. M. & Cruz, C. O. 2021. Green roof and green wall benefits and costs: A review of the quantitative evidence. Renew. Sustain. Energy Rev. **135**, 110111 (2021).

Marotta, I.; Péan, T.; Guarino, F.; Longo, S.; Cellura, M. and Salom, J. 2023. Towards Positive Energy Districts: Energy Renovation of a Mediterranean District and Activation of Energy Flexibility. Solar **3**, 253–282 (2023).

Marotta, I., Guarino, F., Cellura, M. & Longo, S. 2021. Investigation of design strategies and quantification of energy flexibility in buildings: a case-study in southern Italy. J. Build. Eng. **41**, 102392 (2021).

Marotta, I., Guarino, F., Longo, S. & Cellura, M. 2021. Environmental sustainability approaches and positive energy districts: A literature review. Sustain. Switz. **13**, 1–45 (2021).

Méndez Echenagucia, T., Capozzoli, A., Cascone, Y. & Sassone, M. 2015. The early design stage of a building envelope: Multi-objective search through heating, cooling and lighting energy performance analysis. Appl. Energy **154**, 577–591 (2015).

MITECO (Ministerio para la Transición Ecológica y el Reto Demográfico). 2019. El MITECO aprueba la orden para iniciar el calendario de subastas. (In Spanish) https://www.miteco.gob.es/content/dam/miteco/es/prensa/201205primeraordendesubastas_tcm30-518260.pdf

MITECO (Ministerio para la Transición Ecológica y el Reto Demográfico). 2023. Instrumento de financiación privada para la eficiencia energética (PF4EE) (In Spanish) https://www.miteco.gob.es/es/ministerio/servicios/ayudas-subvenciones/programa-life/instrumentos-financieros/instrumento_pf4ee.html

Motiva. 2021. Sustainable Energy Investment Forum Finland 7.10.2021. Available at https://www.motiva.fi/ratkaisut/energiatehokkuuden_rahoitus/tilaisuudet_ja_tapahtumat/sei_forum_suomi_2021

MuniFin. 2023. Green Bond Framework. Available at: https://www.kuntarahoitus.fi/app/uploads/sites/2/2022/12/MuniFin-Green-Bond-framework.pdf

Nada, S. A., Alshaer, W. G. & Saleh, R. M. 2019. Thermal characteristics and energy saving of charging/discharging processes of PCM in air free cooling with minimal temperature differences. Alex. Eng. J. **58**, 1175–1190 (2019).

Najjar, M., Figueiredo, K., Hammad, A. W. A. & Haddad, A. 2019. Integrated optimization with building information modeling and life cycle assessment for generating energy efficient buildings. Appl. Energy **250**, 1366–1382 (2019).

NewBEE. D4.1 Financial Models. 2014. Report from the NewBEE project. Author names not available.

Nykänen, V.; Lahti, P.; Knuuti, A.; Hasu, E.; Staffans, A.; Kurvinen, A.; Niemi O. and Virta, J. 2013. Asuntoyhtiöiden uudistava korjaustoiminta ja lisärakentaminen (Urban infill and residential redevelopment) Espoo 2013. VTT Technology 97. 162 s. + liitt. 3s. https://www.vttresearch.com/sites/default/files/pdf/technology/2013/T97.pdf

OIB (Österreichisches Institut für Bautechnik). 2020. OIB-RICHTLINIE 6; Energieeinsparung und Wärmeschutz; Langfristigen Renovierungsstrategie. https://www.oib.or.at/sites/default/files/oib-ltrs_april_2020.pdf

Péan, T., Costa-Castelló, R. & Salom, J. 2019. Price and carbon-based energy flexibility of residential heating and cooling loads using model predictive control. Sustain. Cities Soc. **50**, 101579 (2019).

Pellegrino, A., Cammarano, S. & Savio, V. 2015. Daylighting for Green Schools: A Resource for Indoor Quality and Energy Efficiency in Educational Environments. Energy Procedia **78**, 3162–3167 (2015).

Pesola, A.; Autio, M.; Alam, J.; Ylimäki, L.; Descombes, L.; Vehviläinen, I. and Vanhanen, J. 2016. Energiatehokkaiden malliratkaisujen seuranta ja asukasnäkökulma. ASUMISEN RAHOITUS- JA KEHITTÄMISKESKUKSEN RAPORTTEJA 1 | 2016.

Piacentino, A.; Duic, N.; Markovska, N.; Vad Mathiesen, B.; Guzović, Z.; Eveloy, V. and Lund, H. 2019. Sustainable and cost-efficient energy supply and utilisation through innovative concepts and technologies at regional, urban and single-user scales. Energy **182**, 254–268 (2019).

Pomianowski, M. Z., Johra, H., Marszal-Pomianowska, A. & Zhang, C.2020. Sustainable and energy-efficient domestic hot water systems: A review. Renew. Sustain. Energy Rev. **128**, 109900 (2020).

Rakhshan, K. & Friess, W. A. 2017. Effectiveness and viability of residential building energy retrofits in Dubai. J. Build. Eng. **13**, 116–126 (2017).

Réfabert, F. 2020. Policy recommendations: how to boost one-stop-shops for integrated home energy renovation in the EU?

Rehman, O. A., Palomba, V., Frazzica, A. & Cabeza, L. F. Enabling technologies for sector coupling: A review on the role of heat pumps and thermal energy storage. Energies **14**, (2021).

RenOnBill. 2022. Valuation of energy efficiency measures for On-bill schemes; Policy paper.

Röck, M.; Baldereschi, E.; Verellen, E.; Passer, A.; Sala, S. and Allacker, K. 2021. Environmental modelling of building stocks – An integrated review of life cycle-based assessment models to support EU policy making. Renew. Sustain. Energy Rev. **151**, 111550 (2021).

Rommel, M., Hauer, A. & van Helden, W. 2016. IEA SHC Task 42 / ECES Annex 29 Compact Thermal Energy Storage. Energy Procedia **91**, 226–230 (2016).

Ruparathna, R., Hewage, K. & Sadiq, R. 2016. Improving the energy efficiency of the existing building stock: A critical review of commercial and institutional buildings. Renew. Sustain. Energy Rev. **53**, 1032–1045 (2016).

Sabnis, G. 2015. Green building with concrete: sustainable design and construction.

Salpakari, J. & Lund, P. 2016. Optimal and rule-based control strategies for energy flexibility in buildings with PV. Appl. Energy **161**, 425–436 (2016).

Stirano, F., Lazzeroni, P. & Olivero, S. 2019. Financing models for deep retrofit actions.

Streimikiene, D. & Balezentis, T. 2019. Innovative policy schemes to promote renovation of multi-flat residential buildings and address the problems of energy poverty of aging societies in former socialist countries. Sustain. 11, (2019).

SYK (University Properties of Finland Ltd) Green Bonds Framework. 2018. Available at: https://sykoy.fi/wp-content/uploads/SYK-Green-Bonds-Framework-11-June-2018-1.pdf

SYK. 2020. Green Bond; Investor Letter and Impact Report. syk_greenbond_investor_2020_FINAL.pdf (sykoy.fi)

Tang, H., Wang, S. & Li, H. Flexibility categorization, sources, capabilities and technologies for energy-flexible and grid-responsive buildings: State-of-the-art and future perspective. Energy **219**, 119598 (2021).

Todorović, M. S., Ećim-Đurić, O., Nikolić, S., Ristić, S. & Polić-Radovanović, S. Historic building's holistic and sustainable deep energy refurbishment via BPS, energy efficiency and renewable energy—A case study. Energy Build. **95**, 130–137 (2015).

Tonellato, G., Kummert, Michael, Candanedo, J. & Pasquier, P. A control strategy evaluation framework for Ground Source Heat Pumps using Standing Column Wells. in (2022). doi:10.22488/okstate.22.000038.

U.S. Green Building Council. 2023. LEED scorecard. Available at: https://www.usgbc.org/leed-tools/scorecard

Vitali Roscini, A.; Fabbri, M.; Glicker, J.; Janković, I.; Rapf, O. and Toth, Z. 2020. An Action Plan for the Renovation Wave: collectively achieving sustainable buildings in Europe. Build. Perform. Inst. Eur. 38 (2020).

Vlaanderen. 2023a. Bijna-energieneutraal bouwen (BEN). Nearly zero-energy construction (NZEB), in Flamish. https://www.energiesparen.be/ben/krediet

Vlaanderen. 2023b. Renovatiekrediet met rentesubsidie (bij energierenovatie na aankoop). Renovation loan with interest subsidy (for energy renovation after purchase), in Flamish. https://www.energiesparen.be/renteloos-renovatiekrediet

Vlaanderen. 2023c. Lenen voor een woning. (In Flamish) https://www.vlaanderen.be/lenen-voor-een-woning

Vlaanderen. 2023d. Mijn VerbouwLening. (In Flamish) https://www.energiesparen.be/energielening

Vlaanderen. 2023e. Ondersteuning van renovatie van noodkoopwoningen. (In Flamish) https://www.vlaanderen.be/ondersteuning-van-renovatie-van-noodkoopwoningen

Vlaanderen. 2023f. Voordelen en premies voor beschermde afnemers. (In Flamish) https://www.vlaanderen.be/voordelen-en-premies-voor-beschermde-afnemers

Vlaanderen. 2023g. Groene energie. (In Flamish) https://www.vlaanderen.be/veka/energie-en-klimaatbeleid/groene-energie

VMSW. Vlaamse Maatschappij voor Social Wonen. 2021. SIMULATIETABEL 2022 Bepaling maximaal subsidiabel bedrag bouw- en investeringsverrrichting. (In Flamish) https://assets.vlaanderen.be/image/upload/v1669098611/SW_-_SW_-_Simulatietabel_2022_s9gszv.pdf

Wang, D. et al. Assessment of the Potential of High-Performance Buildings to Achieve Zero Energy: A Case Study. Appl. Sci. **9**, 775 (2019).

Wiik, M. K., Fufa, S. M., Kristjansdottir, T. & Andresen, I. Lessons learnt from embodied GHG emission calculations in zero emission buildings (ZEBs) from the Norwegian ZEB research centre. Energy Build. **165**, 25–34 (2018).

Zhu, C.; White, A.; Mathew, P.; Deason, J. and Coleman, P. 2018. Raising the Rent Premium: Moving Green Building Research Beyond Certifications and Rent. ACEEE Summer Study on Energy Efficiency in Building.

Ziegler, T.; Shneor, R. and Zhang, B. Z. 2020. The Global Status of the Crowdfunding Industry. Shneor, R. et al. (eds.), Advances in Crowdfunding, https://doi.org/10.1007/978-3-030-46309-0_3