Digital Innovations in Architecture, Engineering and Construction

Belinda López-Mesa
Xabat Oregi *Editors*

Assessing Progress in Decarbonizing Spain's Building Stock

Indicators and Data Availability

OPEN ACCESS

Springer

Digital Innovations in Architecture, Engineering and Construction

The Architecture, Engineering and Construction (AEC) industry is experiencing an unprecedented transformation from conventional labor-intensive activities to automation using innovative digital technologies and processes. This new paradigm also requires systemic changes focused on social, economic and sustainability aspects. Within the scope of Industry 4.0, digital technologies are a key factor in interconnecting information between the physical built environment and the digital virtual ecosystem. The most advanced virtual ecosystems allow to simulate the built to enable a real-time data-driven decision-making. This Book Series promotes and expedites the dissemination of recent research, advances, and applications in the field of digital innovations in the AEC industry. Topics of interest include but are not limited to:

- Industrialization: digital fabrication, modularization, cobotics, lean.
- Material innovations: bio-inspired, nano and recycled materials.
- Reality capture: computer vision, photogrammetry, laser scanning, drones.
- Extended reality: augmented, virtual and mixed reality.
- Sustainability and circular building economy.
- Interoperability: building/city information modeling.
- Interactive and adaptive architecture.
- Computational design: data-driven, generative and performance-based design.
- Simulation and analysis: digital twins, virtual cities.
- Data analytics: artificial intelligence, machine/deep learning.
- Health and safety: mobile and wearable devices, QR codes, RFID.
- Big data: GIS, IoT, sensors, cloud computing.
- Smart transactions, cybersecurity, gamification, blockchain.
- Quality and project management, business models, legal prospective.
- Risk and disaster management.

Belinda López-Mesa · Xabat Oregi
Editors

Assessing Progress in Decarbonizing Spain's Building Stock

Indicators and Data Availability

Springer

Editors
Belinda López-Mesa
Built4Life Lab
University of Zaragoza-I3A
Zaragoza, Spain

Xabat Oregi
Department of Architecture
University of the Basque Country UPV/EHU
Donostia-San Sebastian, Spain

ISSN 2731-7269 ISSN 2731-7277 (electronic)
Digital Innovations in Architecture, Engineering and Construction
ISBN 978-3-031-51828-7 ISBN 978-3-031-51829-4 (eBook)
https://doi.org/10.1007/978-3-031-51829-4

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Paper in this product is recyclable.

Preface

This book is the result of a research project entitled ‘Multi-criteria methodology for the evaluation of local renovation strategies of housing from the perspective of Life Cycle thinking (LocalREGEN)’ developed from June 2020 to September 2023. It is a coordinated project funded by the Ministry of Science and Innovation of the Government of Spain through the 2019 Challenges Call for Research Projects, composed by two subprojects, led by the University of Zaragoza and the University of the Basque Country, respectively. These two subprojects are:

- Subproject 1 (coordinator): PID2019-104871RB-C21 ‘Multi-criteria methodology for the evaluation of local renovation strategies of Aragon housing from the perspective of Life Cycle thinking’ (LocalREGEN-A), whose principal investigator is Belinda López-Mesa, Full Professor of the University of Zaragoza.
- Subproject 2: PID2019-104871RB-C22 ‘Multi-criteria methodology for the evaluation of local renovation strategies of the Basque Country housing from the perspective of Life Cycle thinking’ (LocalREGEN-E), whose principal investigators are Rufino J. Hernández-Minguillón, Full Professor of the University of the Basque Country, and Xabat Oregi, Associate Professor of the University of the Basque Country.

The authors of the 12 chapters comprising this book are affiliated with the University of Zaragoza, the University of the Basque Country, and the European University of Madrid. They are all participants of the mentioned project and its subprojects. Throughout the project, valuable information was obtained through meetings with several companies. We extend our gratitude to the following institutions for their support: 3R City Observatory (*Observatorio Ciudad 3R*), the Zaragoza Housing Municipal Society (*Sociedad Municipal Zaragoza Vivienda*), Green Building Council Spain (GBCe), Alokabide, and the Urban Planning Department of the Madrid City Council.

This book focuses on the topic of monitoring the effectiveness of building renovation policies within the European Union (EU) by Member States (MSs) through the use of indicators. The significance of building renovation in European politics arises from the considerable environmental impact of existing building stocks, contributing substantially to energy consumption and greenhouse gas emissions. The decarbonization of these building stocks is considered pivotal for achieving climate neutrality in Europe. The utilization of indicators to gauge decarbonization progress and for policy evaluation becomes imperative in ensuring the efficiency and effectiveness of building renovation policies aligned with sustainability and climate goals.

While building renovation has been a prominent agenda item since 2012, the European Commission has recently taken proactive steps to establish indicator frameworks for monitoring policy and progress. Notably, during the initiation of the Local-REGEN project, the European Commission had released a list of optional indicators in 2019 to monitor policy and progress. Throughout the development of the project, the Energy Performance of Buildings Directive (EPBD) has been under review, giving rise to three additional versions of the indicator framework, the latest in 2023, which is not yet definitive. The utilization of indicators for policy monitoring will become substantially more challenging when the revised EPBD gets approved, as it involves the establishment of a comprehensive framework encompassing both mandatory and optional indicators. Consequently, EU MSs will face a substantial effort to effectively monitor the impact of their national building renovation policies in the coming years. This book provides valuable insights into these indicator frameworks, focusing on the exploration and analysis of data sources and their quality within one of the MSs, Spain.

The book is organized as follows:

- The first two chapters serve as an introduction to the topic. Chapter "Assessing the Effectiveness of Building Renovation Policies and Decarbonization Progress: A Review of European Legislation" studies the evolution of requirements for monitoring the effectiveness of building renovation policies and decarbonization progress in Europe, and Chapter "Analysis of Institutional Frameworks of Indicators to Measure the Effectiveness of Building Renovation Policy and Decarbonization Progress in Europe" analyzes the indicator frameworks included in the currently in force EPBD and the last version of its ongoing revision and proposes a set of subjects to concentrate data collection efforts on by the MSs.
- The central chapters of this book, Chapters "Indicators and Data in Spain for an Overview of the General Characteristics of the National Building Stock" to "Indicators and Data in Spain Regarding Policies and Measures for the Mobilization of Investments into the Renovation of Buildings", constitute the core of the book, concentrating on proposing indicators for each subject, based on the European indicator frameworks, and exploring data sources in Spain and assessing their quality for each indicator. As in Spain a good part of the promotion and management of building renovation is delegated to the regions, the study is carried out both for Spain as a whole and for two specific regions, Aragon and the Basque Country. Each of these chapters focuses on a different topic, spanning from indicators related to the general attributes of the national building stock, its energy characteristics, and deep renovation to insights into the worst-performing segments, rented properties, and energy poverty. Additionally, the indicators address capacities within the construction, energy efficiency, and renewable energy sectors,

along with actual energy savings and broader advantages resulting from building renovation, evidence-based estimates of expected energy savings, cost reductions associated with building renovation, and policies and measures aimed at mobilizing investments in building renovation.

- The last two chapters are conclusive in nature. Chapter "On the Availability and Quality of Data in Spain for the Development of Indicators to Measure Building Renovation Policies Effectiveness and the Decarbonization of the Building Stock" provides a comprehensive analysis of the developability of indicators collected in the central chapters and evaluates data sources in Spain. Finally, Chapter "New Approaches to Generate Data to Measure the Progress of Decarbonization of the Building Stock in Europe and Spain" suggests the potential improvement of data quality and availability through emerging technologies, specifically exploring georeferencing and automated cross-referencing of existing data, as well as the Digital Building Logbook.

The intended audience for this work is diverse, encompassing public administrations of the central government in European Union member countries responsible for submitting long-term renovation strategies, regional and municipal authorities who have to furnish data on their initiatives in building renovation, institutions tasked with collecting and disseminating building-related data, urban planners dedicated to fostering resilient and sustainable communities, researchers investigating large-scale building renovation, and citizens seeking insights into the impact of building renovation on local environments and broader decarbonization efforts. By addressing this broad spectrum of stakeholders, the book aims to contribute to a more inclusive and well-informed discourse surrounding building renovation and the decarbonization of the European building stock.

Belinda López-Mesa
Built4Life Lab
University of Zaragoza-I3A
Zaragoza, Spain

Xabat Oregi
Department of Architecture
University of the Basque Country
UPV/EHU
Donostia-San Sebastian, Spain

Contents

Abbreviations

3R	3R City Observatory
A3e	Spain's Association of Energy Efficiency Companies
AC	Álava's Cadaster
AOD	Aragon Open Data
BEMS	Building Energy Management System
BG	Basque Government
BHO	Basque Housing Observatory
BPIE	Buildings Performance Institute Europe
BRP	Building Renovation Passport
CO_2	Carbon dioxide
CSCAE	Superior Council of Professional Colleges of Architects of Spain
DALY	Disability Adjusted Life Year
DBL	Digital Building Logbook
DHW	Domestic hot water
EC	European Commission
EED	Energy efficiency directive
EHUrOPE	EHU European Projects Office
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Certificate
EPOV	EU Energy Poverty Observatory
ERESEE	Spain's Long-Term Renovation Strategy
EU	European Union
Eurostat	European Statistical Office
EUSTAT	Basque Institute of Statistics
GA	Government of Aragon
GBCe	Green Building Council Spain
GC	Gipuzkoa's Cadaster
GDP	Gross domestic product
GHG	Greenhouse gas emissions
GWP	Global warming potential
HVAC	Heating, ventilation, and air conditioning

IAEST	Aragon Institute of Statistics
IAQI	Indoor Air Quality Index
IDAE	Spain's Institute for Energy Diversification and Savings
IEA	International Energy Agency
INE	Spain's National Institute of Statistics
IREC	Catalonia Institute for Energy Research
LTRS	Long-Term Renovation Strategy
MEFP	Spain's Ministry of Education and Vocational Training
MH	Spain's Ministry of Finance and Civil Service
MINCOTUR	Spain's Ministry of Industry
MINECO	Spain's Ministry of Economic Affairs and Digital Transformation
MISAN	Spain's Ministry of Health
MITERD	Spain's Ministry of Ecological Transition and Demographic Challenge
MITMA	Spain's Ministry of Transport, Mobility and Urban Agenda
MS	Member State
MU	Spain's Ministry of Universities
NBRP	National Building Renovation Plan
No.	Number
NRPEC	Non-Renewable Primary Energy Consumption
nZEB	Nearly zero-energy building
OMR	Municipal Renovation Observatory
QALY	Quality-adjusted life year
RED	Renewable energy directive
SC	Spain's Cadaster
SDG	Sustainable Development Goals
TCI	Thermal Comfort Index
UBEM	Urban Building Energy Model
UNIZAR	University of Zaragoza
VC	Vizcaya's Cadaster, Trade and Tourism
ZEB	Zero-energy building

Assessing the Effectiveness of Building Renovation Policies and Decarbonization Progress: A Review of European Legislation

Belinda López-Mesa, Rufino J. Hernández-Minguillón, Marta Gómez-Gil, and Markel Arbulu

Abstract Indicators to evaluate the progress and effectiveness of building renovation policies prove essential for evidence-based decision-making, accountability, and achieving long-term goals towards the decarbonization of the building sector, while also promoting public awareness and engagement. This chapter studies the efforts over time in European legislation relating to building decarbonization and the evolution of requirements for monitoring the effectiveness of building renovation policies and decarbonization progress. The results show that the use of indicators for monitoring building renovation policies is a newly legislated activity in Europe that commenced in 2019 and is expected to become more demanding with the approval of the Energy Performance of Buildings Directive revision. This will require significant efforts from European Union Member States to monitor and evaluate their national building renovation policies. Additionally, this underscores the need for new research directions, such as data source evaluation, open big data technologies, and advanced data collection methods, among others.

B. López-Mesa (✉) · M. Gómez-Gil
Built4Life Lab, University of Zaragoza-I3A, 50018 Zaragoza, Spain
e-mail: belinda@unizar.es

M. Gómez-Gil
e-mail: m.gomez@unizar.es

R. J. Hernández-Minguillón · M. Arbulu
Department of Architecture, University of the Basque Country UPV/EHU, 20018 San Sebastian, Donostia, Spain
e-mail: rufinojavier.hernandez@ehu.eus

M. Arbulu
e-mail: markel.arbulu@ehu.eus

B. López-Mesa and X. Oregi (eds.), *Assessing Progress in Decarbonizing Spain's Building Stock*, Digital Innovations in Architecture, Engineering and Construction,
https://doi.org/10.1007/978-3-031-51829-4_1

1 Introduction

This chapter focuses on the critical area of monitoring the effectiveness of building renovation policies developed by the Member States (MSs) within the European Union (EU). Building renovation has been high in the European political agenda in the last decade mainly due to the fact that the existing building stock exerts a significant environmental footprint in Europe, accounting for substantial energy consumption and greenhouse gas (GHG) emissions. The decarbonization of the existing building stocks in Europe has therefore become a priority to achieve climate neutrality objectives in Europe (European Commission 2019a).

The monitoring and evaluation of decarbonization progress and policy effectiveness through the use of indicators is crucial in the field of renovation of buildings for several reasons:

- Effectiveness assessment. It allows policymakers to assess how well their renovation policies are working. By tracking specific indicators, they can determine if the policies are achieving their intended goals, such as energy savings, emissions reductions, or improved building performance.
- Accountability. Indicators provide a basis for accountability. They allow policymakers to measure progress and hold themselves accountable for the outcomes of their policies, which is important for transparency and public trust.
- Informed decision-making. By analyzing indicators, policymakers can make informed decisions about the direction of their renovation policies. They can identify what is working and what needs adjustments, leading to more efficient and effective policy design.
- Resource allocation. Indicators help allocate resources more efficiently. Policymakers can, for example, direct funding and resources to areas and programs that have proven to be effective, optimizing the use of public resources.
- Long-term planning. Policy evaluation with indicators aids in long-term planning. It provides insights into the progress towards long-term objectives, such as achieving energy efficiency or decarbonization goals, and allows for adjustments when necessary.
- Public information tool. Additionally, policy evaluation through indicators serves as an informative tool for the general public. It allows citizens to understand the progress and impact of building renovation policies, promoting transparency and engagement in sustainability efforts.

In summary, progress and policy evaluation through the use of indicators is a valuable tool for ensuring that building renovation policies are efficient, effective, and aligned with broader sustainability and climate goals. It enables evidence-based decision-making, accountability, the achievement of long-term objectives, and informs and engages the public in these important initiatives.

Although building renovation and decarbonization have been prominent on the European political agenda since 2012, it is only recently that the European Commission (EC) has taken proactive measures to establish frameworks of indicators to monitor building renovation policy and progress. Given that this is a novel subject, it has also received limited attention in existing scientific literature. Therefore, in this chapter, we conduct an in-depth analysis of European legislative documents with the aim of uncovering key insights into the obligations and expectations placed upon the MSs due to these novel policy monitoring and evaluation requirements. Furthermore, this chapter aims to shed light on the emerging and crucial areas of research that can provide support for the recently mandated task of policy monitoring by the MSs.

2 Methodology

We started the work presented in this chapter by conducting a state-of-the-art to establish the context of policy monitoring in the field of building renovation. This state-of-the-art aims to provide an answer to the following questions:

- What is the decarbonization of the building sector and why is it important?
- Why is building renovation essential to decarbonize the building sector, and what are its key principles within the European political agenda?

Once the context was established, the research methodology followed the next steps:

- Firstly, European legislative documents (directives, strategies, and recommendations) driving buildings decarbonization and renovation were identified, and a study was carried out on how these documents contributed to promote renovation and the use of indicators to monitor policy effectiveness and decarbonization progress.
- Secondly, we represented all this information in a graph with a timeline. Furthermore, in the graph we indicated when these European legislative documents begin to include the decarbonization of the operational and embedded carbon of new and existing buildings. Three different levels of inclusion were established:
  - Level 1. Measures are encouraged.
  - Level 2. Measures are required.
  - Level 3. Measures and their monitoring by means of indicators are encouraged.
  - Level 4. Measures are required and monitoring their progress by means of indicators is encouraged.
  - Level 5. Measures are encouraged and their monitoring by means of indicators is required.
  - Level 6. Measures and their progress monitoring by means of indicators are required.
- Lastly, conclusions are drawn regarding obligations and expectations placed upon the MSs regarding the monitoring of building renovation policy and decarbonization progress. Additionally, research topics are proposed to give support to the newly required responsibility of policy monitoring by the MSs.

3 Results

3.1 What is the Decarbonization of the Building Sector and Why is It Important?

Decarbonization refers to the process of reducing or eliminating carbon dioxide (CO_2) and other GHG emissions, particularly from human activities. The primary objective of decarbonization is to mitigate climate change by minimizing the amount of CO_2 and other GHG released into the atmosphere.

The emissions reduction goals within the EU have evolved significantly in reaction to changing global and regional climate agendas, scientific assessments, and policy progress. During the first commitment period of the Kyoto Protocol (2005–2012), the EU emerged as an early proponent of binding emissions reduction objectives, pledging to cut its GHG emissions by 8% below 1990 levels (United Nations 1998). In the context of the 2020 Climate and Energy Package, the EU set forth ambitious climate goals. This included the primary objective of reducing GHG emissions to at least 20% below 1990 levels by 2020, coupled with enhancing the share of renewable energy to 20% and elevating energy efficiency by 20% (EUR-Lex 2015). Subsequently, the EU established the 2030 Framework for Climate and Energy Policies in 2014, introducing a binding target to reduce GHG emissions by at least 40% below 1990 levels by 2030 (CLIMATE AND ENERGY POLICY FRAMEWORK 2014). In 2019, the European Green Deal was introduced (European Commission 2019a), establishing even more ambitious objectives. This initiative committed the EU to achieving carbon neutrality (net-zero emissions) by 2050 and substantially elevating the 2030 emissions reduction target from at least 40% to at least 55%. This progression of emissions reduction goals within the EU underscores the EU's firm commitment to taking bolder measures in the fight against climate change and in transitioning towards a sustainable, low-carbon economy.

The building sector is a main contributor to environmental impact in Europe. The EC is aware that this sector consumes the most energy and that it has a high environmental impact not only in terms of energy consumption and GHG emissions but also in terms of extracted material and waste generation (European Commission 2018). Buildings represent about 40% of energy consumption in Europe and 36% of energy related GHG emissions (European Commission 2019a). The construction sector requires vast amounts of resources, accounting for about 50% of all extracted material (Economidou, et al. 2020), and it is responsible for over 35% of the EU's total waste generation (Maduta et al. 2022).

Building decarbonization refers to all activities, measures, and programs that reduce GHG emissions from buildings and the building sector. Building decarbonization encompasses the whole building life cycle, including material extraction, construction, operation, occupancy, and end of life.

In the construction sector, GHG emissions are classified into two types: operational carbon and embodied carbon. Embodied Carbon (also called embedded carbon) includes the amount of carbon emitted during the material phases of the building. This includes extraction of raw materials, manufacture and refinement of materials and building products, transport, the construction phase of the building or structure, the materials used for the building maintenance or renovation, and the deconstruction and disposal of materials at the end of life. Operational carbon is, on the other hand, the amount of carbon emitted during the operational or use phase of a building due mainly to consumptions of energy for heating, cooling, ventilation, domestic hot water, and appliances.

3.2 Why is Building Renovation Essential to Decarbonize the Building Sector, and What Are Its Key Principles Within the European Political Agenda?

The consumption of energy during the operational phase produces the greatest environmental impacts in the buildings' life cycle (European Commission 2020a), due to their high lifespans, so that the added annual operational impacts have higher associated GHG emissions than the material phases. The first European directives on the energy efficiency of buildings focused on the operational phase of new buildings. However, when it was understood that 85%-95% of the existing buildings in Europe will still stand by 2050 (European Commission 2020b) and that at least 97% of EU buildings require energy efficiency improvements (Buildings Performance Institute Europe 2017), the energy-efficiently renovation of the EU building stock at a large scale to reduce its operational carbon became a priority.

Building renovation is perceived not only as an opportunity to decarbonize the existing stock and improve its energy efficiency, but also as a generator of multiple benefits, including job creation, health improvements and increased energy affordability (OECD 2022):

- Building renovation is understood as an economic engine, generator of employment and activity and promoter of digitalization. In the EU, it is estimated that an investment of 1 million euros in energy renovation of buildings will create 18 jobs on average (Buildings Performance Institute Europe 2020). Furthermore, these jobs are low to medium skilled, such as installing insulation and replacing windows, which are accessible to unemployed workers (OECD 2022).
- In the EU, building renovations that simultaneously consider energy efficiency and ventilation are estimated to save EUR 190 billion per year in public health spending (International Energy Agency 2014) because these measures enhance physical health, reducing symptoms of respiratory and cardiovascular conditions, and mental health, reducing chronic stress and depression (International Energy Agency 2019).
- Energy efficiency improvements in housing also leads to increased energy affordability. This is especially important among low-income households. Combining the improvement of the thermal-enclosure and replacing old thermal systems with

more efficient ones can reduce, for example in Spain, heating and cooling expenditures by respectively 49% and 59%, and decrease the winter and summer energy poverty share, correspondingly, by 35% and 63% (Barrella et al. 2023).

The efficient renovation of the building national stocks at a large scale implies the removal and treatment of old materials, the use of a high amount of materials (such as insulation materials), and the installation of advanced technical systems, in a relatively short period of time (from now to 2050), leading to high embodied impacts. Up to now, the comparative estimations of the operational and embodied carbon in the life cycle of buildings had been made by annualizing the embedded impacts throughout the building life cycle and comparing them to the annual operational impacts (e.g. Palacios-Munoz et al. 2019). However, this is only a calculation approach. The required large-scale renovation of the national building stocks in Europe will imply the generation of high amounts of embedded carbon all in a reduced period of time of just 27 years. This is why the application of circularity strategies will be essential in the renovation activity of the coming decades. Recent studies demonstrate the growing importance of embodied energy and emissions (Röck et al. 2020).

The key principles to address the renovation of the building stocks in Europe were stated in the Renovation wave (European Commission 2020b), a strategy which pursues a dual ambition of energy gains and economic growth. These principles are:

- 'Energy efficiency first'. This a horizontal guiding principle of European climate and energy governance to ensure that European countries only produce the energy really required (European Commission 2020c);
- Affordability. In Europe, ensuring widespread availability of energy-efficient and sustainable buildings is deemed essential to leave no one behind. Renovation affordability is in particular important for medium and lower-income households and vulnerable people and areas (European Commission 2020b). It has also been found that renovation affordability is a function of acceptability, that is, if people do not find the renovation affordable, they will not find it acceptable (Cerinsek et al. 2019);
- Decarbonization and integration of renewables. Building renovation should facilitate and accelerate the incorporation of on-site or nearby renewable energy sources and encourage the more extensive utilization of waste heat. This process should also involve the integration of energy systems at local and regional scales, contributing to the reduction of carbon emissions in both transportation and heating and cooling sectors. For example, the integration of buildings, cars, and electricity production is very relevant, as these sectors account for a high percentage of emissions and the synergies between them can help optimize the energy system as a whole. Specifically, buildings, cars and public electricity production accounted for 62.3% of carbon emissions in Europe in 2020 (López-Mesa 2022). The electrification of transport and buildings is a good way to integrate energy systems, since electric vehicles (EV) connect the transport, the power sectors, and buildings, where the charging points are often located. Currently, there

is only a very limited interface between these three sectors. Rethinking the transformation of European cities to turn them into carbon neutral cities by 2050 is one of the great challenges we have ahead of us and necessarily involves the definition of strategies that consider integrated solutions for buildings, cars and electricity production (López-Mesa 2022);

- Life-cycle thinking and circularity. They involve considering the entire life cycle of a building, from its construction and use to its demolition and disposal. This approach focuses on reducing environmental impacts, minimizing resource consumption, and promoting the reuse and recycling of building materials. Circularity in buildings emphasizes the importance of designing structures and systems in a way that allows materials to be reused and repurposed, rather than becoming waste at the end of their life. This includes strategies like using recycled materials, efficient deconstruction processes, and designing for adaptability and longevity. Minimizing the footprint of buildings requires resource efficiency and circularity combined with turning parts of the construction sector into a carbon sink, for example through the promotion of green infrastructure and the use of organic building materials that can store carbon, such as sustainably-sourced wood;
- High health and environmental standards. High air quality, good water management (which encompasses efficient water usage, responsible sourcing of materials, and measures to prevent water damage or leaks within the building), disaster prevention and protection against climate-related hazards, removal of and protection against harmful substances such as asbestos and radon, fire and seismic safety, and accessibility should be ensured. Accessibility in building design means ensuring that buildings are designed and constructed to be inclusive and accessible to all, including persons with disabilities and senior citizens;
- Tackling the twin challenges of the green and digital transitions together. Smart buildings have the potential to enable efficient production and utilization of renewables at the household, district, or city level. When combined with smart energy distribution systems, they can lead to highly efficient and zero-emission buildings. These smart buildings are designed to integrate advanced technologies that optimize energy consumption and increase renewable energy generation;
- Respect for aesthetics and architectural quality. Renovation efforts should uphold design integrity, preserve craftsmanship, honor heritage, and adhere to principles of conserving public spaces. This approach ensures that the historical and cultural significance of a structure or area is maintained while accommodating contemporary needs and sustainability considerations.

3.3 Analysis of the Requirements for Monitoring Building Renovation Policies by MSs in European Legislation

Energy efficiency and sustainability in the building sector are addressed by two interrelated pieces of legislation within the EU: the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED). The EPBD is a crucial component of the EU's efforts to improve the energy efficiency of buildings and reduce carbon emissions. It is the main legislative instrument regulating buildings energy performance across the EU. On the other hand, the EED takes a broader approach to energy efficiency across various sectors, including industry, transportation, and households. It establishes binding measures to drive energy efficiency improvements and reduce energy consumption, setting targets for MSs to achieve.

The origins of the EPBD can be traced to the year 2002 when the initial version was adopted (European Parliament and the Council of the European Union 2003). This directive laid the groundwork for enhancing the energy performance of new and existing buildings. It introduced EPCs and required MSs to establish minimum energy performance standards for new buildings.

In 2010, the EPBD was significantly revised to strengthen its focus on energy efficiency (European Parliament and the Council of the European Union 2010). The recast directive introduced measures to promote nearly zero-energy buildings, enhanced the energy performance certification requirements, and encouraged cost-optimal methodologies for renovations. These amendments aimed to accelerate the renovation of existing buildings and improve their energy efficiency.

The original EED, adopted in 2012 (European Parliament and the Council of the European Union 2012), marked the beginning of more significant EU efforts to address energy efficiency and reduce energy consumption in Europe. The 2012 EED emphasized the importance of building renovation as a means to improve energy efficiency, to enhance energy efficiency, reduce carbon emissions, and contribute to the EU's broader sustainability and climate goals. This was an acknowledgment of the significant role that existing buildings play as consumers of energy and contributors of GHG emissions in Europe. The EED set forth requirements for MSs to establish long-term strategies for the renovation (LTRS) of residential and commercial buildings. LTRSs had to be submitted by MSs in 2014 and updated every three years. These strategies were intended to outline the steps needed to reach specific energy efficiency and performance targets in the building sector.

In 2014, MSs submitted their first LTRSs. The evaluation of the LTRSs (Castellazzi et al. 2016) revealed that, in sum, twenty-three out of the thirty-one submitted strategies (74.2%) effectively addressed the mandatory components of LTRSs. Ten strategies fully adhered to requirements and provided exemplary coverage. However, six strategies were deemed non-compliant. Some of the non-compliant strategies came from MSs that historically excelled in energy efficiency measures and achievements, raising questions about whether the reporting accurately reflected the status of building energy renovation in those countries. MSs submitted their second LTRSs in 2017 and it was found that, overall, the majority of the updated strategies satisfactorily addressed the mandatory elements of the LTRSs (Castellazzi et al. 2019).

In 2016, the EU launched the Clean Energy for All Europeans package (European Commission 2016), often referred to as the 'Clean Energy Package'. It represented a significant step towards a more sustainable, clean, and efficient energy system in the EU. It pursued to align energy policies with the EU's climate and energy objectives.

The package encompasses a range of legislative actions and measures, including updates to directives like the EPBD and the EED.

In 2018, the EU introduced an update to both the EPBD and the EED as part of its efforts to enhance energy efficiency and sustainability (European Parliament and the Council of the European Union 2018). Since then, LTRSs are regulated in the EPBD rather than in the EED. The 2018 recast version of the EPBD is referred to as 2018 EPBD in this book.

The main changes brought about by the updated 2018 EPBD follow next:

- Decarbonization focus. The revised EPBD placed a stronger emphasis on the decarbonization of the building sector, aligning with the EU's commitment to reduce GHG emissions.
- Renovation requirements. It introduced more ambitious requirements for the renovation of existing buildings. The mandatory elements of the long-term renovation strategies to promote energy-efficient renovations were revised.
- Smart technologies. The directive encouraged the use of smart technologies in buildings to improve energy efficiency. This included measures to support the installation of advanced metering systems and automation.
- Energy Performance Certificates (EPCs). Stricter requirements for energy performance certificates were implemented, making them more accessible and informative for building users.
- Electric vehicle charging infrastructure. The EPBD promoted the installation of EV charging infrastructure in buildings to support the transition to electric mobility.

In 2019, the Commission Recommendation (EU) 2019/786 was published in the Official Journal of the EU (European Commission 2019b). This recommendation, to which in this book we refer to as the 2019 EPBD-related Recommendation, provides guidelines for MSs to ensure the accurate transposition of the 2018 EPBD requirements. Among its various aspects, the recommendation suggested a potential framework for establishing progress indicators and milestones. This was the first time a set of indicators was proposed to measure policy effectiveness and decarbonization progress.

In 2020, MSs submitted their third LTRSs. An evaluation report (Castellazzi et al. 2022) found that while the national strategies generally meet the requirements, enhancing template harmonization and offering increased support to MSs, particularly on less addressed aspects of LTRSs (such as progress monitoring and public consultation), are significant steps toward achieving the 2050 goal of decarbonizing the building stock.

On December 2019, the European Green Deal was launched (European Commission 2019a). It is a comprehensive and ambitious policy initiative launched by the EC, aiming at transforming the EU into a climate-neutral and sustainable continent by 2050. As part of these ambitious objectives, a commitment to reduce GHG emissions by 55% by 2030 compared to 1990 levels was announced. The European Climate Law wrote into law the goal of transforming Europe into a climate-neutral continent by 2050. The law also set the intermediate target of reducing net GHG emissions by at least 55% by 2030. 'Fit for 55' is a package of legislative proposals introduced by the EC in July 2021 as part of the broader European Green Deal. It is designed to align EU climate and energy policies with the new target. The 'Fit for 55' package includes various measures such as revising and strengthening existing policies and introducing new regulations.

As a result of the 'Fit for 55' package and the EU's commitment to deeper climate action, the EPBD is currently under review. The ongoing revision of the EPBD involves several key documents, including:

- A legislative proposal. The EC presented a legislative proposal to revise the EPBD in December 2021 (European Commission 2021). This proposal serves as the starting point for discussions and negotiations among EU institutions. A reviewed framework of indicators was proposed in the EPBD revision to be used as a tool for assessing the impact of policies, measures, and initiatives related to energy efficiency and sustainability in the building sector. This new framework has mandatory and optional indicators. The mandatory indicators will ensure a more harmonized monitoring of policy effectiveness and decarbonization progress in Europe.
- Amendments and draft documents. Throughout the legislative process, various amendments and/or draft reports that outline suggested amendments and changes to the legislative proposal are proposed by members of the European Parliament and representatives of EU member states within the Council. So far, amendments have been suggested by the Council of the EU, the Economic and Social Committee, the European Committee of the Regions, the European Central Bank, and the European Parliament. The last draft document dates from March 2023 (European Parliament 2023) and is referred to as '2023 EPBD Proposal recast' in this book.
- Final Text. Once an agreement is reached, the final text of the revised EPBD will be adopted. This text represents the legal framework for the updated directive. For the moment, there is no final text.

Figure 1 shows a summary of all the information previously described. Additionally, it shows the results of the analysis of when the decarbonization of operational and embodied carbon started to be included in the European documents for new and existing buildings.

It can be seen in Fig. 1 that the decarbonization of the operational phase of new buildings was considered in the European legislation from the beginning. In 2002, mandatory measures were established, and since 2019 their monitoring has been recommended.

On the other hand, it is observed that the decarbonization of the operational phase of existing buildings is incorporated into European legislation starting in 2010, with the revision of the EPBD. Between 2010 and 2012, measures were encouraged, and from 2012, measures were required. Since 2019 their monitoring is additionally encouraged.

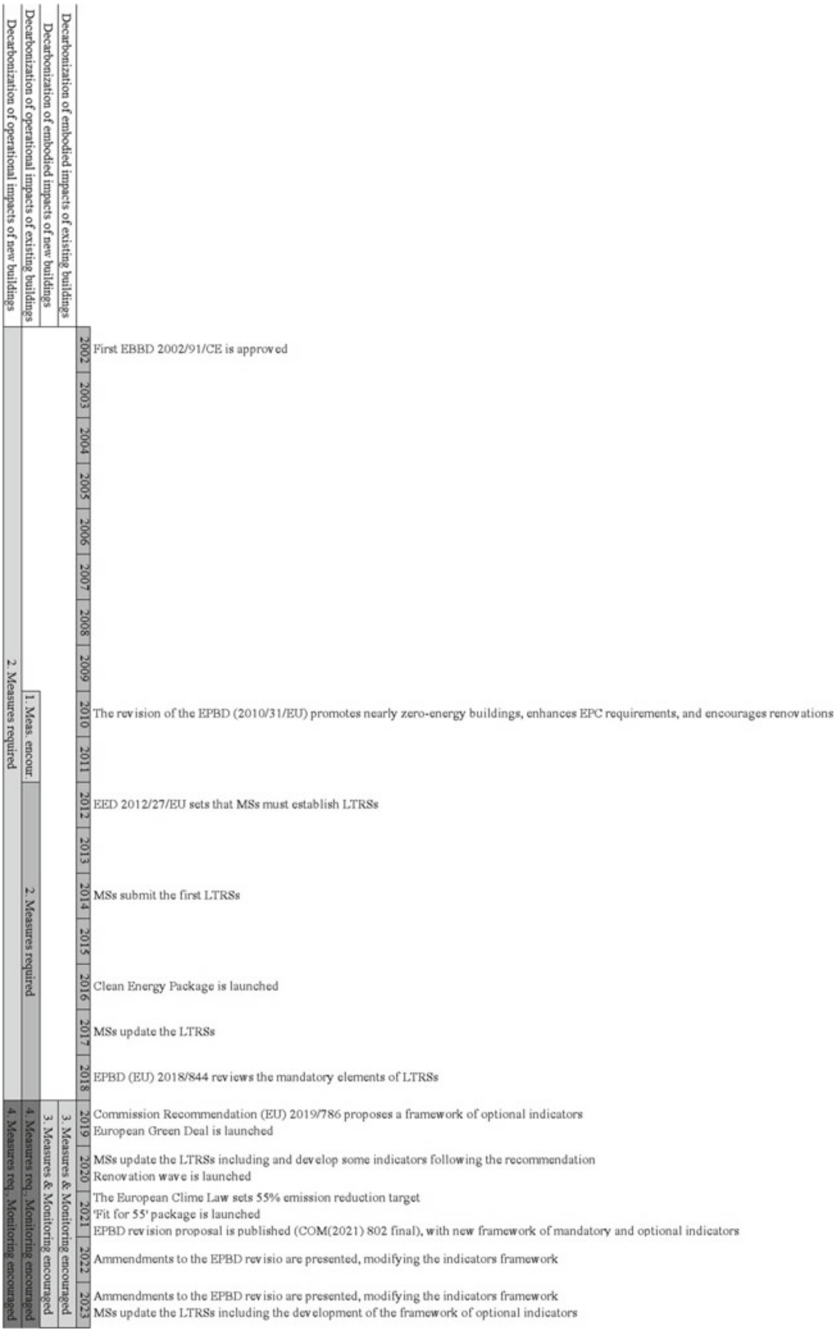


Fig. 1 Temporal analysis of the inclusion of the decarbonization of operational and embodied carbon for new and existing buildings in European legislation. *Source* own creation

The decarbonization of the embodied carbon of new and existing buildings has recently been included in the European legislation. Measures and their monitoring are encouraged since 2019.

Furthermore, we know from the review process that the EPBD is currently in, that it is expected that there will be mandatory measures linked to the reduction of embedded carbon in new buildings and that monitoring policy effectiveness and the progress of decarbonization in the building renovation sector will be obligatory through the use of mandatory and optional indicators.

4 Conclusions

This chapter offers insights into the European building sector's efforts to achieve decarbonization and the progression of policies and legislation in this context. The EU has set ambitious decarbonization goals, with a focus on reducing GHG emissions and achieving carbon neutrality by 2050. The building sector in Europe exerts a significant environmental footprint, accounting for substantial energy consumption, GHG emissions, resource utilization, and waste generation. Therefore, tackling decarbonization within this sector is imperative for broader sustainability initiatives. Building decarbonization encompasses efforts to lower GHG emissions throughout buildings' lifecycle, from construction and operation to maintenance and eventual disposal. Building renovation has been identified as a key to decarbonize the building sector. Moreover, building renovation extends beyond decarbonization, offering various advantages, such as employment opportunities, enhanced public health, and improved affordability of energy, especially for low-income households. For these reasons, renovating and decarbonizing existing buildings has become a priority on the European political agenda since 2012.

In this context, policy evaluation using indicators to assess the effectiveness of building renovation policies and to measure the decarbonization progress is found to be essential. Indicators play a vital role in holding policymakers accountable, facilitating informed decision-making, optimizing resource allocation, and aiding in long-term planning. A study was conducted in this chapter on the efforts over time in European legislation relating to building decarbonization and the evolution of requirements for monitoring the effectiveness of building renovation policies and decarbonization progress, providing the following insights:

- The decarbonization of the operational phase of new buildings has been considered since the beginning of European legislation on energy performance of buildings, with mandatory measures established in 2002 and monitoring recommended since 2019.
- Decarbonization of the operational phase of existing buildings was incorporated into European legislation in 2010, with measures initially encouraged between 2010 and 2012. From 2012, mandatory measures were incorporated, and monitoring was additionally encouraged since 2019.

- The decarbonization of the embodied carbon of new and existing buildings has only recently been included in European legislation, with measures and monitoring encouraged since 2019.
- It is expected that the ongoing revision of the EPBD will introduce mandatory measures to reduce embedded carbon in new buildings, along with obligatory monitoring of policy effectiveness and progress in decarbonization for the building renovation sector through mandatory and optional indicators.

In conclusion, it is observed that in the field of building renovation, the use of indicators for monitoring policies and evaluating the progress of decarbonization is a recently legislated activity, which began in 2019, recommending its use. It is also observed that due to the importance and urgency of building renovation to achieve climate neutrality objectives, the use of indicators for policy monitoring will be considerably more demanding in a short time (when the EPBD revision is approved) given that a framework of indicators that will contain mandatory and optional indicators is being defined. This will imply a significant effort by EU MSs to monitor the effectiveness of their national building renovation policies in the future.

At the same time, this suggests the need for new lines of research including, among others: the study of the data sources and quality of data in European countries for the development of indicators to measure the effectiveness of building renovation policies and the decarbonization progress; the use of open big data technologies to generate enhanced data in an automated way useful for the development of these indicators; new and more advanced methods supported by digitalization for collection and management of data on buildings; the use of circularity principles in the building sector, and especially in the renovation of buildings in order to promote life-cycle thinking in this field, which is not yet planned to be mandatory in European legislation; the evaluation of embodied carbon of new buildings and renovations. In this book, we address the first three research topics mentioned, linked to data availability and quality for the development of indicators.

Acknowledgements This work was funded by the MINISTRY OF SCIENCE AND INNOVATION OF SPAIN, grant number PID2019-104871RB-C21/AEI/10.13039/501100011033 and by GOBIERNO DE ARAGÓN, grant number T37_23R: Built4Life Lab.

References

Barrella, R., Linares, J.I., Romero, J.C., Arenas, E.: Evaluating the impact of energy efficiency strategies on households' energy affordability: A Spanish case study. Energy and Buildings 295, 113289 (2023). https://doi.org/10.1016/j.enbuild.2023.113289

Castellazzi, L., Zangheri, P., Paci, D.: Synthesis Report on the assessment of Member States' building renovation strategies. JRC Technical Report. EUR 27722 EN (2016).

Castellazzi, L., Zangheri, P., Paci, D., Economidou, M., Labanca, N., Ribeiro Serrenho, T., Zancanella, P. and Broc, J.: Assessment of second long-term renovation strategies under the Energy Efficiency Directive. Publications Office of the European Union, Luxembourg (2019). EUR 29605 EN, ISBN 978–92–79–98727–4, doi:https://doi.org/10.2760/973672, JRC114200.

Castellazzi, L., Paci, D., Zangheri, P., Maduta, C., Economidou, M., Ribeiro Serrenho, T., Zancanella, P., Ringel, M., Valentova, M. and Tsemekidi Tzeiranaki, S.: Assessment of first long-term renovation strategies under the Energy Performance of Building Directive (Art. 2a). Publications Office of the European Union, Luxembourg. (2022). EUR 31309 EN, ISBN 978–92–76–58990–7, doi:https://doi.org/10.2760/535845, JRC128067.
Cerinsek, G., Bancic, D., Podjed, D., D'Oca, S., Vetrsek, J., Dolinsek, S., op't Veld, P.: Boosting affordability, acceptability and attractiveness of deep energy renovations of residential buildings – a people-centred ethnographic approach.E3S Web Conf. 111, 03026 (2019). https://doi.org/10.1051/e3sconf/201911103026.
European Council: Conclusions—23/24 October (2014) 2030 CLIMATE AND ENERGY POLICY FRAMEWORK. (2014). http://data.consilium.europa.eu/doc/document/ST-169-2014-INIT/en/pdf, last accessed 2023/09/20.
Economidou, M., Todeschi, V., Bertoldi, P., D'Agostino, D., Zangheri, P., Castellazzi, L.: Review of 50 years of EU energy efficiency policies for buildings. Energy and Buildings 225, 110322 (2020). https://doi.org/10.1016/j.enbuild.2020.110322.
EUR-Lex: 2020 climate and energy package. (2015). https://eur-lex.europa.eu/EN/legal-content/summary/2020-climate-and-energy-package.html, last accessed 2023/09/20.
European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK Clean Energy For All Europeans. COM(2016) 860 final. Brussels (2016). https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1582103368596&uri=CELEX:52016DC0860, last accessed 2023/09/20.
European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK. A Clean Planet for All. A European Strategic Long-Term Vision for a Prosperous, Modern, Competitive and Climate Neutral Economy. COM(2018) 773 Final. Brussels (2018).
European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. The European Green Deal. COM(2019) 640 final. Brussels (2019a).
European Commission: COMMISSION RECOMMENDATION (EU) 2019/786 of 8 May 2019 on building renovation. Official Journal of the European Union (2019: L 127), 34–79 (2019b).
European Commission: Energy efficiency in buildings. Brussels (2020a). https://commission.europa.eu/system/files/2020-03/in_focus_energy_efficiency_in_buildings_en.pdf, last accessed 2023/09/20.
European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. A Renovation Wave for Europe—greening our buildings, creating jobs, improving lives. COM(2020) 662 final. Brussels (2020b).
European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS Powering a climate-neutral economy: An EU Strategy for Energy System Integration. COM(2020) 299 final. Brussels (2020c). https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=COM:2020:299:FIN, last accessed 2023/09/20.
European Commission: Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast). COM/2021/802. Brussels (2021).
European Parliament: Energy performance of buildings (recast) Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and

of the Council on the energy performance of buildings (recast) (COM(2021)0802—C9–0469/2021—2021/0426(COD)). Strasbourg (2023).

European Parliament, Council of the European Union: DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast). Official Journal of the European Communities (2010:L 153), 13–35 (2010).

European Parliament, Council of the European Union: DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Official Journal of the European Union (2012: L315), 1–56 (2012).

Buildings Performance Institute Europe: 97% of buildings in the EU need to be upgraded. Brussels (2017). https://www.bpie.eu/wp-content/uploads/2017/12/State-of-the-building-stock-briefing_Dic6.pdf, last accessed 2023/09/20.

Buildings Performance Institute Europe: Building renovation: A kick-starter for the EU economy. (2020). https://www.renovate-europe.eu/2020/06/10/building-renovation-a-kick-starter-for-the-eu-economy/

International Energy Agency: Capturing the Multiple Benefits of Energy Efficiency: A Guide to Quantifying the Value Added. (2014). https://doi.org/10.1787/9789264220720-en.

International Energy Agency: Multiple Benefits of Energy Efficiency: Health and Wellbeing. (2019). https://www.iea.org/reports/multiple-benefits-of-energy-efficiency/health-and-wellbeing, last accessed 2023/09/20.

López-Mesa, B.: De la sociedad fósil a la sociedad hipocarbónica: la ciudad inteligente como estrategia facilitadora. Arbor 198, 803-804 (2022). https://doi.org/10.3989/arbor.2022.803-804003.

Maduta, C., Melica, G., D'Agostino, D., Bertoldi, P.: Towards a decarbonised building stock by 2050: The meaning and the role of zero emission buildings (ZEBs) in Europe. Energy Strategies Review 44, 101009 (2022). https://doi.org/10.1016/j.esr.2022.101009.

OECD: Decarbonising Buildings in Cities and Regions. OECD Urban Studies, OECD Publishing, Paris (2022) https://doi.org/10.1787/a48ce566-en.

Palacios-Munoz, P., Peuportier, B., Gracia-Villa, L., López-Mesa, B.: Sustainability assessment of refurbishment vs. new constructions by means of LCA and durability-based estimations of buildings lifespans: A new approach. Building and Environment 160, 106203 (2019). https://doi.org/10.1016/j.buildenv.2019.106203.

European Parliament, Council of the European Union: DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on the energy performance of buildings. Official Journal of the European Communities (2003:L 1), 65–71 (2003).

European Parliament, Council of the European Union: 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. Official Journal of the European Union (2018:L 156), 75–91 (2018).

Röck, M., Saade, M.R.M., Balouktsi, M., Rasmussen, F.N., Birgisdottir, H., Frischknecht, R., Habert, G., Lützkendorf, T., Passer, A.: Embodied GHG emissions of buildings - the hidden challenge for effective climate change mitigation. Applied Energy 258, 114107 (2020). https://doi.org/10.1016/j.apenergy.2019.114107.

United Nations: Kyoto protocol to the United Nations framework convention on climate change. (1998). https://unfccc.int/resource/docs/convkp/kpeng.pdf, last accessed 2023/09/20.

Analysis of Institutional Frameworks of Indicators to Measure the Effectiveness of Building Renovation Policy and Decarbonization Progress in Europe

Carlos Beltrán-Velamazán, Marta Gómez-Gil, and Belinda López-Mesa

Abstract The Energy Performance of Buildings Directive (EPBD) establishes that Member States (MSs) should define a long-term renovation strategy (LTRS) which shall set out a roadmap with measures and measurable indicators, with a view to the long-term 2050 goal of reducing greenhouse gas emissions in the European Union by 80–95% compared to 1990. The EPBD is currently under review and the European Commission suggests strengthening the LTRSs towards National building renovation plans (NBRPs). NBRPs will be much more complete than LTRSs and will make easier to compare the national decarbonization targets and their progress between MSs since a set of mandatory indicators is being established. On the contrary, this will involve important amount of policy monitoring and evaluation work for MSs. The objective of this chapter is to analyze the indicator frameworks included in the currently in force EPBD and in its on-going revision, in order to identify the most important subjects the MSs should focus their data collection on, so that they can get prepared for the important monitoring and evaluation work they will have to do.

1 Introduction

The building sector plays a key role in the reduction of greenhouse gas (GHG) emissions in the European Union (EU). Collectively, buildings in the EU are responsible for 40% of our energy consumption and 36% of GHG emissions, which mainly stem from construction, usage, renovation and demolition (European Commission 2019a). The use phase, also called operational phase, of buildings is the one that produces the

C. Beltrán-Velamazán · M. Gómez-Gil · B. López-Mesa (✉)
Built4Life Lab, University of Zaragoza-I3A, 50018 Zaragoza, Spain
e-mail: belinda@unizar.es

C. Beltrán-Velamazán
e-mail: cbeltran@unizar.es

M. Gómez-Gil
e-mail: m.gomez@unizar.es

B. López-Mesa and X. Oregi (eds.), *Assessing Progress in Decarbonizing Spain's Building Stock*, Digital Innovations in Architecture, Engineering and Construction,
https://doi.org/10.1007/978-3-031-51829-4_2

greatest environmental impacts due to higher associated GHG emissions (European Commission 2020a). It has been estimated that 85–95% of the existing buildings in Europe will still stand by 2050 (European Commission 2020b), and that at least 97% of Europe's buildings require upgrades to improve their energy efficiency (Buildings Performance Institute Europe 2017a). In this context, it is urgent that the EU building stock is energy-efficiently renovated to reduce its operational carbon. However, the rate of renovations of existing buildings remains persistently low and the level of energy improvement is not sufficiently deep (European Parliament and the Council of the European Union 2018).

When it became clear that buildings accounted for 40% of the Union's final energy consumption and that renovation is key to reach a decarbonized building sector, Directive 2012/27/EU (European Parliament and the Council of the European Union 2012) established that Member States (MSs) should define a long-term renovation strategy (LTRS), which should contain certain mandatory elements and with the aim of mobilizing investment in the renovation of residential and commercial buildings with a view to improving the energy performance of the building stock. MSs were required to submit the LTRS in 2014 and update it every three years. In 2018, the mandatory elements of the LTRS were revised with the approval of the revision of the Energy Performance of Buildings Directive (European Parliament and the Council of the European Union 2018), which is referred to as 2018 EPBD in this book. According to the 2018 EPBD, in their LTRSs, MSs shall set out a roadmap with measures and domestically established measurable progress indicators, with a view to the long-term 2050 goal of reducing GHG emissions in the EU by 80–95% compared to 1990. The roadmap shall also include indicative milestones for 2030, 2040 and 2050. The LTRSs should be consistent with MSs' National energy and climate plans (NECP) for the period 2021–30, which are 10-year plans outlining how EU countries intend to meet the EU energy and climate targets for 2030. The mandatory elements that the LTRSs must include are:

- An overview of the national building stock, based, as appropriate, on statistical sampling and expected share of renovated buildings in 2020;
- The identification of cost-effective approaches to renovation relevant to the building type and climatic zone, considering potential relevant trigger points, where applicable, in the life-cycle of the building;
- Policies and actions to stimulate cost-effective deep renovation of buildings, including staged deep renovation, and to support targeted cost-effective measures and renovation for example by introducing an optional scheme for building renovation passports;
- An overview of policies and actions to target the worst performing segments of the national building stock, split-incentive dilemmas and market failures, and an outline of relevant national actions that contribute to the alleviation of energy poverty;
- Policies and actions to target all public buildings;

- An overview of national initiatives to promote smart technologies and well-connected buildings and communities, as well as skills and education in the construction and energy efficiency sectors; and
- An evidence-based estimate of expected energy savings and wider benefits, such as those related to health, safety and air quality.

In 2019, the Official Journal of the EU published the Commission Recommendation (EU) 2019/786 of May 2019 on the renovation of buildings (referred to as 2019 EPBD-related Recommendation in this book), which sets out the guidelines that MSs must follow to ensure a precise transposition of the requirements of the 2018 EPBD. The Recommendation proposed, among other issues, a possible framework for defining progress indicators and milestones. MSs could not implement this framework to a large extent in their LTRSs of year 2020 mainly due to absence of data (Beltran-Velamazan et al. 2021). For example, in the case of Spain, only 17 progress indicators were implemented out of the 70 included in the framework (Beltran-Velamazan et al. 2021; 2023).

Following the start of Ursula von der Leyen's mandate as president of the European Commission (EC), the European Green Deal (European Commission 2019a) was first presented in December 2019. The European Green Deal is a package of policy initiatives, which aims to set the EU on the path to a green transition, with the ultimate goal of reaching climate neutrality by 2050. The plan was to review those EU policies that are necessary to meet the GHG reduction objectives, as well as to introduce new legislation on the circular economy, building renovation, biodiversity, farming and innovation. In July 2021, the 'Fit for 55' package (European Commission 2021a) was launched, including drafts of EU climate and energy legislation to underpin the political pledge to cut GHG emissions by at least 55% in 2030 compared with 1990 levels. This target was more ambitious than the one previously agreed of 40% reduction for 2030, and is part of the EU's aim to become climate-neutral by 2050. In June 2021, The European Climate Law (European Parliament and the Council of the European Union 2021) was approved, writing into law the goal for Europe's economy and society to become climate-neutral by 2050. The law also sets the intermediate target of reducing net GHG by at least 55% by 2030.

As part of the Commission's 2021 'Fit for 55' work program package, a review process of the Energy Performance of Buildings Directive (EPBD) was launched, giving its first result in December 2021, when the Proposal for a Directive on the European Parliament and of the Council on the energy performance of buildings (recast) was communicated (referred to as 2021 EPBD Proposal recast in this book) (European Commission 2021b). In this 2021 EPBD Proposal recast, the EC suggests strengthening the LTRSs towards National building renovation plans (NBRPs). These national plans should be submitted every five years and should include national targets (instead of indicative milestones) in a more unified and comparable approach, and should have clear and specific chapters, based on a common template. The plans shall also include an outline of the investment needs for their implementation and an overview of policies and measures. The 2021 EPBD Proposal recast includes the template for the NBRPs, based on a framework of mandatory and optional indicators.

This 2021 EPBD Proposal recast is in the middle of an ordinary legislative procedure consisting of the joint adoption of legislative acts by the European Parliament and the Council of the EU. Its last modification is included in a document named Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (referred to as 2023 EPBD Proposal recast in this book) (European Parliament 2023). These 2023 EPBD Proposal recast is not yet in force. At this time, the EPBD in force is that of 2018. However, the 2023 EPBD Proposal recast represents the closest version of the EPBD that could be approved soon. The mandatory elements that the NBRPs should include according to the 2023 EPBD Proposal recast are:

- An overview of the national building stock based, as appropriate, on statistical sampling, energy and life-cycle Global Warming Potential (GWP) benchmarking and the national database for energy performance certificates. This overview should be done for: a) different building types, including their share in the building stock, in particular of buildings categorized as officially protected as part of a designated environmnet or because of their special architectural or historical merit; b) by construction periods; and c) by the climatic zones of each MS;
- An overview of market barriers and market failures;
- An overview of the share of vulnerable households;
- An overview of the capacities in the construction, energy efficiency and renewable energy sectors;
- An overview of the availability of one-stop shops;
- An overview of implemented and planned policies, including those pursuant to the Pact for Skills set out in the communication of the Commission of 1 July 2020 entitled 'European Skills Agenda for sustainable competitiveness, social fairness and resilience', to increase the availability of qualified professionals in the construction, efficiency, and renewable energy sectors, investments in the development of the required skills, including upskilling or reskilling and targeted training and education programs, for both public and private stakeholders, on the basis of a quantitative and qualitative assessment using key performance indicators, to meet the targets, in accordance with this Directive and the resulting market needs for skilled professionals in the construction and renovation sector;
- A roadmap with nationally established targets and measurable progress indicators, and specific timelines for all existing buildings to achieve higher energy performance classes by 2030, 2040 and 2050, with a view to the 2050 climate neutrality goal, in order to ensure a highly energy efficient and decarbonized national building stock and the transformation of existing buildings into zero-emission buildings by 2050. This roadmap should include: a) National targets and whole life-cycle emissions for different building typologies to be set following the global stock-taking exercise, for the years 2025, 2030, 2035, 2040, in accordance with the ratchet mechanism set out in the Paris Agreement and a 1,5-degree compliant 2050 whole life-cycle performance roadmap, as well as indicative national targets aiming to achieve the deep renovation of at least 35 million

building units by 2030 to support reaching an annual energy renovation rate of 3% or more for the period till 2050; b) The estimated availability of construction materials, renovation materials, including prefabricated building elements, such as those with insulation, building integrated solar photovoltaics, materials with recycled contents, secondary building materials, and, if any, local sustainable materials, as well as national targets for the circular use of materials, recycled contents and secondary materials, and sufficiency for every five-year period; c) The primary and final energy consumption of the national building stock and its operational GHG emission reductions; d) Specific timelines for buildings to achieve higher energy performance classes than the Minimum energy performance standards, by 2030 and every five years thereafter, in line with the pathway for transforming the national building stock into zero-emission buildings; e) An overview of the cost effective potential, availability and expected production and consumption of renewable energy used for heating and cooling in buildings, disaggregated by technology and fuels; f) National targets on the construction and refurbishment of district level heating and cooling systems; g) A pathway with numerical targets for the deployment of solar energy and heat pumps in buildings; h) National phase-out plans for fossil fuel use in buildings with a view to a planned phase out by 2035 and if not feasible as demonstrated to the Commission, by 2040 at the latest; i) An evidence-based estimate of expected energy savings, GHG emission reductions, and wider benefits, including indoor environmental quality, which may be based on an integrated district approach; j) And estimations for the contribution of the building renovation plan to achieving the MS's binding national target for GHG emissions, including the target for the share of energy from renewable sources in the building;
- An overview of implemented and planned policies and measures including their duration in consistency with the implementation of the previous roadmap, including those set out in the integrated national energy and climate plans notified, with a particular focus on vulnerable households and people living in social housing;
- A detailed roadmap up to 2050 of the investment needs for the implementation of the building renovation plan, public and private financing sources and measures, and the administrative resources for building renovation, including those set out in national energy and climate plans;
- A roadmap on the reduction of energy poverty and energy savings achieved among vulnerable households and people living in social housing comprising of nationally established targets and an overview of implemented and planned policies and funding measures supporting the elimination of energy poverty.

As can be seen from the descriptions of the mandatory elements of the LTRS and the NBRP, the latter will be much more complete than the former and it will make easier to compare the national decarbonization targets and their progress between countries since a set of mandatory indicators is being established. On the contrary, this will involve important amount of monitoring work for MSs, for which they may not be sufficiently prepared due to lack of data. The objective of this chapter is to analyze the indicator frameworks proposed in the 2019 EPBD-related Recommendation and in the 2023 EPBD Proposal recast, in order to identify the most important subjects the MSs should focus their data collection on so that they can start getting prepared for the important monitoring and evaluation work they will have to do. In the successive chapters of this book the availability of data on these subjects will be explored for the case of a specific MS, Spain.

2 Methodology

The research methodology followed in this chapter is composed of three main steps:

- Analysis and comparison of the structure (categories, subcategories and types of indicators) of the frameworks proposed in the 2019 EPBD-related Recommendation and in the 2023 EPBD Proposal recast.
- Accounting and comparison of the number of indicators in each framework, category, subcategory and indicator types.
- Study of the relationship of the 2023 EPBD indicators with those of the 2019 Recommendation. We did this by analyzing whether the 2023 EPBD indicators had or not already been included in the 2019 Recommendation. To do this, we established 3 levels of relationship: yes, similar and no. We used 'yes' when the indicator was already included in the 2019 framework as is or practically the same. We used 'similar' when the indicator was included either partially or in other units or classified by other characteristics. We used 'no' when the indicator could be considered essentially new.

3 Results

To analyze the structure of the two proposals of the indicator frameworks by the EC and for the accounting of the number of indicators, we first generated Tables 3 and 4 in Appendix A, which encompass the whole framework of indicators included in Article 2a of the 2019 EPBD-related Recommendation (European Commission 2019b) and annex II of the 2023 EPBD Proposal Amendments (European Parliament 2023) respectively, and then we made the summary Tables 1 and 2. Each of these two indicator frameworks is composed of indicators organized in categories and subcategories. Next, we analyze them.

The indicator framework of the European 2019 EPBD-related Recommendation classifies the indicators into two types:

- Measurable progress indicators, which are defined as quantitative or qualitative variables to measure progress towards the long-term 2050 goal of reducing GHG emissions in the Union and ensuring a highly energy-efficient and decarbonized national building stock.

- Indicative milestones, which are defined as quantitative or qualitative objectives for 2030, 2040 and 2050.

On the other hand, the indicators (both progress ones and milestones) are also classified into indicators regarding the mandatory elements of the LTRSs and indicators regarding mechanisms to support investment mobilization (Table 1). In turn, these categories are composed of the subcategories of Table 1. Categories and subcategories are described below.

The indicators in the first category of Table 1 are those that allow to establish a roadmap with measures, measurable progress indicators, and indicative milestones for 2030, 2040 and 2050 to target the mandatory elements of the LTRS. The subcategories are identified next as well as the justification of their importance:

- Overview of the national building stock. Knowledge of this general overview is considered a necessary starting point in order to be able to define the long-term renovation strategy that each MS is asked to design.
- Cost-effective approaches to renovation. The EPBD provides that each LTRS shall encompass the identification of cost-effective approaches to renovation relevant to the building type and climatic zone, considering potential relevant trigger points. Trigger points are key moments in the life of a building (e.g. rental, sale, change of use, extension, repair or maintenance work) when carrying out energy renovations would be less disruptive and more economically advantageous than in other moments (Buildings Performance Institute Europe 2017b). Taking advantage of these moments would facilitate investment decisions to undertake energy renovation works.
- Policies and actions to stimulate cost-effective deep renovation. Deep renovation is understood as that which leads to significant (typically more than 60%) efficiency improvements. Policies and actions include support for specific measures and renovations as well as staged deep renovation, for example by introducing an optional system for building renovation passports (BRPs). A BRP is a document, in electronic or paper format, outlining a long-term (up to 15–20 years) step-by-step renovation roadmap to achieve deep renovation for a specific building, designed to address the complexity of renovation works and to ensure coordination throughout the different stages (Buildings Performance Institute Europe 2017c).
- Policies and actions to target worst-performing segments, split-incentives dilemma and market failure, and energy poverty. These four cases have been identified as key elements to overcome the barriers of building renovation. Below is an explanation of their definitions. MSs were encouraged to determine the worst-performing segments of their national building stock in the 2019 EPBD-related Recommendation, by setting a specific threshold, such as an energy performance category (e.g. below 'D'), or by using a primary energy consumption figure (expressed in kWh/m^2 per year); or even by targeting buildings built before a specific date (e.g. before 1980). The split-incentive dilemma refers to any situation where the benefits of a transaction do not accrue to the actor who pays for the transaction, what can ultimately result in inaction from either actor's side, despite the fact that many of these upgrades are of positive net present values (European

Table 1 Structure and number of indicators in the framework of indicators in Article 2a of Commission Recommendation (EU) 2019/786 of 8 May 2019 on renovation of buildings (European Commission 2019b). (*Here the name of the subcategories is abbreviated. The full name can be seen in Table 3 of the Appendix). *Source* own creation

Category	Sub-category*	No. of progress indicators	No. of milestones	Total
Mandatory elements of the LTRS (2018 EPBD, Article 2a, Paragraph 1)	(A) Overview of national building stock	23	4	34
	(B) Cost-effective approaches to renovation	3		
	(C) Policies and actions to stimulate cost-effective deep renovation	4		
	(D) Policies and actions to target worst-performing segments, split-incentives dilemma and market failure, and energy poverty	7	2	9
	(E) Policies and actions to target public buildings	3	1	4
	(F) National initiatives to promote smart technologies, energy communities, and skills and education	8	2	10
	(G) Evidence-based estimate of expected energy savings and wider benefits	15	0	15
	Subtotal	63	9	72
Mechanisms to support investment mobilization (2018 EPBD, Article 2a, Paragraph 3)	(A) Aggregation of projects	1	0	1
	(B) Reduction of the perceived risk of energy efficiency operations	1	0	1
	(C) Use of public funding to leverage additional private-sector investment or address specific market failures	2	0	2
	(D) Guiding investments into an energy efficient public building stock	1	0	1
	(E) Accessible and transparent advisory tools for consumers and energy advisory services	2	2	4
	Subtotal	7	2	9
Total		70	11	81

Commission 2017). According to the 2019 EPBD-related Recommendation, the term market failures refers to a range of problems that tend to delay the transformation of the building stock, such as a lack of understanding of energy use and potential savings; limited renovation and construction activity in a post-crisis context; a lack of attractive financing products; limited information on building stock; or limited uptake of efficient and smart technologies (European Commission 2019b). Energy poverty is understood as a household situation in which energy bills represent a high percentage of consumers' income, or in which the consumers must reduce their household's energy consumption to a degree that negatively impacts their health and well-being (Rademaekers et al. 2016).

- Policies and actions to target public buildings. The 2018 EBPD requires public authorities to lead by example by becoming early adopters of energy efficiency improvements in the buildings that are occupied (e.g. leased or rented) by local or regional authorities and buildings that are owned by central government and regional or local authorities, although not necessarily occupied by them.
- National initiatives to promote smart technologies, energy communities, and skills and education. Smart technologies can ensure an optimized energy management by supporting design, monitoring and control with self-learning capacities (European Commission 2017). For occupants, they provide user information, enhancing comfort and optimal indoor conditions as well as enabling real time communication and interactions with the grid (European Commission 2017). On the other hand, training and qualification should ensure that worker qualifications keep pace with the technical complexity of buildings and building components (European Commission 2017). The 2018 EPBD aims to facilitate the incorporation of technological developments such as smart building technologies and the uptake of electric vehicles and other technologies, both through specific installation requirements and by ensuring that building professionals can deliver the requisite skills and know-how.
- Evidence-based estimate of expected energy savings and wider benefits. The importance of making public the benefits of renovation is highlighted. Benefits are not only referred to energy savings, but also to other wider ones such as those related to building health, safety and air quality, lower illness and health costs, greater labor productivity from better working and living conditions, more jobs in the building sector, and reduced emissions and whole life carbon.

The indicators in the second category of Table 1 respond to the requirement to the MSs to facilitate access to financial mechanisms to support the mobilization of investments in the renovation needed to achieve the goals of the mandatory elements of the LTRS, in particular the use of innovative financing is encouraged to effectively enable small clients and small providers. This category is divided into several subcategories, whose descriptions and importance are justified next:

- Aggregation of projects. This term includes aggregations by investment platforms or groups, and by consortia of small and medium-sized enterprises, to enable investor access as well as packaged solutions for potential clients. According to the 2019 EPB-related Recommendation, examples of this type of financing would include procurement by a municipality of an energy-service contract for retrofitting multi-family buildings financed through energy savings, capacity-building and stakeholder dialogue to improve relevant entities' ability to offer aggregation services, procurement by a group of municipalities of an energy-service contract for some of their public buildings; and offering integrated renovation services in which an entity (e.g. energy agency, local or regional authority, energy service company (ESCO), financial institution) creates a one-stop shop offering renovation services and financing, in a standardized way, making it possible to refinance the aggregated projects.

- Reduction of the perceived risk of energy efficiency operations. According to the 2019 EPBD-related Recommendation, this can be done by mechanisms such as standardization (e.g. through protocols, certification, standards) to reduce performance risks ex post; mortgages/loans that take account of the positive impact of the energy efficiency component of a project on the value of the asset and on default risk; refinancing (funds, bonds, factoring) to provide ESCOs and financial investors with long-term financing; on-tax financing, i.e. the money lent for investment in building improvements is repaid through property tax; n-bill financing, i.e. the loan is repaid through the utility bill, with the energy savings covering the investment costs; support for collecting evidence of the real technical and financial performance of energy efficiency investments, e.g. contributing to the European de-risking energy efficiency platform (DEEP) database (De-risking Energy Efficiency Platform 2021), or creating similar national databases; encouraging the development and use of guidance on how to assess the risk for energy efficiency investments; or guarantees for beneficiaries and guarantee facilities for financial intermediaries.
- Use of public funding to leverage additional private-sector investment or address specific market failures. According to the 2019 EPBD-related Recommendation, public funding includes solutions such as loan schemes co-financed by public funds; risk-sharing instruments (e.g. loans, guarantee facilities and technical assistance); grants targeting vulnerable consumers; grants for technical assistance and to cover the costs of energy performance certificates (EPCs) and energy audits, and (where these are not mandatory) to encourage their use and raise awareness of investment opportunities; and energy efficiency funds.
- Guiding investments into an energy efficient public building stock. According to the 2019 EPBD-related Recommendation, this guiding investment includes assistance for the use of energy performance contracts (market facilitators, framework contracts, practical guides, etc.); a legislative framework conducive to the development of ESCOs and the energy services market in general; capacity-building through project development assistance, training, peer-to-peer assistance, etc.; and facilitating the aggregation of small projects in public buildings (e.g. similar projects from different municipalities or public owners).
- Accessible and transparent advisory tools for consumers and energy advisory services. According to the 2019 EPBD-related Recommendation, this tools include, among others, one-stop shop or integrated service for financing and renovation; advisory services; technical guidance on financing and renovation; and financial education to improve the understanding of different financial instruments.

The indicators framework of the 2023 EPBD Proposal recast (Table 2) differs from the 2019 EPBD-related Recommendation in important aspects:

- On the one hand, the term milestone is substituted by target.
- A distinction is made between mandatory and optional indicators. In the 2019 EPBD-related Recommendation all indicators were optional. In the 2023 EPBD Proposal recast there are mandatory indicators included in the template for NBRPs which will facilitate the comparison of targets and progress between countries.
- The categories are not organized by the mandatory elements of the NBRPs, as was the case with the 2019 EPB-related Recommendation framework, but by whether they are overview indicators or roadmap indicators. In total there are five categories in the framework of the 2023 EPBD Proposal recast, namely: (A) Overview of the national building stock; (B) Roadmap for 2030, 2040, 2050; (C) Overview of implemented and planned policies and measures; (D) Detailed roadmap of the investment needs, the budgetary sources and the administrative resources; and (E) Roadmap on energy poverty.
- The number of indicators is considerably higher in the 2023 EPBD Proposal recast. There are a total of 117 mandatory indicators among categories A, B, C, and D (Table 2), and 33 optional indicators among categories A, B, and C, which sum up a total of 150 indicators, 69 more than in the 2019 EPB-related Recommendation framework. Additionally, the indicators have also been revisited significantly. Tables 5 and Table 6 in Appendix A show the compulsory and optional indicators of the 2023 EPBD Proposal recast that had already been included in the 2019 EPBD-related Recommendation. Figure 1 shows the results of the analysis of the similarity between the indicators of the 2019 EPBD-related Recommendation (European Commission 2019b) and the 2023 EPBD Proposal recast. About 37% of the indicators in the 2023 EPBD Proposal recast are derived from those proposed in the 2019 EPBD-related Recommendation. The remaining 63% are new indicators.

Table 2 Structure and number of indicators in the framework of progress indicators in annex II of the 2023 EPBD proposal recast (European Parliament 2023). *Source* own creation

Category	Subcategory	No. of mandatory indicators	No. of optional indicators	Total
Renovation Building Plans (Article 3 of the 2023 EPBD Proposal recast)	(A) Overview of national building stock	52	25	78
	(B) Roadmap for 2030, 2040, 2050	31	2	33
	(C) Overview of implemented and planned policies and measures	25	6	31
	(D) Detailed roadmap of the investment needs, the budgetary sources and the administrative resources	5	0	5
	(E) Roadmap on energy poverty	4	0	4
Total		117	33	150

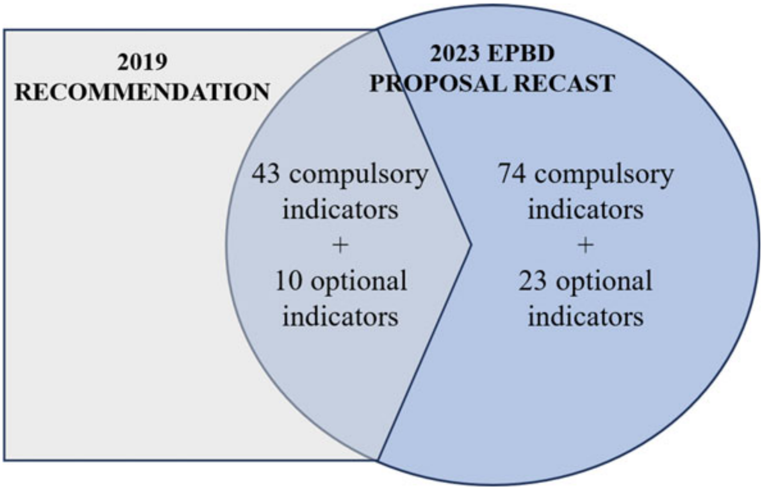


Fig. 1 Similarity between the indicators of the 2019 EPBD-related Recommendation (European Commission 2019b) and the 2023 EPBD Proposal recast (European Parliament 2023). *Source* own creation

The coincident indicators encompass various subjects, spanning from an analysis of the general attributes of the national building stock, its energy characteristics, and deep renovation to insights into the worst-performing segments, rented properties, and energy poverty. Additionally, the indicators address capacities within the construction, energy efficiency, and renewable energy sectors, along with actual energy savings and broader advantages resulting from building renovation, evidence-based estimates of expected energy savings, cost reductions associated with building renovation, and policies and measures aimed at mobilizing investments in building renovation.

The topics covered by the new indicators are related to new requirements that will have to be implemented by the MSs when the new EPBD is finally approved, such as the life-cycle assessment of buildings or the Minimum Energy Performance Standard, as well as topics that were already present in the framework of 2019 but have been improved in the new one, such as market failures, which were mentioned but did not have a specific proposal of indicators.

4 Conclusions

The review of the evolution of the indicator frameworks proposed in European documents to measure the progress of the renovation and decarbonization of the building sector allowed us to understand that MSs will have to carry out important policy monitoring and evaluation work. Since 2020, this evaluation has been carried out by MSs following an indicator framework with 81 optional indicators. However, the

Energy Performance of Buildings Directive (EPBD), currently under review, points towards a new evaluation framework with 118 mandatory and 33 optional indicators. In 2020, the first time that the MSs had to submit a long-term renovation strategy that included indicators, the countries could not follow the optional framework closely due to lack of data in their countries. For example, in the case of Spain, only 17 indicators were developed (Beltran-Velamazan et al. 2021; 2023). The new framework will be significantly more data demanding.

MSs should involve in data collection regarding renovation and decarbonization of their building stocks as soon as possible. MSs should start focusing on the indicators related to overlapping themes in the two indicator frameworks discussed in this chapter for two main reasons. On one hand, because they are the most mature indicators since they were proposed in the first indicator framework and were reformulated after MSs submitted their 2020 LTRSs in the 2023 EPBD Proposal recast. The other reason is that the new EPBD has not yet a final text and the indicator framework could be subject to new changes when it finally gets approved. Therefore, the topics in which we consider that data collection should currently focus on are:

- An overview of the general characteristics of the national building stock.
- An overview of the energy characteristics of the national building stock.
- An overview of deep renovation of buildings.
- An overview of worst performing segments of the national building stock, rented properties, and energy poverty.
- An overview of the capacities in the construction, energy efficiency and renewable energy sector.
- An overview of actual energy savings and wider benefits of renovation of buildings.
- Evidence-based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation.
- Policies and measures for the mobilization of investments into the renovation of buildings.

In this book, our objective is to conduct a thorough exploration and analysis of the sources at our disposal for the purpose of developing indicators related to these topics, focusing on the case of one of the MSs, Spain. We will delve into a comprehensive examination of available resources at national and regional levels to gather valuable insights and contribute to a deeper understanding of the subject matter.

Acknowledgements This work was funded by the MINISTRY OF SCIENCE AND INNOVATION OF SPAIN, grant number PID2019-104871RB-C21/AEI/10.13039/501100011033 and by GOBIERNO DE ARAGÓN, grant number T37_23R: Built4Life Lab.

Appendix A

Table 3 Framework of indicators in Article 2a of the 2019 EPBD-related Recommendation. *Source* own creation from data in (European Commission 2019b)

Indicators related to the mandatory elements of LTRSs, included in article 2a Paragraph 1–2018 EPBD	Indicators	Milestones
(a) overview of the national building stock, based, as appropriate, on statistical sampling and expected share of renovated buildings in 2020;	No. of buildings per building type	Energy savings (in absolute and relative % terms) per building sector (residential, non-residential, etc.) % of renovated buildings (per renovation type) Carbon dioxide (CO_2) emissions reduction in the building sector (renovation/new buildings) % of nearly zero-energy buildings (nZEBs) (per building sector)
	No. of buildings per building age	
	No. of buildings per building size	
	No. of buildings per climatic zone	
	No. of dwellings per building type	
	No. of dwellings per building age	
	No. of dwellings per building size	
	No. of dwellings per climatic zone	
	m^2 per building type	
	m^2 per building age	
	m^2 per building size	
	m^2 per climatic zone	
	Annual energy consumption per building type	
	Annual energy consumption per end use	
	Annual % of renovated buildings per renovation type	
	Annual % of renovated buildings per building sector2013residential/non residential	
	Renovated m^2 per building type	

(continued)

Table 3 (continued)

Indicators related to the mandatory elements of LTRSs, included in article 2a Paragraph 1–2018 EPBD	Indicators	Milestones
	Renovated m^2 per building size	
	Renovated m^2 per building age	
	No. of EPCs per building type	
	No. of EPCs per energy class	
	No. of nZEBs per building sector	
	m^2 of nZEBs per building sector	
(b) identification of cost-effective approaches to renovation relevant to the building type and climatic zone, considering potential relevant trigger points, where applicable, in the life-cycle of the building;	Cost-effectiveness of main renovation measures (e.g. net present values, payback period, investment costs per annual savings) per building type	
	Cost-effectiveness of main renovation measures (e.g. net present values, payback period, investment costs per annual savings) per climatic zone	
	Total energy saving potential per building sector	
(c) policies and actions to stimulate cost-effective deep renovation of buildings, including staged deep renovation, and to support targeted cost-effective measures and renovation, for example by introducing an optional scheme for building renovation pass ports	Total and annual proportion of buildings undergoing deep and nZEB renovation	
	Public incentives for deep renovation	
	Public and private investments in deep renovations	
	Energy savings from deep renovations	

(continued)

Table 3 (continued)

Indicators related to the mandatory elements of LTRSs, included in article 2a Paragraph 1–2018 EPBD	Indicators	Milestones
(d) overview of policies and actions to target the worst-performing segments of the national building stock, split-incentive dilemmas and market failures, and an outline of relevant national actions that contribute to the alleviation of energy poverty;	Public investments in policy addressing the issues mentioned (split incentives, energy poverty, etc.)	% reduction of people affected by energy poverty % reduction of buildings in the lowest energy classes
	% of rented houses with EPCs below a certain performance level	
	Energy poverty indicators: % of people affected by energy poverty	
	Energy poverty indicators: proportion of disposable household income spent on energy	
	Energy poverty indicators: arrears on utility bills	
	Energy poverty indicators: population living in inadequate dwelling conditions (e.g. leaking roof) or with inadequate heating and cooling	
	% of buildings in lowest energy classes	
(e) policies and actions to target all public buildings;	m^2 of renovated public buildings per building type	Energy savings in public buildings
	m^2 of renovated public buildings per building size	
	m^2 of renovated public buildings per climatic zone	
(f) overview of national initiatives to promote smart technologies and well-connected buildings and communities, as well as skills and education in the construction and energy efficiency sectors;	No. of buildings equipped with building energy management systems (BEMSs) or similar smart systems per building type (focus on non-residential)	Percentage of buildings equipped with BEMSs or similar smart systems: per building type
	Public and private investments in smart technologies (including smart grids)	
	Citizens participating in energy communities	

(continued)

Table 3 (continued)

Indicators related to the mandatory elements of LTRSs, included in article 2a Paragraph 1–2018 EPBD	Indicators	Milestones
	No. of graduated students university courses with focus on energy efficiency and related smart technologies	
	No. of graduated students professional/technical training (EPC certifiers; heating, ventilation, and air conditioning inspectors; etc.)	
	No. of installers skilled in new technologies and working practices	
	Budget of national research programs in the field of building energy efficiency	
	Participation of national universities in international scientific research projects (e.g. H2020) on energy efficiency in buildings related topics	
(g) evidence-based estimate of expected energy savings and wider benefits, such as those related to health, safety and air quality	Reduction in energy costs per household (average)	
	Decrease in energy poverty	
	Actual energy savings achieved	
	Average/aggregate indoor air quality in dices (IAQIs) and	
	Thermal comfort index (TCI)	
	Cost of avoided illnesses	
	Reduction in health costs attributable to energy efficiency measures	

(continued)

Table 3 (continued)

Indicators related to the mandatory elements of LTRSs, included in article 2a Paragraph 1–2018 EPBD	Indicators	Milestones
	Reduction of whole life carbon	
	Disability Adjusted Life Year (DALY)/Quality Adjusted Life Year (QALY) improvements attributable to the improvement of building stock and living conditions	
	Labor productivity gains from better working environment and improved living conditions	
	Reduction of emissions	
	Employment in the building sector (No. of jobs created per EUR million invested in the sector)	
	Gross domestic product (GDP) increase in the building sector	
	% energy imports for the MS (energy security measures)	
	Removal/prevention of accessibility barriers for persons with disabilities	
Indicators related to Mechanisms to support investment mobilization, included in article 2a Paragraph 3–2018 EPBD	*Indicators*	*Milestones*
(a) the aggregation of projects, including by investment platforms or groups, and by consortia of small and medium-sized enterprises, to enable investor access as well as packaged solutions for potential clients;	No. of integrated/aggregated projects	

(continued)

Table 3 (continued)

Indicators related to the mandatory elements of LTRSs, included in article 2a Paragraph 1–2018 EPBD	Indicators	Milestones
(b) reduction of the perceived risk of energy efficiency operations for investors and the private sector;	Perceived risk of energy efficiency operation (survey-based)	
(c) use of public funding to leverage additional private-sector investment or address specific market failures;	Public investments as percentage of total investments in energy saving	
	Public–private partnership initiatives	
(d) guiding investments into an energy efficient public building stock, in line with Eurostat guidance; and	Investment in energy efficiency renovation on the public building stock	
(e) accessible and transparent advisory tools, such as one-stop shops for consumers and energy advisory services, on relevant energy efficiency renovations and financing instruments	One-stop shop initiatives in place	No of one-stop shop initiatives Awareness is raised and leads to concrete action
	Awareness-raising initiatives (number, target audience reached, target audience taking action)	

Table 4 Framework of indicators in annex II of the 2023 EPBD proposal. Indicators marked with an asterisk are mandatory. Those not marked are optional. *Source* own creation from data in (European Parliament 2023)

EPBD Article 3	Mandatory and optional indicators
(a) Overview of the national building stock	No. of buildings per building type*
	No. of buildings per building age
	No. of buildings per building size
	No. of buildings per climatic zone
	No. of building demolitions
	No. of buildings per energy performance class*
	No. of buildings worst-performing*
	m^2 per building type*
	m^2 per building age
	m^2 per building size
	m^2 per climatic zone
	m^2 of building demolitions
	m^2 per energy performance class*
	m^2 of worst-performing segments*
	Overview of energy source types for space and water heating, cooling and estimated obsolescence dates of heating and cooling systems: annual replacement rates for heating and cooling appliances for space and water heating and cooling*
	Overview of energy source types for space and water heating, cooling and estimated obsolescence dates of heating and cooling systems: number and type of appliances replaced every year (over the previous 5 years covered by the plan)*
	Overview of energy source types for space and water heating, cooling and estimated obsolescence dates of heating and cooling systems: type of appliances newly installed*
	Overview of the total share, number and location of unoccupied buildings, and vacant properties in common-property buildings*
	No. of buildings categorized as officially protected as part of a designated environment or because of their special architectural or historical merit as compared to 2020*
	No. of EPCs per building type*
	No. of EPCs per energy class*
	No. of EPCs per construction period
	Annual renovation rates: number of buildings per building type*

(continued)

Table 4 (continued)

EPBD Article 3	Mandatory and optional indicators
	Annual renovation rates: number of buildings to nZEB and zero-energy building (ZEB) levels*
	Annual renovation rates: number of buildings per renovation depth*
	Annual renovation rates: number of public buildings*
	Annual renovation rates: m^2 per building type*
	Annual renovation rates: m^2 to nZEB and ZEB levels*
	Annual renovation rates: m^2 per renovation depth*
	Annual renovation rates: m^2 of public buildings*
	Primary and final annual energy consumption (ktoe) and (annual demand in ktoe and seasonal peak demand in GWh/day) per building type*
	Primary and final annual energy consumption (ktoe) and (annual demand in ktoe and seasonal peak demand in GWh/day) per end use*
	Energy savings (Ktoe) per building type*
	Energy savings (Ktoe) in public buildings*
	Reduction in energy costs (EUR) per household (average)
	Primary energy demand of a building corresponding to the top 15% (substantial contribution threshold) and the top 30% (do no significant harm threshold) of the national building stock, as per the EU Climate Taxonomy Delegated Act
	Share of renewable energy in the building sector: for different uses*
	Share of renewable energy in the building sector: on-site*
	Share of renewable energy in the building sector: off-site*
	Share of heating system in the building sector per boiler/heating system type
	Annual operational GHG emissions per building type (including public buildings)*
	Annual operational GHG emission reduction: per building type (including public buildings)*
	Annual life-cycle GWP per building type*
	Annual life-cycle GWP reduction per building type*
	Market barriers and failures: Split incentives*
	Market barriers and failures: Capacity of construction and energy sector*
	Market barriers and failures: Administrative
	Market barriers and failures: Financial
	Market barriers and failures: Technical

(continued)

Table 4 (continued)

EPBD Article 3	Mandatory and optional indicators
	Market barriers and failures: Awareness
	Market barriers and failures: Other
	Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: Energy service companies*
	Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: construction companies*
	Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: architects and engineers*
	Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: skilled workers*
	Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: microenterprises and SMEs in the construction/renovation sector*
	Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: training programs and facilities focused on energy renovation*
	Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: one-stop-shops per 45,000 inhabitants*
	Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: renewable energy communities and citizen energy communities*
	Projections of the construction workforce: Architects/ engineers/skilled workers retired
	Projections of the construction workforce: Architects/ engineers/skilled workers entering the market
	Projections of the construction workforce: installers and/or installation companies of heating systems
	Projections of the construction workforce: maintenance personnel of heating systems
	Projections of the construction workforce: Young people in the sector
	Projections of the construction workforce: Women in the sector
	Overview and forecast of the evolution of prices of construction materials and national market developments

(continued)

Table 4 (continued)

EPBD Article 3	Mandatory and optional indicators
	Energy poverty: % of people affected (by gender)*
	Energy poverty: Proportion of disposable household income spent on energy*
	Energy poverty: population living in inadequate dwelling conditions or with inadequate thermal comfort conditions*
	Primary energy factors: per energy carrier*
	Primary energy factors: non-renewable primary energy factor*
	Primary energy factors: renewable primary energy factor*
	Primary energy factors: total primary energy factor*
	Definition of nearly-zero energy building for new and existing buildings*
	Description of regions belonging to which climatic zone in accordance with Annex III and number of zero emission buildings per climate zone*
	Overview of the legal and administrative framework (nZEB)
	Cost-optimal minimum requirements for new and existing buildings*
(b) Roadmap for 2030, 2040, 2050	Targets for annual renovation rates: number and total floor area: per building type*
	Targets for annual renovation rates: number and total floor area: worst-performing*
	Targets for annual renovation rates: number and total floor area: deep renovations*
	Targets for expected share of renovated buildings: per building type*
	Targets for expected share of renovated buildings: per renovation depth*
	Targets for expected share of renovated buildings: per measures for building elements that form part of the building envelope and technical building systems, that have a significant impact of the energy performance of the building*
	Target for expected primary and final annual energy consumption and annual demand in ktoe and seasonal peak demand in GWh/day: per building type*
	Target for expected primary and final annual energy consumption and annual demand in ktoe and seasonal peak demand in GWh/day: per end use*
	Expected energy savings: per building type*
	Expected energy savings: share of energy from renewable sources in the building sector*

(continued)

Table 4 (continued)

EPBD Article 3	Mandatory and optional indicators
	Expected energy savings: numerical targets for the deployment of solar energy and heat pumps in buildings*
	Targets for the replacement of old and inefficient heaters*
	Targets for phasing out fossil fuels from heating and cooling systems per building type*
	Targets for phasing out fossil fuels from heating and cooling systems as a proportion of total renovation*
	Targets for phasing out fossil fuels from heating and cooling systems for building achieving over EPC D rating*
	Milestones and trajectories for buildings to achieve the performance classes pursuant to Article 9(1) and higher energy performance classes in line with the climate neutrality goal*
	Targets for increase of share of renewable energy in line with the target for the share of energy from renewable sources in the building sector set out in Directive (EU)*
	Targets for the decarbonization of heating and cooling, including through district heating and cooling networks using renewable energy and waste heat in line with the requirements set in Articles 23 and 24 of Directive (EU)*
	Targets for expected operational GHG emissions: per building type*
	Targets for expected whole life-cycle GHG emission ($kgCO_2eq/(m^2.y)$ with five year milestones: per building type*
	Targets for expected whole life-cycle GHG emission reduction (%) with five-year milestones: per building type*
	Targets aligned to Regulation (EU) No 305/2011 for circular use of materials, recycled contents and secondary materials, and sufficiency with five-year milestones*
	Targets to increase carbon removals associated to the temporary storage of carbon in or on buildings*
	Split between emissions covered by Chapter III [stationary installations], Chapter IVa [new emissions trading for buildings and road transport] of Directive 2003/87/EC, and other stock
	Expected wider benefits: Creation of new jobs*
	Expected wider benefits: % reduction of people affected by energy poverty*
	Expected wider benefits: % reduction of people living in inadequate indoor environment and reduction of costs for health systems due to health improvements through improved indoor environmental quality after renovation*

(continued)

Table 4 (continued)

EPBD Article 3	Mandatory and optional indicators
	Expected wider benefits: resource efficiency, including efficiency of water usage*
	Increase of GDP (share and billion Euros)
	Contribution to the Union's energy efficiency targets in accordance with Directive (EU) …/…. [recast Energy Efficiency Directive (EED)] (share and figure in ktoe, primary and final consumption): against the overall energy efficiency target*
	Contribution to the Union's renewable energy targets in accordance with Directive (EU) 2018/2001 [amended Renewable Energy Directive (RED)] (share, MW generated): against the overall target for energy from renewable sources*
	Contribution to the Union's renewable energy targets in accordance with Directive (EU) 2018/2001 [amended RED] (share, MW generated): against the target for the share of energy from renewable sources in the building sector*
	Contribution to Union's 2030 climate target and 2050 climate neutrality goal in accordance with Regulation (EU) 2021/1119 (share and figure in ($kgCO_2eq/(m^2.y)$)): against the overall decarbonization target*
(c) Overview of implemented and planned policies and measures	Policies and measures with regard to the following elements: (a) the identification of cost-optimal approaches to renovation for different building types and climatic zones, considering potential relevant trigger points in the lifecycle of the building*
	Policies and measures with regard to the following elements: (b) national minimum energy performance standards pursuant to Article 9 and other policies and actions to target the worst-performing segments of the national building stock*
	Policies and measures with regard to the following elements: (c) the promotion of deep renovation of buildings, including staged deep renovation*
	Policies and measures with regard to the following elements: (d) high indoor environmental quality in new and renovated buildings*
	Policies and measures with regard to the following elements: (e) empowering and protecting vulnerable customers and the alleviation of energy poverty, including policies and measures pursuant to Article 22 of Directive (EU) …/… [recast EED], and housing affordability*

(continued)

Table 4 (continued)

EPBD Article 3	Mandatory and optional indicators
	Policies and measures with regard to the following elements: (f) the creation of one-stop shops or similar mechanisms for the provision of technical, administrative and financial advice and assistance*
	Policies and measures with regard to the following elements: (g) the decarbonization of heating and cooling, including through efficient district heating and cooling networks in alignment with [revised EED], and the phase out of fossil fuels in heating and cooling in buildings with a view to a planned phase-out by 2035 and, if not feasible as demonstrated to the Commission, by 2040 at the latest(fa) the roadmap to the phase out of fossil fuel use in buildings by 2035 and if not feasible as demonstrated to the Commission, by 2040 at the latest*
	Policies and measures with regard to the following elements: (h) the promotion of renewable energy sources in buildings in line with the target for the share of energy from renewable sources in the building sector set in Article 15a(1) of Directive (EU) 2018/2001 [amended RED]*
	Policies and measures with regard to the following elements: (i) the deployment of solar energy installations on buildings*
	Policies and measures with regard to the following elements: (j) the reduction of whole life-cycle GHG emissions for the construction, renovation, operation and end of life of buildings, and the uptake of carbon removals*
	Policies and measures with regard to the following elements: (k) the reduction of the overall environmental footprint of all parts and components of buildings, including through the use of sustainable, secondary, preferably locally sourced construction and renovation products*
	Policies and measures with regard to the following elements: (l) prevention and high-quality treatment of construction and demolition waste in line with Directive 2008/98/EC, in particular as regards the waste hierarchy, and the objectives of the circular economy*
	Policies and measures with regard to the following elements: (m) increase in the coverage of the building stock with energy performance certificates including towards low-income households*
	Policies and measures with regard to the following elements: (n) district and neighborhood approaches, including the role of renewable energy communities and citizen energy communities*

(continued)

Table 4 (continued)

EPBD Article 3	Mandatory and optional indicators
	Policies and measures with regard to the following elements: (ñ) the improvement of buildings owned by public bodies, including policies and measures pursuant to Articles 5, 6 and 7 of the [recast EED]*
	Policies and measures with regard to the following elements: (o) the promotion of smart technologies and infrastructure for sustainable mobility in buildings*
	Policies and measures with regard to the following elements: (p) addressing market barriers and market failures*
	Policies and measures with regard to the following elements: (q) addressing skills gaps and mismatches in human capacities, and promoting education, training, upskilling and reskilling in the construction, sector and energy efficiency and renewable energy sectors including with a gender dimension*
	Policies and measures with regard to the following elements: (r) Key performance indicators for upskilling and/or reskilling actions, as well as jobs created*
	Policies and measures with regard to the following elements: (s) awareness raising campaigns and other advisory tools*
	Policies and measures with regard to the following elements: (t) new the promotion of smart technologies for monitoring, analysis and simulation of buildings' energy performance across the whole-life cycle, including 3D modelling technologies*
	Policies and measures with regard to the following elements: (u) new inspection schemes including digital tools and checklists, to verify compliance with Building Automation and Control capabilities*
	Policies and measures with regard to the following elements: (v) the promotion of energy management solutions, such as Energy Performance Contracts (EnPCs)*
	Policies and measures with regard to the following elements: (w) measures to increase the coverage of the building stock with energy performance certificates or alternative real time measurement systems*
	Policies and measures with regard to the following elements: (x) new development and support of citizen-led energy efficiency and renovation initiatives, in particular the role of renewable energy communities and citizen energy communities*
	Policies and measures with regard to the following elements: (a) the increase of climate resilience of buildings

(continued)

Table 4 (continued)

EPBD Article 3	Mandatory and optional indicators
	Policies and measures with regard to the following elements: (b) the promotion of the energy services market
	Policies and measures with regard to the following elements: (c) the increase of fire safety
	Policies and measures with regard to the following elements: (d) the increase of resilience against disaster risks, including risks related to intense seismic activity
	Policies and measures with regard to the following elements: (e) the removal of hazardous substances including asbestos
	Policies and measures with regard to the following elements: (f) accessibility for persons with disabilities
(d) Detailed roadmap of the investment needs, the budgetary sources and the administrative resources	Total investment needs for 2030, 2040, 2050 (million EUR)*
	Public investments*
	Private investments (million EUR), including energy efficiency loans, mortgages for building renovation, bond issuance or other financing mechanisms*
	Budgetary resources*
	Secured budget*
(e) roadmap on energy poverty	Targets for reducing energy poverty rates*
	Number of households in energy poverty*
	List implemented and planned policies to reduce energy poverty*
	List of implemented and planned funding measures to reduce energy poverty*

Table 5 Mandatory indicators in annex II of the 2023 EPBD proposal recast and whether they were or not included in the 2019 EPBD-related Recommendation. *Source* own creation

Mandatory indicators of 2023 EPBD Proposal recast	Was it included in the 2019 EPBD-related Recommendation?
No. of buildings per building type	Yes
No. of buildings per energy performance class	Similar
No. of buildings worst-performing	Yes
m^2 per building type	Yes
m^2 per energy performance class	Similar
m^2 of worst-performing segments	Similar

(continued)

Table 5 (continued)

Mandatory indicators of 2023 EPBD Proposal recast	Was it included in the 2019 EPBD-related Recommendation?
Overview of energy source types for space and water heating, cooling and estimated obsolescence dates of heating and cooling systems: annual replacement rates for heating and cooling appliances for space and water heating and cooling	No
Overview of energy source types for space and water heating, cooling and estimated obsolescence dates of heating and cooling systems: number and type of appliances replaced every year (over the previous 5 years covered by the plan)	No
Overview of energy source types for space and water heating, cooling and estimated obsolescence dates of heating and cooling systems: type of appliances newly installed	No
Overview of the total share, number and location of unoccupied buildings, and vacant properties in common-property buildings	No
No. of buildings categorized as officially protected as part of a designated environment or because of their special architectural or historical merit as compared to 2020	No
No. of EPCs per building type	Yes
No. of EPCs per energy class	Yes
Annual renovation rates: number of buildings per building type	Yes
Annual renovation rates: number of buildings to nZEB and ZEB levels	Similar
Annual renovation rates: number of buildings per renovation depth	Yes
Annual renovation rates: number of public buildings	Similar
Annual renovation rates: m^2 per building type	Yes
Annual renovation rates: m^2 to nZEB and ZEB levels	Similar
Annual renovation rates: m^2 per renovation depth	Similar
Annual renovation rates: m^2 of public buildings	Yes
Primary and final annual energy consumption (ktoe) and (annual demand in ktoe and seasonal peak demand in GWh/day) per building type	Similar
Primary and final annual energy consumption (ktoe) and (annual demand in ktoe and seasonal peak demand in GWh/day) per end use	Similar
Energy savings (Ktoe) per building type	Similar
Energy savings (Ktoe) in public buildings	Yes
Share of renewable energy in the building sector: for different uses	No
Share of renewable energy in the building sector: on-site	No

(continued)

Table 5 (continued)

Mandatory indicators of 2023 EPBD Proposal recast	Was it included in the 2019 EPBD-related Recommendation?
Share of renewable energy in the building sector: off-site	No
Annual operational GHG emissions per building type (including public buildings)	Similar
Annual operational GHG emission reduction: per building type (including public buildings)	Similar
Annual life-cycle GWP per building type	No
Annual life-cycle GWP reduction per building type	No
Market barriers and failures: Split incentives	No
Market barriers and failures: Capacity of construction and energy sector	No
Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: Energy service companies	No
Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: construction companies	No
Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: architects and engineers	Similar
Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: skilled workers	Yes
Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: microenterprises and SMEs in the construction/renovation sector	No
Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: training programs and facilities focused on energy renovation	Similar
Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: one-stop-shops per 45,000 inhabitants	Yes
Overview of the capacities in the construction, energy efficiency and renewable energy sectors. Number of: renewable energy communities and citizen energy communities	No
Energy poverty: % of people affected (by gender)	Yes
Energy poverty: Proportion of disposable household income spent on energy	Yes
Energy poverty: population living in inadequate dwelling conditions or with inadequate thermal comfort conditions	Yes
Primary energy factors: per energy carrier	No
Primary energy factors: non-renewable primary energy factor	No

(continued)

Table 5 (continued)

Mandatory indicators of 2023 EPBD Proposal recast	Was it included in the 2019 EPBD-related Recommendation?
Primary energy factors: renewable primary energy factor	No
Primary energy factors: total primary energy factor	No
Definition of nearly-zero energy building for new and existing buildings	No
Description of regions belonging to which climatic zone in accordance with Annex III and number of zero emission buildings per climate zone	No
Cost-optimal minimum requirements for new and existing buildings	No
Targets for annual renovation rates: number and total floor area: per building type	No
Targets for annual renovation rates: number and total floor area: worst-performing	No
Targets for annual renovation rates: number and total floor area: deep renovations	No
Targets for expected share of renovated buildings: per building type	No
Targets for expected share of renovated buildings: per renovation depth	Similar
Targets for expected share of renovated buildings: per measures for building elements that form part of the building envelope and technical building systems, that have a significant impact of the energy performance of the building	No
Target for expected primary and final annual energy consumption and annual demand in ktoe and seasonal peak demand in GWh/day: per building type	No
Target for expected primary and final annual energy consumption and annual demand in ktoe and seasonal peak demand in GWh/day: per end use	No
Expected energy savings: per building type	Similar
Expected energy savings: share of energy from renewable sources in the building sector	No
Expected energy savings: numerical targets for the deployment of solar energy and heat pumps in buildings	No
Targets for the replacement of old and inefficient heaters	No
Targets for phasing out fossil fuels from heating and cooling systems per building type	No
Targets for phasing out fossil fuels from heating and cooling systems as a proportion of total renovation	No
Targets for phasing out fossil fuels from heating and cooling systems for building achieving over EPC D rating	No

(continued)

Table 5 (continued)

Mandatory indicators of 2023 EPBD Proposal recast	Was it included in the 2019 EPBD-related Recommendation?
Milestones and trajectories for buildings to achieve the performance classes pursuant to Article 9(1) and higher energy performance classes in line with the climate neutrality goal	No
Targets for increase of share of renewable energy in line with the target for the share of energy from renewable sources in the building sector set out in Directive (EU)	No
Targets for the decarbonization of heating and cooling, including through district heating and cooling networks using renewable energy and waste heat in line with the requirements set in Articles 23 and 24 of Directive (EU)	No
Targets for expected operational GHG emissions: per building type	No
Targets for expected whole life-cycle GHG emission ($kgCO_2eq/(m^2.y)$) with five year milestones: per building type	No
Targets for expected whole life-cycle GHG emission reduction (%) with five-year milestones: per building type	No
Targets aligned to Regulation (EU) No 305/2011 for circular use of materials, recycled contents and secondary materials, and sufficiency with five-year milestones	No
Targets to increase carbon removals associated to the temporary storage of carbon in or on buildings	No
Expected wider benefits: Creation of new jobs	Yes
Expected wider benefits: % reduction of people affected by energy poverty	Yes
Expected wider benefits: % reduction of people living in inadequate indoor environment and reduction of costs for health systems due to health improvements through improved indoor environmental quality after renovation	Yes
Expected wider benefits: resource efficiency, including efficiency of water usage	No
Contribution to the Union's energy efficiency targets in accordance with Directive (EU) Energy Efficiency Directive (EU) 2023/1791 [recast EED] (share and figure in ktoe, primary and final consumption): against the overall energy efficiency target	No
Contribution to the Union's renewable energy targets in accordance with Directive (EU) 2018/2001 [amended RED] (share, MW generated): against the overall target for energy from renewable sources	No
Contribution to the Union's renewable energy targets in accordance with Directive (EU) 2018/2001 [amended RED] (share, MW generated): against the target for the share of energy from renewable sources in the building sector	No

(continued)

Table 5 (continued)

Mandatory indicators of 2023 EPBD Proposal recast	Was it included in the 2019 EPBD-related Recommendation?
Contribution to Union's 2030 climate target and 2050 climate neutrality goal in accordance with Regulation (EU) 2021/1119 (share and figure in ($kgCO_2eq/(m^2.y)$): against the overall decarbonization target	No
Policies and measures with regard to the following elements: (a) the identification of cost-optimal approaches to renovation for different building types and climatic zones, considering potential relevant trigger points in the lifecycle of the building;	Similar
Policies and measures with regard to the following elements: (b) national minimum energy performance standards pursuant to Article 9 and other policies and actions to target the worst-performing segments of the national building stock	No
Policies and measures with regard to the following elements: (c) the promotion of deep renovation of buildings, including staged deep renovation	Similar
Policies and measures with regard to the following elements: (d) high indoor environmental quality in new and renovated buildings	Yes
Policies and measures with regard to the following elements: (e) empowering and protecting vulnerable customers and the alleviation of energy poverty, including policies and measures pursuant to Article 22 of Directive (EU) Directive (EU) Energy Efficiency Directive (EU) 2023/1791 [recast EED], and housing affordability	Similar
Policies and measures with regard to the following elements: (f) the creation of one-stop shops or similar mechanisms for the provision of technical, administrative and financial advice and assistance	Yes
Policies and measures with regard to the following elements: (g) the decarbonization of heating and cooling, including through efficient district heating and cooling networks in alignment with Directive (EU) Energy Efficiency Directive (EU) 2023/1791, and the phase out of fossil fuels in heating and cooling in buildings with a view to a planned phase-out by 2035 and, if not feasible as demonstrated to the Commission, by 2040 at the latest(fa) the roadmap to the phase out of fossil fuel use in buildings by 2035 and if not feasible as demonstrated to the Commission, by 2040 at the latest	No
Policies and measures with regard to the following elements: (h) the promotion of renewable energy sources in buildings in line with the target for the share of energy from renewable sources in the building sector set in Article 15a(1) of Directive (EU) 2018/2001 [amended RED]	No

(continued)

Table 5 (continued)

Mandatory indicators of 2023 EPBD Proposal recast	Was it included in the 2019 EPBD-related Recommendation?
Policies and measures with regard to the following elements: (i) the deployment of solar energy installations on buildings	No
Policies and measures with regard to the following elements: (j) the reduction of whole life-cycle GHG emissions for the construction, renovation, operation and end of life of buildings, and the uptake of carbon removals	Yes
Policies and measures with regard to the following elements: (k) the reduction of the overall environmental footprint of all parts and components of buildings, including through the use of sustainable, secondary, preferably locally sourced construction and renovation products	No
Policies and measures with regard to the following elements: (l) prevention and high-quality treatment of construction and demolition waste in line with Directive 2008/98/EC, in particular as regards the waste hierarchy, and the objectives of the circular economy	No
Policies and measures with regard to the following elements: (m) increase in the coverage of the building stock with energy performance certificates including towards low-income households	No
Policies and measures with regard to the following elements: (n) district and neighborhood approaches, including the role of renewable energy communities and citizen energy communities	No
Policies and measures with regard to the following elements: (ñ) the improvement of buildings owned by public bodies, including policies and measures pursuant to Articles 5, 6 and 7 of the Directive (EU) Energy Efficiency Directive (EU) 2023/1791 [recast EED]	No
Policies and measures with regard to the following elements: (o) the promotion of smart technologies and infrastructure for sustainable mobility in buildings	Similar
Policies and measures with regard to the following elements: (p) addressing market barriers and market failures	No
Policies and measures with regard to the following elements: (q) addressing skills gaps and mismatches in human capacities, and promoting education, training, upskilling and reskilling in the construction, sector and energy efficiency and renewable energy sectors including with a gender dimension; and	Similar
Policies and measures with regard to the following elements: (r) Key performance indicators for upskilling and/or reskilling actions, as well as jobs created	No
Policies and measures with regard to the following elements: (s) awareness raising campaigns and other advisory tools	Yes

(continued)

Table 5 (continued)

Mandatory indicators of 2023 EPBD Proposal recast	Was it included in the 2019 EPBD-related Recommendation?
Policies and measures with regard to the following elements: (t) new the promotion of smart technologies for monitoring, analysis and simulation of buildings' energy performance across the whole-life cycle, including 3D modelling technologies	No
Policies and measures with regard to the following elements: (u) new inspection schemes including digital tools and checklists, to verify compliance with Building Automation and Control capabilities	No
Policies and measures with regard to the following elements: (v) the promotion of energy management solutions, such as Energy Performance Contracts (EnPCs)	No
Policies and measures with regard to the following elements: (w) measures to increase the coverage of the building stock with energy performance certificates or alternative real time measurement systems	No
Policies and measures with regard to the following elements: (x) new development and support of citizen-led energy efficiency and renovation initiatives, in particular the role of renewable energy communities and citizen energy communities	No
Total investment needs for 2030, 2040, 2050 (million EUR)	No
Public investments	Yes
Private investments (million EUR), including energy efficiency loans, mortgages for building renovation, bond issuance or other financing mechanisms	No
Budgetary resources	No
Secured budget	No
Targets for reducing energy poverty rates	No
Number of households in energy poverty	No
List implemented and planned policies to reduce energy poverty	No
List of implemented and planned funding measures to reduce energy poverty	No

Table 6 Optional indicators in annex II of the 2023 EPBD proposal recast and whether they were or not included in the 2019 EPBD-related Recommendation. *Source* own creation

Optional indicators of 2023 EPBD Proposal recast	Was it included in the 2019 EPBD-related Recommendation?
No. of buildings per building age	Yes
No. of buildings per building size	Yes
No. of buildings per climatic zone	Yes
No. of building demolitions	No
m^2 per building age	Yes
m^2 per building size	Yes
m^2 per climatic zone	Yes
m^2 of building demolitions	No
No. of EPCs per construction period	Similar
Reduction in energy costs (EUR) per household (average)	Yes
Primary energy demand of a building corresponding to the top 15% (substantial contribution threshold) and the top 30% (do no significant harm threshold) of the national building stock, as per the EU Climate Taxonomy Delegated Act	No
Share of heating system in the building sector per boiler/heating system type	No
Market barriers and failures: Administrative	No
Market barriers and failures: Financial	No
Market barriers and failures: Technical	No
Market barriers and failures: Awareness	No
Market barriers and failures: Other	No
Projections of the construction workforce: Architects/engineers/skilled workers retired	No
Projections of the construction workforce: Architects/engineers/skilled workers entering the market	Yes
Projections of the construction workforce: installers and/or installation companies of heating systems	No
Projections of the construction workforce: maintenance personnel of heating systems	No
Projections of the construction workforce: Young people in the sector	No
Projections of the construction workforce: Women in the sector	No

(continued)

Table 6 (continued)

Optional indicators of 2023 EPBD Proposal recast	Was it included in the 2019 EPBD-related Recommendation?
Overview and forecast of the evolution of prices of construction materials and national market developments	No
Overview of the legal and administrative framework (nZEB)	No
Split between emissions covered by Chapter III [stationary installations], Chapter IVa [new emissions trading for buildings and road transport] of Directive 2003/87/EC, and other stock	No
Increase of GDP (share and billion Euros)	Yes
Policies and measures with regard to: (a) the increase of climate resilience of buildings	No
Policies and measures with regard to: (b) the promotion of the energy services market	No
Policies and measures with regard to: (c) the increase of fire safety	No
Policies and measures with regard to: (d) the increase of resilience against disaster risks, including risks related to intense seismic activity	No
Policies and measures with regard to: (e) the removal of hazardous substances including asbestos	No
Policies and measures with regard to: (f) accessibility for persons with disabilities	No

References

Beltran-Velamazan, C., Monzón-Chavarrías, M., López-Mesa, B.: Review of the Current State of Development of the Progress Indicators in National Long-Term Renovation Strategies. In: Jornada de jóvenes investigadores del I3A. 9, pp. 1 - 2. Zaragoza, (2021). ISSN 2341–4790

Beltrán-Velamazán C., Gómez-Gil M., López-Mesa B., Monzón-Chavarrías M., González González F.: Comparison of Frameworks for the Assessment of Decarbonisation of European National Building Stocks. Environmental and Climate Technologies, Vol.27 (Issue 1), pp. 506–515. (2023). https://doi.org/10.2478/rtuect-2023-0037

European Commission, Joint Research Centre, Castellazzi, L., Bertoldi, P., Economidou, M.: Overcoming the split incentive barrier in the building sector: unlocking the energy efficiency potential in the rental & multifamily sectors. Publications Office of the European Union, Luxembourg. ISSN: 1831–9424, ISBN: 978–92–79–58837–2, doi: https://doi.org/10.2790/912494, Catalogue number: LD-NA-28058-EN-N (2017).

De-risking Energy Efficiency Platform (2021), https://deep.ec.europa.eu/#:~:text=DEEP%20is%20an%20open%2Dsource,evidence%20and%20investment%20track%20records, last accessed 2023/09/20.

European Commission: Good practice in energy efficiency. For a sustainable, safer and more competitive Europe. Publications Office of the European Union, Luxembourg. ISBN: 978–92–79–65331–5, doi: https://doi.org/10.2833/75367, Catalogue number: MJ-01–17–061-EN-N. (2017).

European Commission: COMMISSION RECOMMENDATION (EU) 2019/786 of 8 May 2019 on building renovation. Official Journal of the European Union (2019: L 127), 34–79 (2019b).

European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. The European Green Deal. COM(2019) 640 final. Brussels (2019a).

European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. COM(2020) 662 final. Brussels (2020b).

European Commission: Energy efficiency in buildings. Brussels (2020a). https://commission.europa.eu/system/files/2020-03/in_focus_energy_efficiency_in_buildings_en.pdf, last accessed 2023/09/20.

European Commission: European Green Deal: Commission proposes transformation of EU economy and society to meet climate ambitions. Brussels (2021a). https://ec.europa.eu/commission/presscorner/detail/en/IP_21_3541, last accessed 2023/09/20.

European Commission: Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast). COM/2021/802. Brussels (2021b).

European Parliament, Council of the European Union: DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Official Journal of the European Union (2012: L 315), 1–56 (2012).

European Parliament, Council of the European Union: 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. Official Journal of the European Union (2018: L 156), 75–91 (2018).

European Parliament, Council of the European Union: REGULATION (EU) 2021/1119 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law'). Official Journal of the European Union (2021: L 243), 1–17 (2021).

European Parliament: Energy performance of buildings (recast) Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (COM(2021)0802 – C9–0469/2021 – 2021/0426(COD)). Strasbourg (2023).

Buildings Performance Institute Europe: Building Renovation Passports: consumer's journey to a better home. Brussels (2017c). https://www.bpie.eu/wp-content/uploads/2017/09/Factsheet_D-170918_Final-2.pdf, last accessed 2023/09/20.

Buildings Performance Institute Europe: Trigger points as a "must" in national renovation strategies. Brussels (2017b). https://bpie.eu/wp-content/uploads/2017/05/Factsheet_B-170511_v4.pdf, last accessed 2023/09/20.

Buildings Performance Institute Europe: 97% of buildings in the EU need to be upgraded. Brussels (2017a). https://www.bpie.eu/wp-content/uploads/2017/12/State-of-the-building-stock-briefing_Dic6.pdf, last accessed 2023/09/20.

Rademaekers, K., Yearwood, J., Ferreira, A., Pye, S., Hamilton, I., Agnolucci, P., Grover, D., Karásek, J., Anisimova, N.: Selecting Indicators to Measure Energy Poverty. Trinomics B.V., Rotterdam (2016).

Indicators and Data in Spain for an Overview of the General Characteristics of the National Building Stock

Marta Gómez-Gil, Matxalen Etxebarria-Mallea, Markel Arbulu, Xabat Oregi, Almudena Espinosa-Fernández, and Marta Monzón-Chavarrías

Abstract A country or a city is largely characterized by its architecture and urbanism. A robust understanding of the characteristics of the existing building stock provides a more solid basis for the development of European or national policies. In this chapter, we propose indicators to measure the general characteristics of the buildings at the national and regional levels, using as case studies Spain and two of its regions, Aragon and the Basque Country. Given there is no official definition of what the general characteristics of a building are, in this chapter we propose the general characteristics of a building whose knowledge can allow to lay the foundations for its improvement. We also studied the sources of information available in Spain and in the two mentioned regions for the development of these indicators and developed them when there were available data. Out of the fourteen proposed indicators, five could be fully developed, eight were partially developed, and one could not be developed due to lack of data.

M. Gómez-Gil · A. Espinosa-Fernández · M. Monzón-Chavarrías (✉)
Built4Life Lab, University of Zaragoza-I3A, 50018 Zaragoza, Spain
e-mail: monzonch@unizar.es

M. Gómez-Gil
e-mail: m.gomez@unizar.es

A. Espinosa-Fernández
e-mail: almudenaef@unizar.es

M. Etxebarria-Mallea · M. Arbulu · X. Oregi
Department of Architecture, University of the Basque Country UPV/EHU, 20018 Donostia-San Sebastian, Spain
e-mail: matxalen.etxebarria@ehu.eus

M. Arbulu
e-mail: markel.arbulu@ehu.eus

X. Oregi
e-mail: xabat.oregi@ehu.eus

B. López-Mesa and X. Oregi (eds.), *Assessing Progress in Decarbonizing Spain's Building Stock*, Digital Innovations in Architecture, Engineering and Construction,
https://doi.org/10.1007/978-3-031-51829-4_3

1 Introduction

A country or a city is largely characterized by its architecture and urbanism, as has been documented in the literature over the years (Jacobs, 1961) (Lynch, 1960). The conditions of its buildings, such as their age, building typology or state of conservation, are usually characteristic of a place. In order to formulate effective policies, focused as proposals for the improvement or transformation of urban environments or buildings, the first step is to know the current state, the starting point.

A robust understanding of the characteristics of the existing building stock provides a more solid basis for the development of European or national policies. At the urban level, knowing building characteristics allows local authorities to make informed decisions regarding zoning, constructions density, land use, or infrastructure, among others. At the building scale, issues such as building safety and habitability of dwellings can be regulated according to existing conditions. Furthermore, it can also serve as a basis for designing policies related to accessibility, vulnerability, acoustics, conservation and, especially in recent years, to obtaining a highly energy-efficient and decarbonized building stock.

There is no official definition of what the general characteristics of a building are. In this study it has been considered that the general characteristics of a building whose knowledge can allow to lay the foundations for its improvement are:

- Type of building, understood as the differentiation between single-family, multi-family or non-residential buildings.
- Type of residential building, differentiating between single family (1 dwelling), two family (2 dwellings), collective/multi-family (>3 dwelling).
- Building age, according to year or period of construction.
- Building size, defined as area (m^2) or number of properties.
- Climate zone, according to national norms definition.

It is crucial to know the composition of the building stock according to its use to establish clusters. In the case of residential buildings, a division into single-family and multi-family buildings, additionally to other aspects as floor numbers or use area, is of interest, as they have significant differences in terms of construction systems, energy demand and consumption. In the case of non-residential buildings, the distribution of uses and the characteristics of their buildings also define other interesting aspects.

The need for a description of the general characteristics of the national real estate stock have been included in European Directives principally with the objective of guiding the energy renovation policies. In this way, Directive 2002/91/CE on the energy performance of buildings (EPBD) (European Parliament and Council of the European Union 2002) make it mandatory for Member States (MSs) to establish a system of buildings energy certification. This was an important step in the recompilation of information about energy efficiency of buildings.

Then, Directive 2012/27/EU on energy efficiency (European Parliament and the Council of the European Union 2012) established that each MS shall set a long-term renovation strategy (LTRS) to support the renovation of the national stock of residential and non-residential buildings, both public and private, into a highly energy efficient and decarbonized building stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly zero-energy buildings. This strategy shall encompass an overview of the national building stock, based, as appropriate, on statistical sampling and expected share of renovated buildings in 2020. Article 4 of the Directive on energy efficiency established the obligation to review the Strategy every 3 years.

Spain's Ministry of Development (as it was called at the time) published a LTRS in the building sector in 2014, and an updated it 2017 and in 2020. The latter is hereinafter referred to as 2020 ERESEE (Ministry of Transport, Mobility and Urban Agenda 2020), which is the acronym of its name in Spanish ('*Estrategia a largo plazo para la Rehabilitación Energética en el Sector de la Edificación en España*'). This document included a chapter about assessment of the residential and non-residential building stock in Spain. In the 2020 ERESEE, the residential assessment comprises two separate parts: the first involves an overview analysis of the Spanish residential building stock and, in light of the above analysis, the second part segments this residential stock into typological clusters. The first section covers the following aspects:

– Analysis of the Spanish residential stock according to its occupation: main and secondary dwellings.
– Type analysis, by building age and size of the dwellings in Spain.
– Analysis of the distribution of dwellings according to municipality size.
– Analysis of the tenure status of households in Spain.

In light of the above analysis, the second part segments this residential stock into typological clusters, which will be used throughout the 2020 ERESEE to propose renovation approaches within the clusters and to economically assess the different options, while at the same time taking into account the different climate zones and energy consumption. Subsequent directives, such as 2018/844/UE Directive (European Parliament and the Council of the European Union 2018), encourage the incorporation of smart technologies for the digitization of building information, so that the collection of building characteristics and performance becomes more widespread.

In addition to the directives, some European documents have dealt with the diagnosis of the characteristics of the existing building stock. The Buildings Performance Institute Europe (BPIE) is a leading independent center of expertise on energy performance of buildings. This association published in 2011 the report "Europe's buildings under the microscope" (Buildings Performance Institute Europe 2011). As there is a lack of comprehensive data on buildings at European level, BPIE analyzed Europe's building stock (EU 27 plus Switzerland and Norway) including building characteristics, building codes and other regulatory measures.

The objective of the European research Project TABULA is the national typological classification of residential buildings. According to the report of this project (Loga et al. 2012) the typological classification of a country consists of a classification system of the building stock according to its size, age, and other parameters. The classification is presented through a set of example buildings representing the different building types established. As a result, each participating country publishes a "catalog of residential building typology" containing the matrix of building types in the country and a sheet for each type explaining its energy characteristics and illustrating the measures to be taken graphically. The catalog for the case of Spain has been elaborated by the Buildings Institute of Valencia (IVE).

Based on data from the Spain´s National Statistics Institute of Statistics' Population and Housing Census, the Spanish Government publishes a report on the Analysis of the characteristics of residential building in Spain. This report is published at the national scale, differentiating by regions and provinces, the main characteristics of the Spanish residential building stock. In addition, it analyzes various variables related to residential building (typology, age, surface area, state of conservation, accessibility…) based on statistical data.

Recent scientific literature has addressed the study of the physical characteristics of existing buildings with the main objective of knowing their energy efficiency. Some studies focus on physical characteristics such as age (Nachtigall et al., 2023), building structures (Zhou et al. 2023) and building typology construction (Landolfo et al. 2022).

Having data on the progress in the characteristics that define the buildings that make up a region is important for decision making in the context of designing building renovation policies. This chapter proposes and collects a series of indicators for Europe, and we develop them for the case of Spain.

2 Methodology

To develop the indicators that allow an overview of the general characteristics of the national building stock in Aragon, the Basque Country and Spain, the process indicated in Fig. 1 was followed.

The first step consisted in the development of a common template for these indicators based on:

- Indicator:
  - Definition of the indicator.
  - Variables to quantify it and their unit of measurement.
  - Purpose and advantages of implementing this indicator.
  - Alignment of the indicator with the directives, agendas, action plans and strategies, covering the European and international, national, and regional scales.
  - Relationship of this indicator with other similar ones.
- Information sources:
  - Availability of information to generate this indicator at different scales.
  - Entity responsible for providing this information.

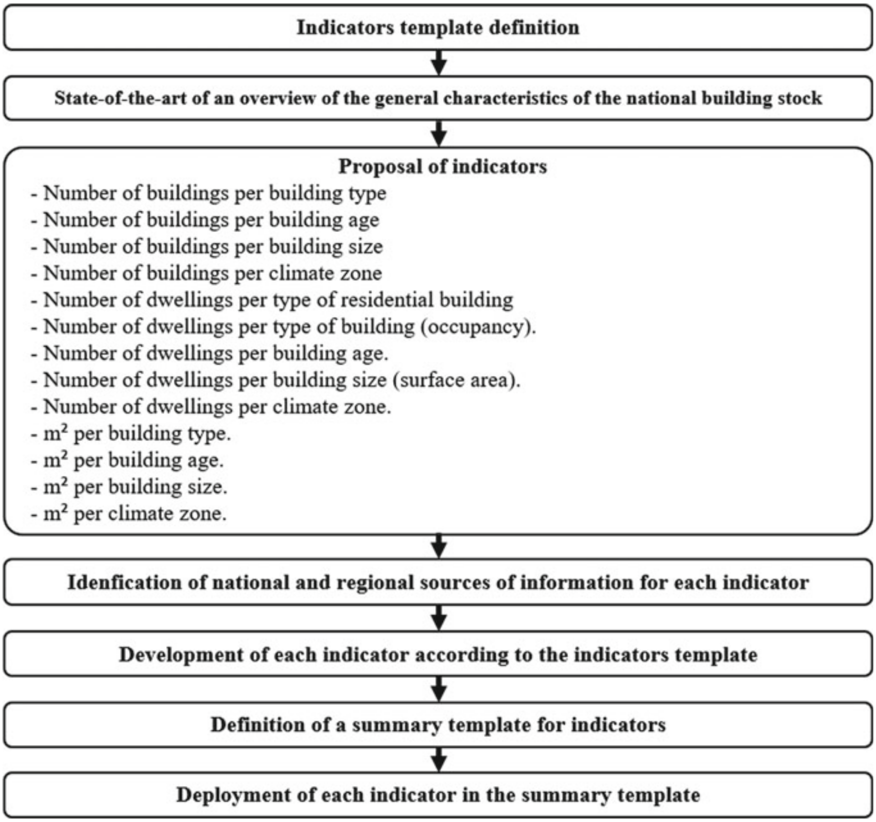


Fig. 1 Methodology implemented to generate indicators on an overview of the general characteristics of the national building stock in Sapin, and the regions of Aragon and the Basque Country. *Source* own creation

- Measurement:
  - Measurement method.
  - Methodology.
  - Current possibilities of obtaining it.
  - Information necessary to generate it.
  - Availability and quality of data.

To select the indicators related to the study of the general characteristics of the national building stock to develop, we considered the indicators which have been suggested in European directives and related documents. For this study, we considered two documents: the Commission Recommendation (EU) 2019/786 (European Commission 2019) (referred to as 2019 EPBD-related Recommendation in this book) and the Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (European Parliament 2023) (referred to as 2023 EPBD Proposal recast in this book). The first one is the first document in which a framework of indicators was proposed to measure the effectiveness of building renovation policies and the decarbonization of the European building stock, and the last one is the document with the last version of the framework of indicators. Table 1 shows the indicators about general characteristics of buildings included in both documents. As can be seen in Table 1, the indicators related with this field in both documents are similar. In the most recent version, some of these indicators have been considered as optional, however in this study it is considered that having information such as building age, size and climatic zone can be important when designing renovation policies.

For this reason, we proposed to consider all the indicators among the two documents by number of buildings, number of dwellings and surface area. Thus, the following indicators were further studied:

- Number of buildings per building type.
- Number of buildings per building age.
- Number of buildings per building size.
- Number of buildings per climate zone.
- Number of dwellings per type of residential building.
- Number of dwellings per type of building (occupancy).
- Number of dwellings per building age.
- Number of dwellings per building size (surface area).
- Number of dwellings per climate zone.
- m^2 per building type.
- m^2 per building age.
- m^2 per building size.

Table 1 General characteristics indicators included in selected European directives and related documents. *Source* own creation from data in (European Commission 2019; European Parliament 2023)

Document	General characteristics of buildings
2019 EPBD-related Recommendation	– Number of buildings/dwellings/m^2 per building type – Number of buildings/dwellings/m^2 per buildings age – Number of buildings/dwellings/m^2 per building size – Number of buildings/dwellings/m^2 per climate zone
2023 EPBD Proposal recast	– Number of buildings and total floor area (m^2) per building type (including public buildings and social housing) (mandatory indicators) – Number of buildings and total floor area (m^2) per building age (optional indicators) – Number of buildings and total floor area (m^2) per building size (optional indicators) – Number of buildings and total floor area (m^2) per climatic zone (optional indicators)

- m^2 per climate zone.

Once the key indicators to cover this topic were identified, the available sources of information were studied and the standard template for each indicator was developed and generated. Since in Spain a great share of the promotion and aid management of building renovation is delegated to regions, we used as regional case studies the regions of Aragon and the Basque Country. The previously defined indicator template was used to develop each indicator.

3 Indicators

3.1 Number of Buildings Per Building Type

The purpose of this indicator is to know the composition of the building stock according to its use to establish clusters. In the case of residential buildings, a division into single-family and multi-family buildings is of interest, as they have significant differences in terms of construction systems, energy demand and consumption. The information sources to obtain this indicator can be divided in national sources and regional ones (Table 2). The national ones are Spain´s National Institute of Statistics (INE) and the Digital Atlas of Urban Areasof Spain's Ministry of Transport, Mobility and Urban Agenda (MITMA). In the case of Aragon, the only source of information is the Aragon Institute of Statistics (IAEST). In the case of Basque Country, there are two sources, the Basque Institute of Statistics (EUSTAT) and the long-term intervention strategy for the Basque Country's building stock.

The variables used in each of the sources of information shown in Table 2 are different. Generally, they differentiate between residential buildings and non-residential buildings. In the regional sources non-residential buildings are differentiated per type of use. To develop this indicator, the Population and Housing Census of INE are used to obtain the number of residential and non-residential buildings. In the case of residential buildings, it is possible to differentiate between single-family and multi-family. Whereas the number of single-family buildings is obtained directly, the number of multi-family buildings is obtained by adding up all the residential buildings with more than one building.

Figure 2 shows the number of buildings per type and Fig. 3 shows the number of single-family residential buildings and number of multi-family residential buildings with the date of Population and Housing Census 2011.

3.2 Number of Buildings Per Building Age

The purpose of the indicator Number of existing buildings according to their construction period is to know the composition of building stock according to the building

Table 2 Sources for indicator buildings per building type. *Source* own creation

Indicator: Number of existing buildings by use and typology for residential use	
Variables	• Residential buildings: single-family buildings, multi-family buildings • Non-residential buildings
Indicator developability	• Data availability: fully available • Processing method from source: the first classification (residential or non-residential buildings) is obtained by directly consulting the data from all the indicated sources, except for the data on non-residential buildings from Eustat. The second classification (single-family or multi-family buildings) can be obtained through an operational process i.e., by summing direct data obtained from INE • Data processability: yes, CSV, XLS, Json, txt, PDF, PPT
National source	Population and Housing Census. Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/edificios/p03/l0/&file=01001.px&L=0 https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/e244/edificios/p04/&file=pcaxis&L=0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: Decennial. Last update in 2011
National source	Digital Atlas of Urban Areas. Ministry of Transport, Mobility and Urban Agenda (MITMA)
Source link	http://atlasau.mitma.gob.es/#c=home
Characteristics of the source	• Availability: open data • Data collection method: cadastral • Data processability: yes, XLS and CSV formats • Georeferencing: no • Data update frequency/last update: Unspecified. Last update in 2021
Regional source	Aragon Institute of Statistics (IAEST)
Source link	https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/01/010023TP&Action=Navigate&Options=df&NQUser=granpublico&NQPassword=granpublico
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: Decennial. Last update 2019
Regional source	Basque Institute of Statistics (EUSTAT)
Source link	https://www.eustat.eus/elementos/ele0000600/edificios-normales-de-la-ca-de-euskadi-por-ambitos-territoriales-segun-el-destino-del-edificio/tbl0000640_c.html

(continued)

Table 2 (continued)

Indicator: Number of existing buildings by use and typology for residential use	
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: Decennial. Last update in 2021
Regional source	Long-term intervention strategy for the Basque Country's building stock. Basque government
Source link	https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.2_Informe_A1.pdf https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.4_Informe_G1.pdf https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.3_Informe_B1.pdf
Characteristics of the source	• Availability: open data • Data collection method: cadastral • Data processability: no • Georeferencing: no • Data update frequency/last update: Single publication in 2020

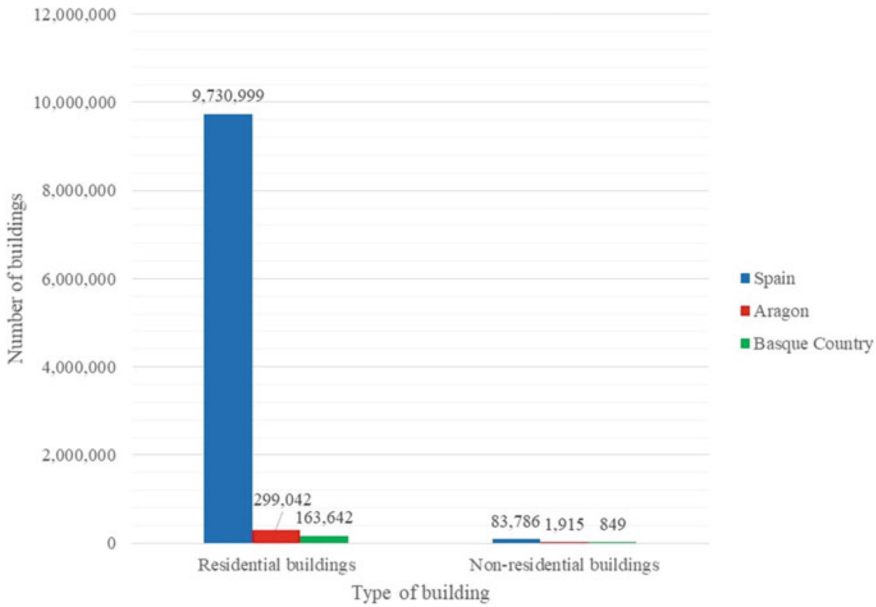


Fig. 2 Number of buildings per type, in Spain, Aragon and Basque Country, according to the Population and Housing Census 2011. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011)

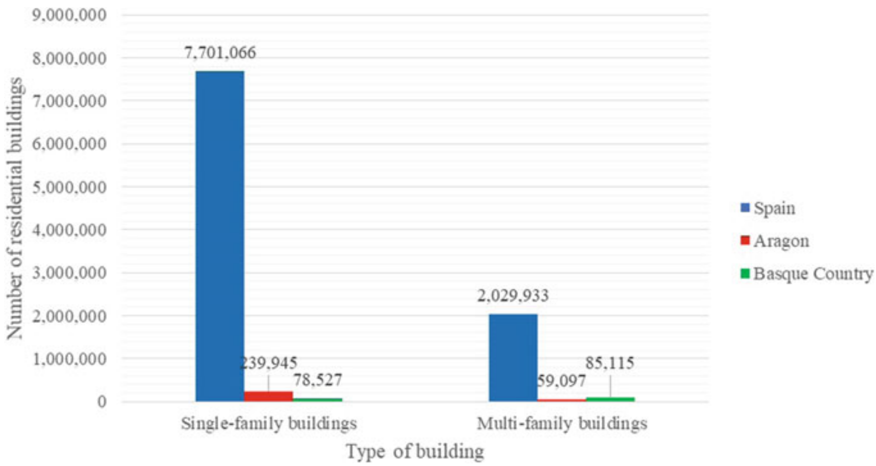


Fig. 3 Number of single-family residential buildings and number of multi-family residential buildings in Spain, Aragon, and Basque Country. Source: own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011)

age. In combination with the variable on building type, clusters of buildings with similar construction characteristics and with similar energy efficiencies depending on the construction year can be obtained, as they comply with the same technical building standards. In this way, the least energy-efficient clusters can be identified, and renovation priorities can be set. The sources of the indicator in Spain are national and regional (Table 3).

The sources showed in Table 3 provide data of residential buildings, but there are no data about non-residential ones. The periods chosen to define the indicator are the same used in the Population and Housing Census of INE. Aragon defines same periods until 2001, but then collects data annually. Basque Country defines same periods until 1990, but then uses different ones. The national source, MITMA, uses longer construction periods. The periods of construction defined to obtain the number of existing buildings are:

- Buildings built before 1900.
- Buildings built between 1900 and 1920.
- Buildings built between 1921 and 1940.
- Buildings built between 1941 and 1950.
- Buildings built between 1951 and 1960.
- Buildings built between 1961 and 1970.
- Buildings built between 1971 and 1980.
- Buildings built between 1981 and 1990.
- Buildings built between 1991 and 2001.
- Buildings built between 2002 and 2011.
- Buildings built after 2011.

Table 3 Sources for indicator buildings per building age. *Source* own creation

Indicator: Number of existing buildings per building age	
Variables	The number of existing buildings built in the following periods of construction: • < 1900, • 1900–1920, • 1921–1940, • 1941–1950, • 1951–1960, • 1961–1970, • 1971–1980, • 1981–1990, • 1991–2001, • 2002–2011, • > 2011 In addition, between 2002 and 2011, each year is also taken individually as a variable
Indicator developability	• Data availability: partially available • Processing method from source: Direct from some sources but with incomplete information. Indirect from source with complete information, but tedious to obtain • Data processability: yes, CSV, XLS, Json, text, PDF, PPT
National source	Population and Housing Census. Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/edificios/p03/l0/&file=01001.px&L=0 https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/e244/edificios/p04/&file=pcaxis&L=0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: Decennial. Last update in 2011
National source	Digital Atlas of Urban Areas. Ministry of Transport, Mobility and Urban Agenda (MITMA)
Source link	http://atlasau.mitma.gob.es/#c=home
Characteristics of the source	• Availability: open data • Data collection method: cadastral • Data processability: yes, XLS and CSV formats • Georeferencing: no • Data update frequency/last update: Unspecified. Last update in 2021
National source	Spanish Cadaster
Source link	https://www.sedecatastro.gob.es/

(continued)

Table 3 (continued)

Indicator: Number of existing buildings per building age	
Characteristics of the source	• Availability: partially open data (non-available in the Basque Country) • Data collection method: statistical summaries based on administrative data, usually from the database of the Cadaster General Directorate • Data processability: yes (XLSX, PDF) • Georeferencing: yes • Data update frequency/last update: biannual (February and August). Last update in February 2022
Regional source	Aragon Institute of Statistics (IAEST)
Source link	https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/ED4_P&Action=Navigate&NQUser=granpublico&NQPassword=granpublico&Options=df
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: Decennial. Last update 2021
Regional source	Basque Institute of Statistics (EUSTAT)
Source link	https://www.eustat.eus/elementos/ele0011100/edificios-de-viviendas-de-la-ca-de-euskadi-por-ambitos-territoriales-por-ano-de-construccion-del-edificio/tbl0011180_c.html
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: Decennial. Last update in 2021
Regional source	Long-term intervention strategy for the Basque Country's building stock. Basque government
Source link	https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.2_Informe_A1.pdf https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.4_Informe_G1.pdf https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.3_Informe_B1.pdf
Characteristics of the source	• Availability: open data • Data collection method: cadastral • Data processability: no • Georeferencing: no • Data update frequency/last update: Single publication in 2020

However, the INE collects disaggregated data on buildings built between 2002 and 2011, and therefore annual results are obtained for this period.

In the case of the Spanish Cadaster, the (Ministry of Finance and Public Administration 2022) data can be viewed and downloaded per plot and municipality, so that to obtain the data corresponding to the whole municipality, province, or region it would be necessary to classify the buildings by year of construction and then add up the surface areas of all the plots in each age range to do this, it is necessary to download the data from the Electronic Spanish Cadaster web at province scale, which contains different files at municipality scale and to carry out a processing of the data to group them, which can be very complex. The use of Cadaster data to obtain these indicators involves data management with computer tools, which is a tedious task only for people with advanced knowledge.

In the case of the INE and IAEST, the data collection is mostly direct but it only provides information on residential buildings. The method is direct for all variables up to 2001. As the data for the years 2002 to 2011 are broken down by year, these data must be summed up to obtain the variable corresponding to the period 2002–2011. However, this disaggregated data is also used to obtain annual indicators. In this case there is no data of non-residential buildings. The data from the Eustat are grouped according to variables that are different to those proposed for this indicator and those used by the INE and the IAEST. Moreover, the classification used by the source itself is slightly different in the two reference periods for which data are available. This means that it is not possible to obtain disaggregated data for the first decades of the twentieth century, and the proposed division for the end of the measurement period does not coincide either, as the Eustat analyses the decade 2001–2010 as opposed to the proposed period 2002–2011. The data published in the architectural characterization report from the long-term intervention strategy for the Basque Country's building stock are grouped into variables that are different to the two previous ones; however, it is considered preferable to use the two previous sources, as greater accuracy in the data is detected.

Figures 4 and 5 show the number of residential buildings built in periods and years defined, in Spain, Aragon and the Basque Country, according to the Spain´s Population and Housing Census (INE).

3.3 Number of Buildings Per Building Size

The purpose of this indicator is to know the composition of the building stock according to the size of its buildings. It would therefore be possible to identify the most widespread building typologies in terms of the number of buildings, and to study their relationship with other parameters such as the period of construction or state of conservation. This would allow the most vulnerable buildings to be arranged more accurately in clusters and renovation solutions to be standardized. It would also give an idea of who or what the process management unit would be, whether individual owners or homeowner associations. The sources of information to develop this indicator in Spain are only national ones (Table 4). The data are easy to process because of the exportable formats.

The variables used to develop this indicator are the ones used in the 2011 Population and Housing Census of Spain´s INE, which are number of existing residential buildings according to the number of properties housed in each building:

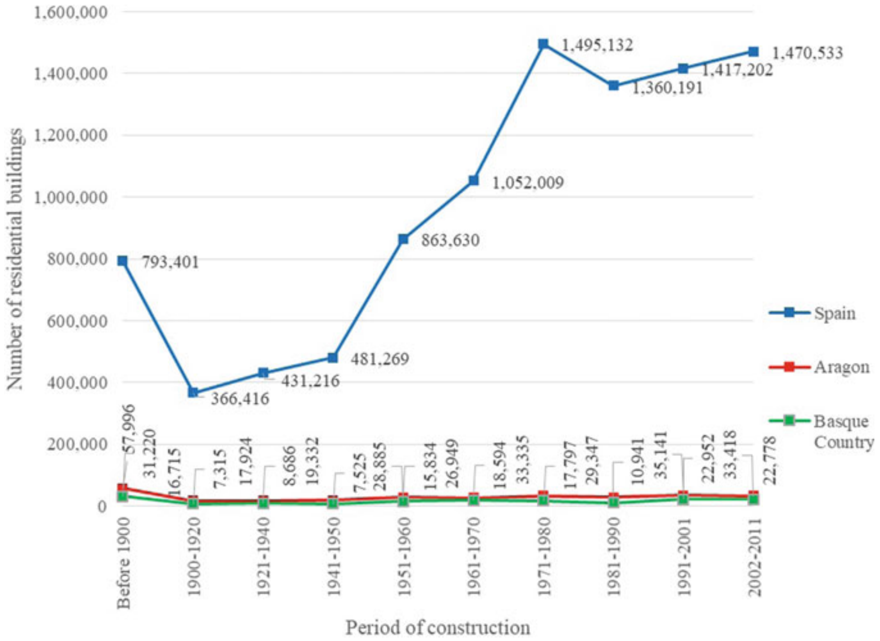


Fig. 4 Number of residential buildings per age, in Spain, Aragon and the Basque Country. The periods of constructions comprise between before 1900 until 2011. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011)

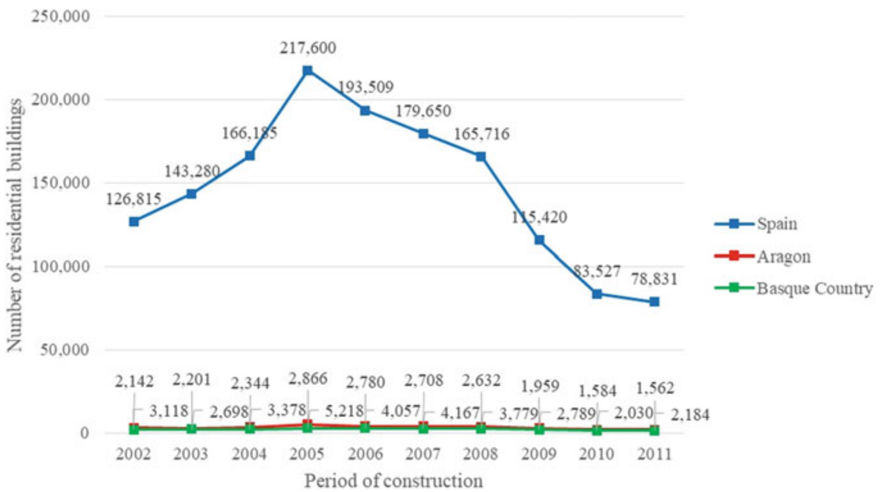


Fig. 5 Number of residential buildings per age in Spain, Aragon, and the Basque Country. Yearly, from 2002 to 2011. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011)

Table 4 Sources for indicator buildings per building size (number of properties). *Source* own creation

Indicator: Number of existing buildings per building size (number of properties)	
Variables	The number of existing residential buildings according to the number of properties housed in each building: • 1 property • 2 properties, • 3 properties, • 4 properties, • 5 to 9 properties, • 10 to 19 properties, • 20 to 29 properties, • 30 to 39 properties, • 40 or more properties
Indicator developability	• Data availability: fully available • Processing method from source: direct from the source • Data processability: yes (CSV, XLS, Json, txt, PDF, PPT)
National source	Population and Housing Census. Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/edificios/p03/l0/&file=01001.px&L=0 https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/e244/edificios/p04/&file=pcaxis&L=0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: Decennial. Last update in 2011
National source	Digital Atlas of Urban Areas. Ministry of Transport, Mobility and Urban Agenda (MITMA)
Source link	http://atlasau.mitma.gob.es/#c=home
Characteristics of the source	• Availability: open data • Data collection method: cadastral • Data processability: yes, XLS and CSV formats • Georeferencing: yes, but below the municipal scale is not possible • Data update frequency/last update: unspecified

- 1 property
- 2 properties,
- 3 properties,
- 4 properties,
- 5 to 9 properties,
- 10 to 19 properties,
- 20 to 29 properties,
- 30 to 39 properties,

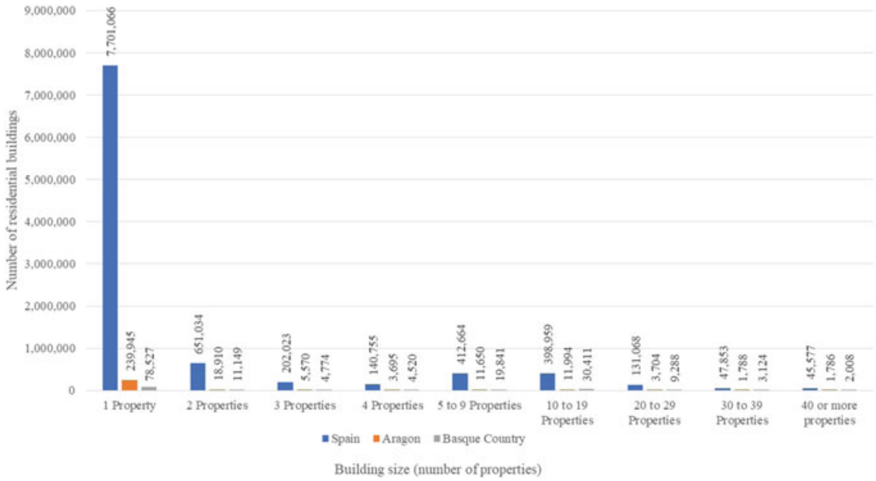


Fig. 6 Number of residential buildings per building size, depending on the number of properties of buildings, Source: own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011)

- 40 or more properties.

Figure 6 shows the number of existing residential buildings according to the number of properties housed in each building, for the Spanish case.

3.4 Number of Buildings Per Climate Zone

The purpose of this indicator is to know the composition of the building stock according to the climate zone of its buildings. This is a very relevant characterization, as buildings in the same climate zone will tend to have similar construction characteristics, which are also strongly influenced by the construction period. It is also important to consider that climate zones within the same province change according to altitude, and a wide range of climate zones can be found in some territories. Table 5 shows the national and regional sources of information to develop this indicator.

The variables of this indicator are the number of existing residential and non-residential buildings located in the following climate zone:

- Number of buildings located in Winter Climate Severity (SCI) A.
- Number of buildings located in Winter Climate Severity (SCI) B.
- Number of buildings located in Winter Climate Severity (SCI) C.
- Number of buildings located in Winter Climate Severity (SCI) D.
- Number of buildings located in Winter Climate Severity (SCI) E.
- Number of buildings located in Winter Climate Severity (SCI) α.
- Number of buildings located in Summer Climate Severity (SCV) 1.

Table 5 Sources for indicator buildings per climate zone. *Source* own creation

Indicator: Number of existing buildings per climate zone	
Variables	Number of existing residential and non-residential buildings according to the climate zone in which they are located: • Winter Climate Severity (SCI): A, B, C, D, E, α • Summer Climate Severity (SCV): 1, 2, 3, 4
Indicator developability	• Data availability: partially available • Processing method from source: indirect. The climate zone must be determined for each municipality, after which the number of buildings in all municipalities belonging to each zone can be added up • Data processability: yes (CSV, XLS, Json, txt, PDF, PPT)
National source	Population and Housing Census. Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/e244/edificios/p03/&file=pcaxis&L=0 https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/e244/edificios/p04/&file=pcaxis&L=0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: decennial. Last update in 2011
National source	Climate zones map. Institute for Energy Diversification and Savings (IDAE)
Source link	http://zonasclimaticas.idae.es/
Characteristics of the source	• Availability: open data • Data collection method: based on the Spanish Technical Building Code (CTE) Basic Document HE Energy Savings, Annex A Terminology • Data processability: no • Georeferencing: no • Data update frequency/last update: Unspecified
Regional source	The Aragon Institute of Statistics (IAEST)
Source link	https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/01/010023TM&Action=Navigate&Options=df&P0=1&P1=eq&P2=%22Territorio%22.%22Provincia%20codigo%22&P3=&NQUser=granpublico&NQPassword=granpublico
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: decennial. Last update 2019
Regional source	Basque Institute of Statistics (EUSTAT)

(continued)

Table 5 (continued)

Indicator: Number of existing buildings per climate zone	
Source link	https://www.eustat.eus/elementos/ele0018900/edificios-de-la-ca-de-euskadi-por-ambitos-territoriales-segun-tipo-de-edificio-p/tbl0018925_c.html
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: decennial. Last update 2021

- Number of buildings located in Summer Climate Severity (SCV) 2.
- Number of buildings located in Summer Climate Severity (SCV) 3.
- Number of buildings located in Summer Climate Severity (SCV) 4.

To obtain this indicator, it is necessary to combine data from two different sources. On the one hand, it is necessary to know the number of existing buildings located in each of the municipalities and, on the other hand, to know to which climate zone each locality belongs. Once both data are known, the number of buildings in all the municipalities belonging to the same climate zone is added up, and totals can be calculated by climate zone on a regional, provincial, autonomous, regional, national, etc. scale. The IAEST and Eustat sources also allow this indicator to be calculated by disaggregating between residential and non-residential buildings.

The sources only provide information on winter climate zones and not on summer climate zones, so the indicator can only be developed for winter zones. Figure 7 shows the number of residential buildings per winter climate zones. To simplify the calculation of the graphic at the national scale, all the buildings in each of the provinces have been considered to belong to the climate zone of the capital of the province. The data source used is the 2011 Population and Housing Census (INE) and the IDAE webpage. In Fig. 7, only the winter climate zones are considered, excluding the α zone, since this was the information available on the IDAE web page.

3.5 Number of Dwellings Per Type of Residential Building

The purpose of this indicator is to know the composition of the residential building stock according to the number of dwellings in the different types of buildings. This allows clusters of single-family, two-family, and multi-family residential buildings to be established.

It is therefore possible to detect the clusters with the greatest potential for intervention and to establish renovation priorities so that the improvement measures affect both a greater number of dwellings and a greater number of residents. It also allows strategies to be focused on a greater number of dwellings with greater energy

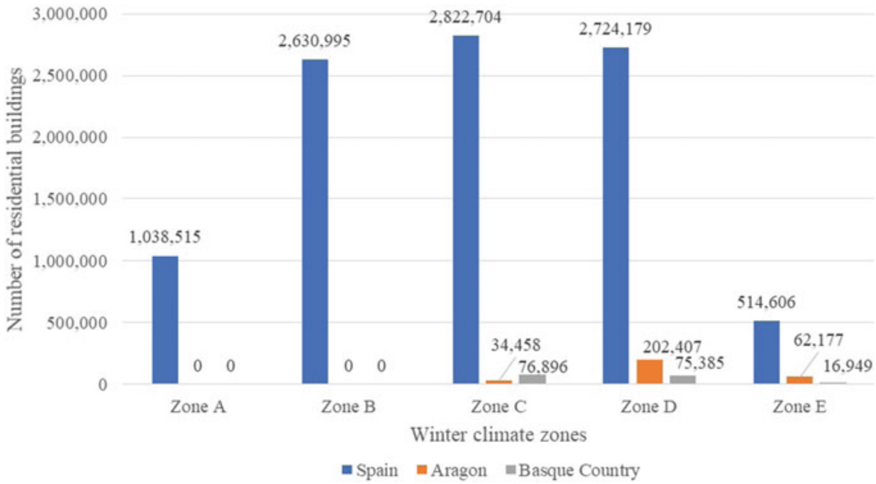


Fig. 7 Number of residential buildings per winter climate zone in Spain, and the regions of Aragon and the Basque Country, with data from 2011. *Source*: own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011) and from (Institute for Energy Diversification and Savings 2020)

savings and a greater reduction in CO_2 emissions. The information sources to obtain this indicator can be divided in national sources and regional ones (Table 6).

The variables chosen to define the indicator are single family, two-family, and multi-family buildings. Continuous Household Surveys provides information on a national scale and on an autonomous scale. In the first case, the variable 'single-family' is obtained from the sum of 'single-family detached house' and 'single-family semi-detached or semi-detached house', the variable 'two-family' is obtained directly, and the variable 'multi-family/collective' from the sum of 'building with 3 to 9 dwellings' and 'building with 10 or more dwellings'. However, the regional data only differentiate between single-family dwellings and buildings with more dwellings, without considering the 'two-family' variable. Therefore, it is not possible to differentiate this variable at the regional scale.

In the case of the Population and Housing Census, and in the case of EUSTAT, buildings used exclusively for housing are classified according to the properties they house. In this case, it is possible to obtain the number of buildings in the case of single-family and 'two-family' dwellings, but it is impossible in the case of multi-family buildings. In the case of the IAEST, the data are incomplete and do not allow this indicator to be obtained. Therefore, the results of this indicator are obtained indirectly by performing operations.

Figure 8 shows the number of dwellings by residential buildings per type, single-family buildings and two-family buildings, according to the 2011 Population and Housing Census in the case of Spanish. Figures 9 and 10 use data from the ECH between 2013 and 2019. The first one represents the number of single-family dwellings built per year between 2013 and 2019 in Spain, Aragon and

Table 6 Sources for indicator dwellings per type of residential building. *Source* own creation

Indicator: Number of dwellings per type of residential building	
Variables	Number of dwellings in a residential building according to its type of construction: • Single family (1 dwelling) • Two family (2 dwellings) • Collective/multi-family (>3 dwelling)
Indicator developability	• Data availability: partially available • Processing method from source: indirect. Some summations have to be made to obtain the results of the three pro-posed variables • Data processability: yes, partially. Data in XLS, CSV, Pc-Axis, Json, and Plain Text formats
National source	Population and Housing Census. Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/viviendas/p01/l0/&file=00011.px&L=0 https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/viviendas/p01/l0/&file=01010a.px&L=0 https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/edificios/p02/l0/&file=00001.px&L=0 https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/edificios/p03/l0/&file=01001.px&L=0
Characteristics of the source	• Availability: open data • Data collection method: "pre-census", census and other administrative documents information complemented with other calibrating techniques • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: decennially Last update in 2011
National source	Continuous Household Surveys (ECH). Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxi/Tabla.htm?path=/t20/p274/serie/prov/p07/l0/&file=01001.px&L=0 https://www.ine.es/jaxi/Tabla.htm?path=/t20/p274/serie/prov/p08/l0/&file=02001.px&L=0
Characteristics of the source	• Availability: open data • Data collection method: "pre-census", census and other administrative documents information complemented with other calibrating techniques • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: annually. Last update in 2020
Regional source	Aragon Institute of Statistics (IAEST)

(continued)

Table 6 (continued)

Indicator: Number of dwellings per type of residential building	
Source link	https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Economia/0803/08030201TP https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Economia/0803/08030201A https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Economia/0803/08030201TM https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/ED1_P https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V1_P
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: decennial. Last update October in 2020; population and dwelling census last update in 2011
Regional source	Basque Institute of Statistics (EUSTAT)
Source link	https://www.eustat.eus/elementos/ele0011300/viviendas-familiares-de-la-ca-de-euskadi-por-ambitos-territoriales-segun-caracteristicas-estructurales/tbl0011354_c.html
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: annual. Last update in June 2020

the Basque Country. Data of the Basque Country are shown in Fig. 11 using the latest updating of 2019. In this case, the three provinces are differentiated, and three variables are developed: single-family buildings, two-family-buildings, and multi-family-buildings.

3.6 *Number of Dwellings Per Type of Building (Occupancy)*

The purpose of this indicator is to determine the occupancy of the residential building stock according to the number of dwellings used as primary dwelling (conventional and accommodation) as opposed to non-primary use (secondary or empty). The sources of information to develop this indicator are national and regional (Table 7).

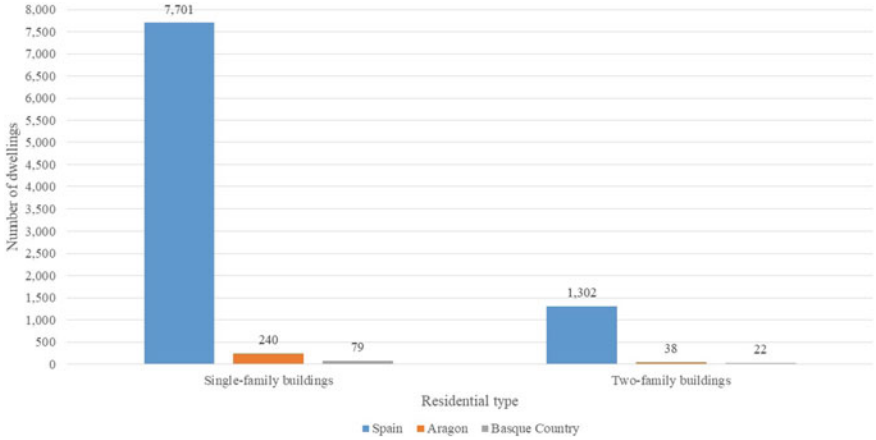


Fig. 8 Number of dwellings per type of residential building (single-family and two-family buildings) in Spain, and the regions of Aragon and the Basque Country. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011)

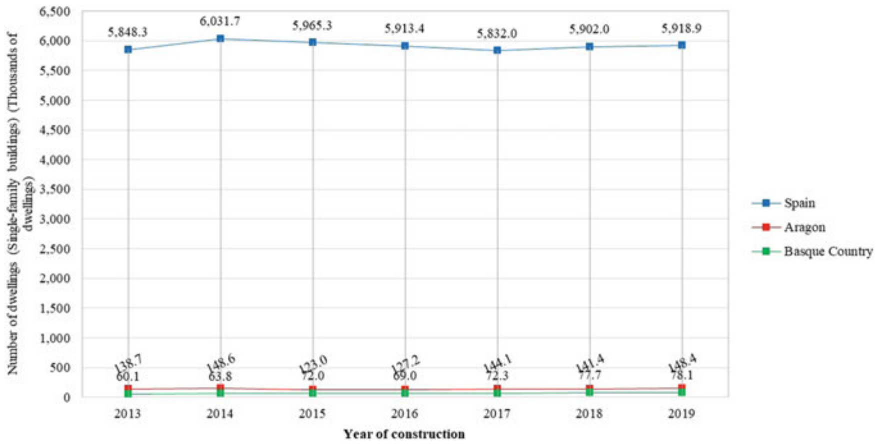


Fig. 9 Number of single familiar dwellings built per year between 2013 and 2019, in Spain, Aragon and the Basque Country. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2023)

To determine the occupancy of the dwellings, the variables differentiated are primary dwellings and non-primary dwellings, the latest defined as secondary or empty ones. Population and Housing Census, MITMA and IAEST classify dwellings in primary dwellings and non-primary ones, as in our proposed indicator, so these are the principal sources of information. The EUSTAT differentiates between primary dwellings and non-primary dwellings, however the second ones are defined in a different way.

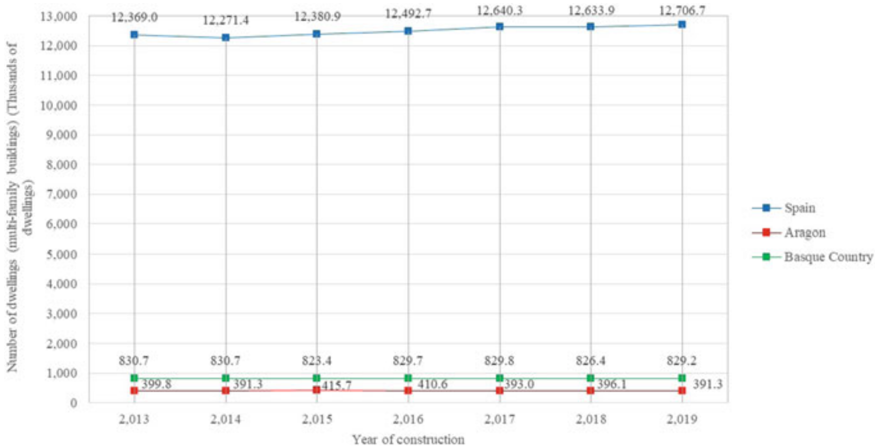


Fig. 10 Number of multi-family dwellings built per year between 2013 and 2019, in Spain, Aragon and the Basque Country. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2023)

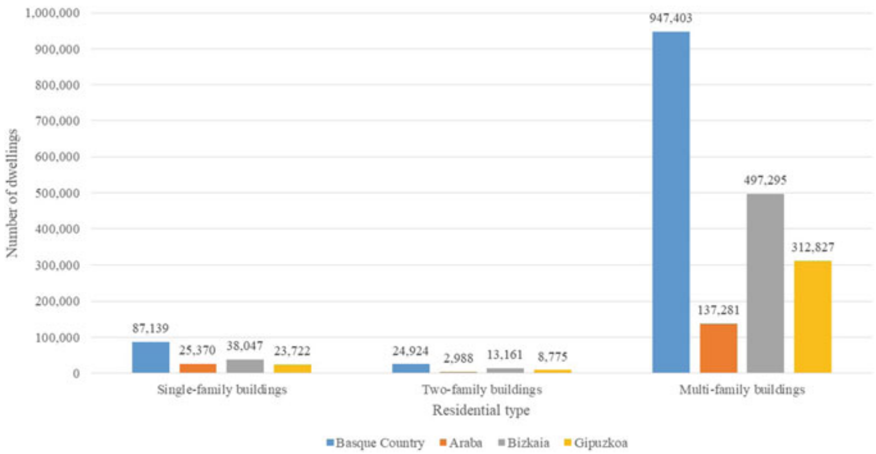


Fig. 11 Number of dwellings per type of building: single-family buildings, two-family-buildings, and multi-family buildings. *Source* own creation from data in (Basque Institute of Statistics 2023)

Figure 12 shows the number of dwellings per type of building according to its occupation, in Spain, Aragon and the Basque Country, with the latest update of Census. The data differentiates between primary dwellings and non-primary ones. Figures 13 and 14 show the number of dwellings built per year of construction, for the case of primary dwelling and non-primary ones in Spain, Aragon and the Basque Country, according to MITMA information.

Table 7 Sources for indicator dwellings per type building (occupancy). *Source* own creation

Indicator: Number of dwellings per type building (occupancy)	
Variables	Number of dwellings in existing residential buildings according to occupancy: • Primary dwelling: conventional dwelling, accommodation • Non-primary dwelling: secondary dwelling, empty dwelling
Indicator developability	• Data availability: fully available • Processing method from source: direct from data source with the following caveats: Data from the INE's 2011 Population and Housing Census are grouped into "primary dwellings" on the one hand which includes "primary residential dwellings" and "accommodation", and on the other hand, into "non-primary dwellings" classified into "secondary dwellings" and "empty dwellings" Data published by the Ministry of Transport, Mobility and Urban Agenda can be used to directly measure the two variables for the national total, Autonomous Communities and provinces. However, it is not known what each of the variables encompasses Data from the IAEST are comparable to those from the INE, as they are based on the same classification. The measurement method is therefore the same Data from the Eustat, like those from the INE and the Ministry, are grouped by "primary dwellings" and "non-primary dwellings". Therefore, data can be obtained directly from the source. However, in contrast to the two national sources, "non-primary dwellings" are characterized by "seasonal; uninhabited; on offer; manageable; other situations; manageable, excluded from relocation" In the case of data from the INE, the data could be combined and studied together with other building parameters, such as the building year of construction • Data processability: yes. Data in XLS, CSV, Json, text, PDF, PPT
National source	Population and Housing Census. Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/viviendas/p01/l0/&file=00011.px&L=0 https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/viviendas/p06/l0/&file=9mun00.px&L=0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, XLS, CSV, Pc-Axis, Json, and Plain Text formats • Georeferencing: no • Data update frequency / last update: decennially Last update in 2011
National source	Ministry of Transport, Mobility and Urban Agenda (MITMA)
Source link	https://apps.fomento.gob.es/BoletinOnline2/?nivel=2&orden=33000000

(continued)

Table 7 (continued)

Indicator: Number of dwellings per type building (occupancy)	
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, data in XLS format • Georeferencing: no • Data update frequenc /last update: decennial. Last update in 2019
Regional source	Aragon Institute of Statistics (IAEST)
Source link	https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V1_P https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V1_C https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V1_M10 https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V1_M2 https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V1_M0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, XLS format • Georeferencing: no • Data update frequency/last update: decennial. Last update 2011
Regional source	Basque Institute of Statistics (EUSTAT)
Source link	https://www.eustat.eus/elementos/ele0011600/viviendas-de-la-ca-de-euskadi-por-tipo-segun-territorio-historico/tbl0011633_c.html https://www.eustat.eus/elementos/ele0011300/viviendas-de-la-ca-de-euskadi-por-ambitos-territoriales-segun-tipo/tbl0011353_c.html
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV and XLS formats • Georeferencing: no Data update frequency/last update: biennial. Last update in June 2021

3.7 Number of Dwellings Per Building Age

The purpose of the indicator Number of dwellings per building age is to know the composition of the residential building stock and the state of the dwellings according to building age. This can be used to establish clusters of buildings with similar construction characteristics depending on the construction year. In this way, the least energy-efficient clusters and the number of dwellings in each cluster can be identified

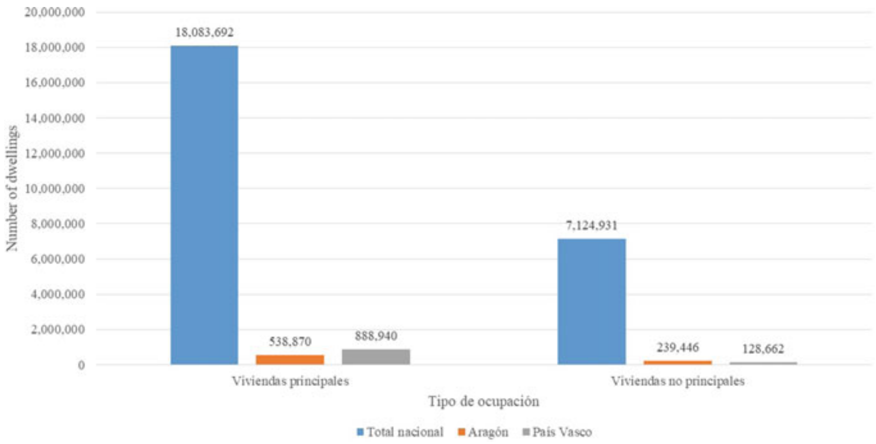


Fig. 12 Number of dwellings per occupation type in Spain, and the regions of Aragon and the Basque Country. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011)

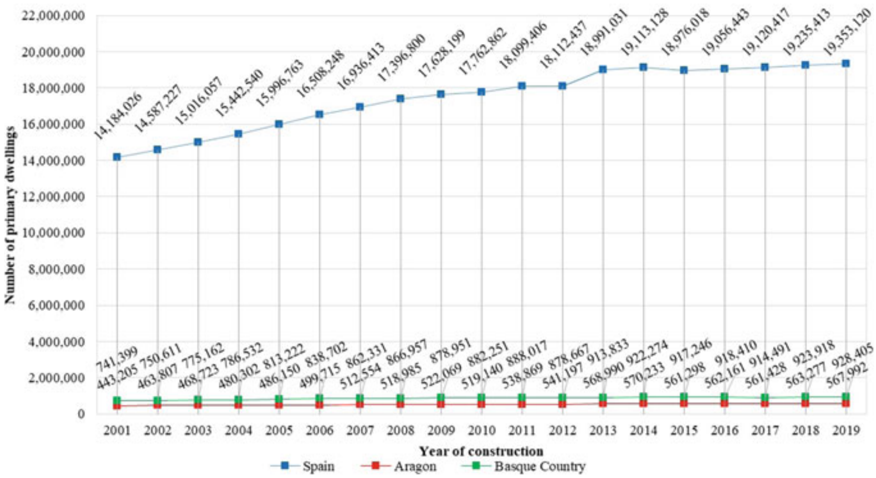


Fig. 13 Number of primary dwellings per year of construction, between 2001 and 2019 in Spain, Aragon, and the Basque Country. *Source* own creation using open data from the MITMA website: www.mitma.es (Ministry of Transport, Mobility and Urban Agenda, 2019)

and renovation priorities can be set. The sources of the indicator in Spain are national and regional (Table 8).

The periods of construction defined to obtain the number of existing buildings are:

- Buildings built before 1900.
- Buildings built between 1900 and 1920.

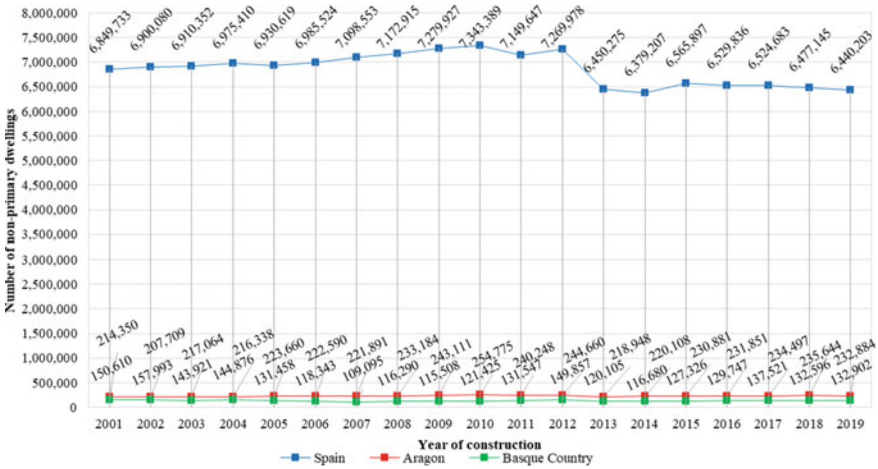


Fig. 14 Number of non-primary dwellings per year between 2001 and 2019 in Spain, and the regions of Aragon and the Basque Country. *Source* own creation using open data from the MITMA website: www.mitma.es (Ministry of Transport, Mobility and Urban Agenda, 2019)

- Buildings built between 1921 and 1940.
- Buildings built between 1941 and 1950.
- Buildings built between 1951 and 1960.
- Buildings built between 1961 and 1970.
- Buildings built between 1971 and 1980.
- Buildings built between 1981 and 1990.
- Buildings built between 1991 and 2001.
- Buildings built between 2002 and 2011.
- Buildings built after 2011.

The variables chosen to define this indicator are the same periods used in the Population and Housing Census of the INE, so the measurement method is direct for data from the INE's 2011 Census. In the case of the Continuous Household Survey (ECH), some periods coincide with the previous source, but other groups consider different years. For example, this source groups in the same period the buildings constructed before 1921, and the years used to consider the buildings constructed after 1991 do not coincide with the variables chosen in this indicator, so this source cannot be used to define all the variables. The Spanish Cadaster (Ministry of Finance and Public Administration 2022) offers complete information on the year of construction per building, however, extracting this information necessitates the use of specific computer tools, making it a challenging endeavor suited primarily for individuals with specialized skills.

Aragon defines same periods until 2001, but then collects data annually. So, the method is direct for all variables up to 2001 obtained from the IAEST data, and indirect for the data of years 2002 to 2011, which must be summed up. Data from the Eustat are grouped according to variables that are different to those proposed for

Table 8 Sources for indicator dwellings per building age. *Source* own creation

Indicator: Number of existing dwellings per building age	
Variables	The number of dwellings in existing residential buildings according to their construction period: • < 1900, • 1900–1920, • 1921–1940, • 1941–1950, • 1951–1960, • 1961–1970, • 1971–1980, • 1981–1990, • 1991–2001, • 2002–2011, • > 2011
Indicator developability	• Data availability: partially available • Processing method from source: direct for Spain, indirect for Aragon. No available in the case of Basque Country • Data processability: yes (CSV, XLS, Json, text, PDF, PPT)
National source	Population and Housing Census. Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/viviendas/p01/l0/&file=01011a.px&L=0 https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/e244/viviendas/p04/&file=pcaxis&L=0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, Pc-Axis, Json, and Plain Text formats • Georeferencing: no • Data update frequency / last update: decennial. Last update in 2011
National source	Continuous Household Survey (ECH). Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxi/Tabla.htm?path=/t20/p274/serie/prov/p08/l0/&file=02001.px&L=0 https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/p274/serie/prov/p07&file=pcaxis&L=0&dh=0&capsel=0 https://www.ine.es/jaxi/Tabla.htm?path=/t20/p274/serie/prov/p08/l0/&file=02007.px&L=0
Characteristics of the source	• Availability: open data • Data collection method: cadastral • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency / last update: annually. Last update in 2020
National source	Spanish Cadaster
Source link	https://www.sedecatastro.gob.es/

(continued)

Table 8 (continued)

Indicator: Number of existing dwellings per building age	
Characteristics of the source	• Availability: partially open data (non-available in the Basque Country) • Data collection method: statistical summaries based on administrative data, usually from the database of the Cadaster General Directorate • Data processability: yes (XLSX, PDF) • Georeferencing: yes • Data update frequency/last update: biannual (February and August). Last update in February 2022
Regional source	Aragon Institute of Statistics (IAEST)
Source link	https://bi.aragon.es/analytics_pub/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V6_P https://bi.aragon.es/analytics_pub/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V6_C https://bi.aragon.es/analytics_pub/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V6_M10 https://bi.aragon.es/analytics_pub/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V6_M2 https://bi.aragon.es/analytics_pub/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V6_M0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, XLS format • Georeferencing: no • Data update frequency/last update: population and housing census, decennial. Last update 2011; Household survey annually. Last update 2020
Regional source	Basque Institute of Statistics (EUSTAT)
Source link	https://www.eustat.eus/elementos/ele0015900/24-viviendas-familiares-de-la-ca-de-euskadi-por-la-fecha-de-construccion-la-antiguedad-media-y-la-desviacion-tipica-segun-la-zona/tbl0015911_c.html https://www.eustat.eus/elementos/ele0015900/25-viviendas-familiares-de-la-ca-de-euskadi-por-la-comarca-segun-la-fecha-de-construccion-la-antiguedad-media-y-la-desviacion-tipica/tbl0015913_c.html https://www.eustat.eus/elementos/ele0015900/26-viviendas-familiares-de-la-ca-de-euskadi-por-el-municipio-segun-la-fecha-de-construccion-la-antiguedad-media-y-la-desviacion-tipica/tbl0015918_c.html
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV and XLS formats • Georeferencing: no • Data update frequency/last update: every five years. Last update November 2016

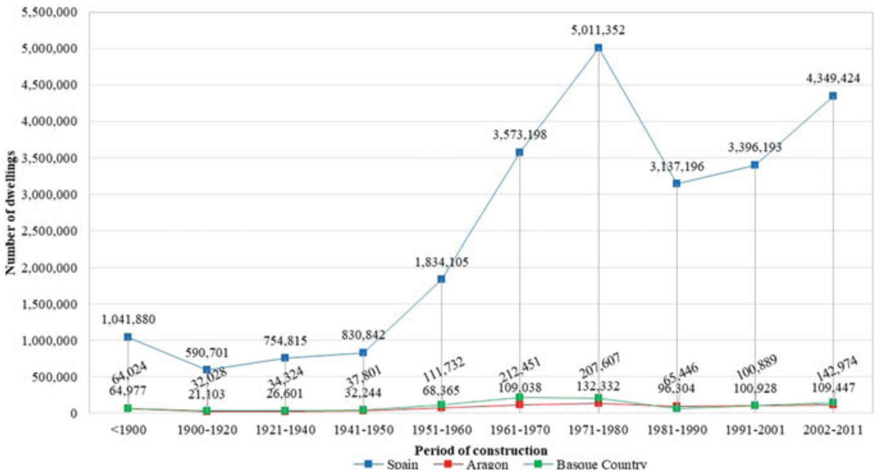


Fig. 15 Number of dwellings by building construction period in Spain, and the regions of Aragon and the Basque Country, with data available until 2011. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011)

this indicator and those used by the INE and the IAEST. The classification used by this source is as follows: ≤ 1900; 1901–1940; 1941–1950; 1951–1960; 1961–1970; 1971–1980; 1981–1990; 1991–2000; 2001–2010; ≥ 2011. This means that it is not possible to obtain disaggregated data for the first decades of the twentieth century, and the proposed division for the end of the measurement period does not coincide either, as the Eustat analyzes the decade 2001–2010 as opposed to the proposed period 2002–2011.

Figure 15 shows the number of dwellings according to the building age, defined as the periods of construction previously presented obtained from the data source, which is the Population and Housing Census from 2011. The good availability of data makes it possible to generate this graphic almost directly, by transferring the numerical data to the graphic and after adding the dwellings classified as 'main dwellings', 'secondary dwellings', 'empty dwellings'. Data are shown for the case of Spain, Aragon, and the Basque Country.

3.8 Number of Dwellings Per Size (Surface Area)

The purpose of this indicator is to know the composition of the residential building stock and the size of the dwellings according to their usable surface area. This allows clusters of dwellings to be established according to ranges of surface area. The information sources to obtain this indicator can be divided in national sources and regional ones (Table 9).

The sources of information collected in Table 9 use different ranges to group the surface area of the dwellings. The variables used in this indicator coincide with the ranges used in the INE's 2011 Population and Housing Census, so the method for obtaining them from this source is direct. The variables used to define this indicator are the number of dwellings in existing residential buildings according to surface area:

- < 30 m^2,
- 30–45 m^2,
- 46–60 m^2,
- 61–75 m^2
- 76–90 m^2,
- 91–105 m^2,
- 106–120 m^2,
- 121–150 m^2,
- 151–180 m^2
- 180 m^2.

The method is also direct for national data derived from the Continuous Household Survey (ECH). However, the surface area ranges for regional data derived from this source do not coincide with the ranges proposed for this indicator. In this case, the groups of surfaces are ' < 46 m^2; 46–75 m^2; 76–105 m^2; 106–150 m^2; > 150 m^2', so each range covers two of the proposed ranges and it is not possible to break it down into the variables that define this indicator. This case is similar to that of Aragon. The IASEST groups dwellings with a floor area of less than 45 m^2, and dwellings with a floor area greater than 151 m^2.

The data from the Eustat are grouped according to variables that are different to those proposed for this indicator and those used in the INE's Population and Housing Census. The classification used by this source is as follows: ≤ 30 m^2; 31–60 m^2; 61–90 m^2; 91–120 m^2; 121–150 m^2; 151–180 m^2; ≥ 181 m^2. As can be seen, the first and last two ranges coincide with the variables proposed for this indicator, but each intermediate range of the Eustat data groups together two of those from the INE Census or for the proposed variables. This means that it is not possible to obtain data with the same breakdown.

The number of dwellings according to their surface area in Spain, Aragon, and the Basque Country are shown in Fig. 16. To do this graphic, the 2011 Population and Housing Census were used. The good availability of the data makes it possible to generate this graph almost directly, by transferring the numerical data to the graphic.

3.9 Number of Dwellings Per Building Size

The purpose of this indicator is to know the composition of the building stock and the distribution of dwellings based on the size of the residential buildings. It would

Table 9 Sources for indicator buildings per building size (surface area). *Source* own creation

Indicator: Number of existing buildings per building size (surface area)	
Variables	The number of dwellings in existing residential buildings according to surface area: • < 30 m^2 • 30–45 m^2, • 46–60 m^2, • 61–75 m^2 • 76–90 m^2, • 91–105 m^2, • 106–120 m^2, • 121–150 m^2, • 151–180 m^2 • > 180 m^2
Indicator developability	• Data availability: fully available • Processing method from source: direct from the source • Data processability: yes (CSV, XLS, Json, Pc-Axis, txt formats)
National source	Population and Housing Census. Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/viviendas/p01/l0/&file=02002.px&L=0 https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/viviendas/p03/l0/&file=03002.px&L =
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, data in XLS, CSV, Pc-Axis, Json, and Plain Text formats • Georeferencing: no • Data update frequency/last update: decennial. Last update in 2011
National source	Continuous Household Survey (ECH). Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/p274/serie/prov/p07&file=pcaxis&L=0&dh=0&capsel=0 https://www.ine.es/jaxi/Tabla.htm?path=/t20/p274/serie/prov/p08/l0/&file=02007.px&L=0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, data in XLS, CSV, Pc-Axis, Json, and Plain Text formats • Georeferencing: no • Data update frequency/last update: annually, last update 2020
Regional source	Aragon Institute of Statistics (IAEST)

(continued)

Table 9 (continued)

Indicator: Number of existing buildings per building size (surface area)	
Source link	https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V4_P https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V4_C https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V4_C https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V4_M2 https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V4_M0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, data in XLS format • Georeferencing: no • Data update frequency/last update: decennial. Last update 2011
Regional source	The Basque Institute of Statistics (EUSTAT)
Source link	https://www.eustat.eus/elementos/ele0015900/27-viviendas-familiares-de-la-ca-de-euskadi-por-la-superficie-util-la-media-y-la-desviacion-tipica-m2-segun-la-zona/tbl0015924_c.html
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, data in CSV and XLS format • Georeferencing: no • Data update frequency/last update: every five years. Last update November 2016

therefore be possible to identify the most widespread building typologies in terms of the number of buildings, and to study their relationship with the dwellings their house and other parameters such as the period of construction or state of conservation. This would allow the most vulnerable buildings and dwellings to be arranged more accurately in clusters and renovation solution to be standardized. It would also provide insight into who or what might constitute the process management unit, whether it be individual property owners or owner associations. The information sources to obtain this indicator can be divided in national sources and regional ones (Table 10).

This indicator measures the number of dwellings per building, while the INE data provides information on the number of buildings according to the number of properties they house. Therefore, the data can be obtained indirectly for buildings used exclusively for housing and containing 1, 2, 3 or 4 dwellings by multiplying the total number of buildings of each type by the number of dwellings they contain. However, it is impossible to calculate the exact number of dwellings located in

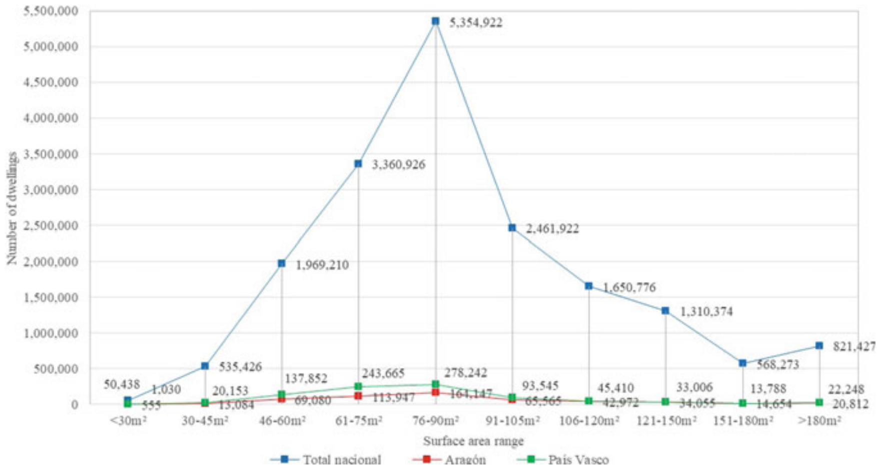


Fig. 16 Number of dwellings per surface area in Spain, and the regions of Aragon and the Basque Country. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011)

buildings of '5 to 9; 10 to 19; 20 to 29; 30 to 39; 40 or more' because only the number of buildings is specified in relation to ranges.

The data from Eustat are grouped according to other variables, i.e., the ranges defining the size of the buildings vary. The classification used by this source is based on the number of dwellings in a residential building. The classification is as follows: 1; 2; 3–10; 11–20; 21–40, > = 41. In this case the measurement is direct from the source but differs from the classification used by the INE.

Due to the limitations to evaluate the national set, the number of dwellings by building size of the regions the Basque Country is expressed in Fig. 17 according to the 2019 latest update of Eustat. The good availability of data allows the graph to be generated almost directly, by transferring the numerical data to the graph, but there is not data for the cases of Spain and Aragon.

3.10 Number of Dwellings Per Climate Zone

The purpose of this indicator is to identify the number of dwellings characterized by the same climate zone. Allows aggregates of dwellings affected by the same climate severity and renovation criteria to be identified. The information sources to obtain this indicator can be divided in national sources and regional ones (Table 11).

The variables of this indicator are the number of existing residential and non-residential buildings located in the following climate zone:

- Number of buildings located in Winter Climate Severity (SCI) A.
- Number of buildings located in Winter Climate Severity (SCI) B.

Table 10 Sources for indicator dwellings per building size. *Source* own creation

Indicator: Number of existing dwellings per building size	
Variables	The number of dwellings in existing residential buildings as a function of the number of properties they house: • 1 property, • 2 properties, • 3 properties, • 4 properties, • 5 to 9 properties, • 10 to 19 properties, • 20 to 29 properties, • 30 to 39 properties, • 40 or more properties
Indicator developability	• Data availability: partially available • Processing method from source: indirect from the source • Data processability: yes (CSV, XLS, Pc-Axis, Json, txt formats)
National source	Population and Housing Census. Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/edificios/p03/l0/&file=01001.px&L=0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, in XLS, CSV, Pc-Axis, Json, and Plain Text formats • Georeferencing: no • Data update frequency / last update: decennial. Last update in 2011
Regional source	Basque Institute of Statistics (EUSTAT)
Source link	https://www.eustat.eus/elementos/ele0011300/viviendas-familiares-de-la-ca-de-euskadi-por-ambitos-territoriales-segun-caracteristicas-estructurales/tbl0011354_c.html
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, XLS and CSV formats • Georeferencing: no • Data update frequency/last update: annual. Last update 2020

- Number of buildings located in Winter Climate Severity (SCI) C.
- Number of buildings located in Winter Climate Severity (SCI) D.
- Number of buildings located in Winter Climate Severity (SCI) E.
- Number of buildings located in Winter Climate Severity (SCI) α.
- Number of buildings located in Summer Climate Severity (SCV) 1.
- Number of buildings located in Summer Climate Severity (SCV) 2.
- Number of buildings located in Summer Climate Severity (SCV) 3.
- Number of buildings located in Summer Climate Severity (SCV) 4.

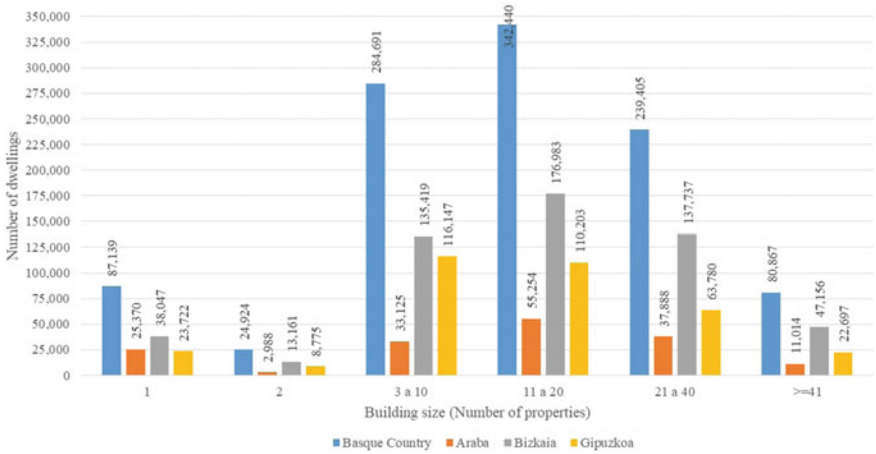


Fig. 17 Number of dwellings by building size, in the Basque Country, including Araba, Bizkaia and Gipuzkoa. *Source* own creation from data in (Basque Institute of Statistics 2023)

For the measurement of this indicator, it is necessary to relate the number of dwellings in the municipality with their respective climate zone, in order to subsequently add up the number of dwellings per climatic zone. The winter climate zone classification is obtained directly from the IDAE website. The number of dwellings per municipality is obtained directly from the 2011 INE Population and Housing Census. The number of dwellings per municipality can also be obtained directly from Eustat. However, in the case of the IAEST, the total number of dwellings can be obtained by adding the "main dwellings and non-main dwellings (secondary and empty)". Nor is there a single list of all the municipalities in Aragon, but the data is broken down according to the number of inhabitants of the municipalities. Since IDAE does not provide information on the summer climate zone, it is not possible to obtain the indicator of number of dwellings per summer climate zone.

Figure 18 shows the number of dwellings per winter climate zone. The number of dwellings in Spain, Aragon and the Basque Country are obtained from data of municipalities of the 2011 Population and Housing Census, and the climate zone are obtained in IDAE.

3.11 Square Meters (m^2) Per Building Type

The purpose of this indicator is to quantify the existing built surface area of each type of building in order to know the predominant types and their relationship with other indicators for each territory. The information sources to obtain this indicator can be divided in national sources and regional ones (Table 12).

Table 11 Sources for indicator dwellings per climate zone. *Source* own creation

Indicator: Number of existing dwellings per climate zone	
Variables	The number of dwellings located in each climate zone defined by the Technical Building Code: • Winter Climate Severity (SCI): A, B, C, D, E, α • Summer Climate Severity (SCV): 1, 2, 3, 4
Indicator developability	• Data availability: partially available • Processing method from source: indirect. To calculate the indicator the source for general data on number of dwellings needs to be related to the source data for climate zones • Data processability: yes (XLS, CSV, Pc-Axis, Json, txt format)
National source	Population and Housing Census. Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/e244/edificios/p03/&file=pcaxis&L=0 https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/e244/edificios/p04/&file=pcaxis&L=0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, XLS, CSV, Pc-Axis, Json, and Plain Text formats • Georeferencing: no • Data update frequency/last update: Decennial. Last update in 2011
National source	Climate zones map. Institute for Energy Diversification and Savings (IDAE)
Source link	http://zonasclimaticas.idae.es/
Characteristics of the source	• Availability: open data • Data collection method: based on the Spanish Technical Building Code (CTE) Basic Document HE Energy Savings, Annex A Terminology • Data processability: no • Georeferencing: no • Data update frequency/last update: unspecified
Regional source	Aragon Institute of Statistics (IAEST)
Source link	https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V1_M10 https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V1_M2 https://obiee.aragon.es/analytics/saw.dll?Go&Action=Navigate&Options=df&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/V1_M0
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency / last update: decennial. Last update 2019
Regional source	Basque Institute of Statistics (EUSTAT)

(continued)

Table 11 (continued)

Indicator: Number of existing dwellings per climate zone	
Source link	https://www.eustat.eus/elementos/ele0011300/viviendas-de-la-ca-de-euskadi-por-ambitos-territoriales-segun-tipo/tbl0011353_c.html
Characteristics of the source	• Availability: open data • Data collection method: statistical sampling • Data processability: yes, CSV, XLS, and Json formats • Georeferencing: no • Data update frequency/last update: municipal Housing Statistics annual; Housing Use Survey twice a year. Last update January 2019

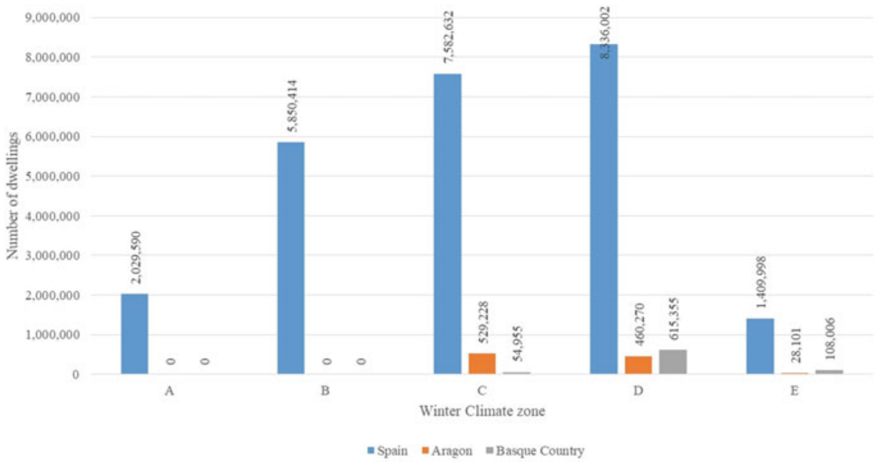


Fig. 18 Number of dwellings per winter climate zone in Spain, and the regions of Aragon and the Basque Country, according to 2011 data. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011) and from (Institute for Energy Diversification and Savings 2020)

The variable of this indicator is the area measured in number of m^2 by residential and non-residential buildings. In the case of residential buildings, it is differentiated by typology, between single family and multi-family buildings. In the case of the Spanish Cadaster, the data can be viewed and downloaded by plot and municipality. The surface area of all plots of each type would need to be added up to obtain the data corresponding to the entire municipality, province, or region, a process that should be possible to carry out simply by downloading "mass" data. Users must identify themselves to do this.

The data from the architectural characterization report from the long-term intervention strategy for the Basque Country's building stock are broken down into single-family and multi-family buildings and there is a separate document for each of the three provinces. Each of these variables is further grouped into clusters according to the year of construction. However, total data are also shown, without disaggregating

Table 12 Sources for indicator m^2 per building type. *Source* own creation

Indicator: m^2 per building type	
Variables	The number of existing m^2 by use and typology for residential use: • Residential buildings: single family, multi-family buildings • Non-residential buildings
Indicator developability	• Data availability: partially available • Processing method from source: indirect • Data processability: data from the Cadaster are available in XLS format whereas data from the report are available only in PDF format
National source	Spanish Cadaster
Source link	https://www.sedecatastro.gob.es/
Characteristics of the source	• Availability: partially open data (non-available in the Basque Country) • Data collection method: statistical summaries based on administrative data, usually from the database of the Cadaster General Directorate • Data processability: yes (XLSX, PDF) • Georeferencing: yes • Data update frequency/last update: biannual (February and August). Last update in February 2022
Regional source	Long-term intervention strategy for the Basque Country's building stock. Basque Government
Source link	https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.2_Informe_A1.pdf https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.4_Informe_G1.pdf https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.3_Informe_B1.pdf
Characteristics of the source	• Availability: open data • Data collection method: data obtained from the Cadaster of each of the Basque provinces • Data processability: no • Georeferencing: no • Data update frequency/last update: single publication in 2020

them. Therefore, direct data at provincial level are available. The data for the three provinces would need to be added together to obtain the total data for the Basque Country. No municipal level data are published through this source.

Figure 19 shows the area (m^2) of residential buildings per building type, differentiating between single-family buildings and multi-family ones, in the case of the Basque Country in 2020. The indicator was not developed for the case of Spain and Aragon because the handling of cadaster data requires further research beyond the scope of this chapter. Figure 20 shows the area (m^2) of residential building at province level of the regions studied. The sources of information cannot provide data for non-residential buildings.

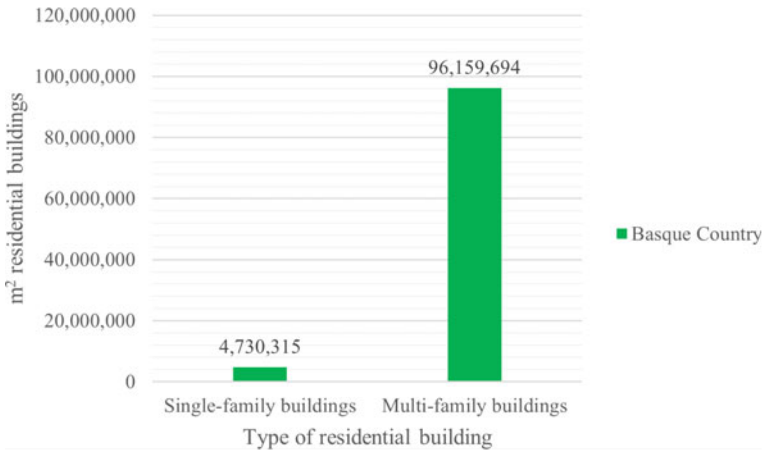


Fig. 19 Square meters (m^2) of residential buildings per building type in the Basque Country. *Source* own creation from data in (Basque Government, 2020)

Fig. 20 Square meters (m^2) of residential buildings per building type, in provinces of the Basque Country. *Source* own creation from data in (Basque Government, 2020)

3.12 Square Meters (m^2) Per Building Age

The purpose of this indicator is to quantify the built and/or usable surface area of residential and non-residential buildings according to the building age. These means surface areas with similar construction characteristics and with similar energy efficiencies depending on the construction year can be obtained, as they comply with the same technical building standards. In this way, the least energy-efficient clusters and the number of dwellings in each cluster can be identified and renovation priorities can be set. The information sources to obtain this indicator can be divided in national sources and regional ones (Table 13).

The periods of construction defined to obtain the number of m^2 according to year of construction are the same used in other indicators previously defined:

Table 13 Sources for indicator m^2 per building age. *Source*: own creation

Indicator: m^2 per building age	
Variables	The number of existing m^2 according to year of construction: • 1900, • 1900–1920, • 1921–1940, • 1941–1950, • 1951–1960, • 1961–1970, • 1971–1980, • 1981–1900, • 1991–2001, • 2002–2011, • > 2011
Indicator developability	• Data availability: partially available • Processing method from source: Indirect, the data needs to be summed • Data processability: Data from the Cadaster are available in XLS format whereas data from the report are available only in PDF format
National source	Spanish Cadaster
Source link	https://www.sedecatastro.gob.es/
Characteristics of the source	• Availability: partially open data (non-available in the Basque Country) • Data collection method: statistical summaries based on administrative data, usually from the database of the Cadaster General Directorate • Data processability: yes (XLSX, PDF) • Georeferencing: yes • Data update frequency/last update: biannual (February and August). Last update in February 2022
Regional source	Long-term intervention strategy for the Basque Country's building stock. Basque Government
Source link	https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.2_Informe_A1.pdf https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.4_Informe_G1.pdf https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.3_Informe_B1.pdf
Characteristics of the source	• Availability: open data • Data collection method: data obtained from the Spanish Cadaster of each of the Basque provinces • Data processability: no • Georeferencing: no • Data update frequency/last update: single publication in 2020

- Buildings built before 1900.
- Buildings built between 1900 and 1920.
- Buildings built between 1921 and 1940.
- Buildings built between 1941 and 1950.
- Buildings built between 1951 and 1960.
- Buildings built between 1961 and 1970.
- Buildings built between 1971 and 1980.
- Buildings built between 1981 and 1990.
- Buildings built between 1991 and 2001.
- Buildings built between 2002 and 2011.
- Buildings built after 2011.

The number of m^2 is an information not commonly provided.

In the case of the Spanish Cadaster, the data can be viewed and downloaded per plot and municipality, so that to obtain the data corresponding to the whole municipality, province, or region it would be necessary to classify the buildings by year of construction and then add up the surface areas of all the plots in each age range. To do this, it is necessary to download the data from the Electronic Spanish Cadaster web at province scale, which contains different files at municipality scale and to carry out a processing of the data to group them, which can be very complex. Utilizing Cadaster data for obtaining these indicators entails the utilization of specialized computer tools for data management, a task that demands additional research and advanced expertise.

The data from the architectural characterization report of the strategy for long-term intervention in the Basque Country's building stock, of which there is a separate document for each of the three provinces, are broken down into single-family and multi-family buildings. Each of these variables is also grouped into clusters according to the year of construction and without disaggregation. Therefore, at the provincial scale, the data is available directly. On the other hand, to obtain the total data for the Basque Country, the sum of the three provinces would have to be added together. There are no data for non-residential buildings.

Figure 21 shows the number of m^2 of residential buildings in the Basque Country and Fig. 22 shows the number of m^2 of residential building in the three provinces of this region.

3.13 Number of m² Per Building Size

The purpose of this indicator is to know the composition of the building stock according to the size of its buildings. The aim is to know the size of each type of residential building, according to the properties that each one houses. This, together with the number of floors, can be used to calculate the volume of the building and thus its form factor. The predominant typologies could therefore be established, and

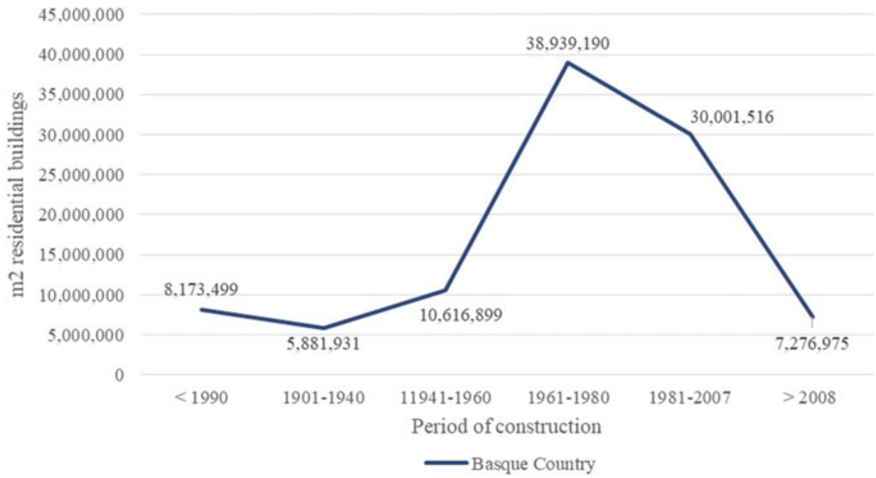


Fig. 21 Square meters (m^2) of residential buildings per year of construction in the Basque Country. *Source* own creation from data in (Basque Government, 2020)

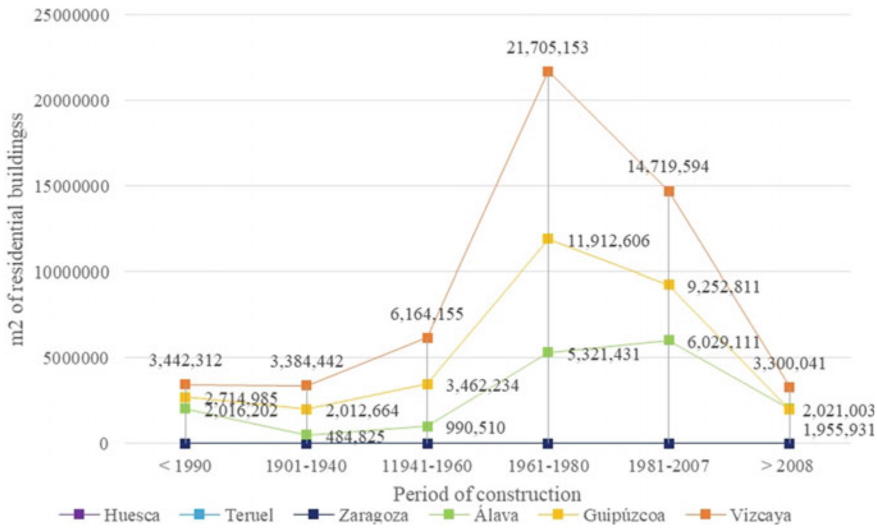


Fig. 22 Square meters (m^2) of residential buildings per year of construction in the three provinces of the Basque Country: Araba, Gipuzkoa and Bizkaia. *Source* own creation from data in (Basque Government, 2020)

more standardized renovation solutions could be explored. In this case, no sources have been found that compile this indicator.

The variables to define the number of existing m^2 in buildings according to the number of properties housed in each residential building:

- 1 property
- 2 properties,
- 3 properties,
- 4 properties,
- 5 to 9 properties,
- 10 to 19 properties,
- 20 to 29 properties,
- 30 to 39 properties,
- 40 or more properties

However, as have been previously said, the data is non-available.

3.14 Number of m^2 Per Climate Zone

The purpose of this indicator is to know the composition of the building stock according to the climate zone of its buildings and the surface area they represent. As all buildings located in the same climate zone have similar external loads, they will also have similar heating and cooling requirements. Buildings in the same climate zone will therefore tend to have similar construction characteristics, which are also strongly influenced by the construction period. The information sources to obtain this indicator can be divided in national sources and regional ones (Table 14).

The variables to define the indicator m^2 of existing buildings according to the climate zone in which they are located are the winter (A, B, C, D, E, α) and summer climate zones (1, 2, 3, 4). This information can be obtained in the webpage of IDAE. The data coming from the Cadasters must be processed for their use. This process is very tedious as it is done manually municipality by municipality. The process could be partially automated, as pointed out in (Beltran-Velamazan et al. under review), but this requires additional research and advanced expertise in computer programming. Due to the complexity of obtaining this indicator, no results were collected.

4 Conclusions

In this chapter, we proposed a set of indicators to measure the evolution of the general characteristics of the Spanish national building stock. Related to this indicator, we studied the sources of information and developed these indicators when there were data.

A list of indicators is proposed whose units are units of buildings, units of dwellings and m^2 (floor areas). The variables include building typology, building age, building size and the climate zone in which the building is located. The indicators proposed are fourteen: (a) Number of buildings per building type; (b) Number of buildings per building age; (c) Number of buildings per building size; (d) Number of

Table 14 Sources for indicator buildings per climate zone. *Source* own creation

Indicator: Number of existing buildings per climate zone (surface area)	
Variables	The number of m^2 of existing buildings according to the climate zone in which they are located: • Winter Climate Severity (SCI): A, B, C, D, E, α • Summer Climate Severity (SCV): 1, 2, 3, 4
Indicator developability	• Data availability: partially available • Processing method from source: indirect. It is necessary to compile the climate zone of each municipality, and then add up the number of m^2 of buildings in all the municipalities belonging to each zone • Data processability: yes (XLS, CSV)
National source	Climate zones map. Institute for Energy Diversification and Savings (IDAE)
Source link	http://zonasclimaticas.idae.es/
Characteristics of the source	• Availability: open data • Data collection method: based on the Spanish Technical Building Code (CTE) Basic Document HE Energy Savings, Annex A Terminology • Data processability: no • Georeferencing: no • Data update frequency/last update: unspecified
National source	Spanish Cadaster
Source link	https://www.sedecatastro.gob.es
Characteristics of the source	• Availability: partially open data (non-available in the Basque Country) • Data collection method: statistical summaries based on administrative data, usually from the database of the Cadaster General Directorate • Data processability: yes (XLSX, PDF) • Georeferencing: yes • Data update frequency/last update: biannual (February and August). • Last update in February 2022
Regional source	Alava Cadaster
Source link	https://catastroalava.tracasa.es/
Characteristics of the source	• Availability: open data • Data collection method: statistical summaries based on administrative data • Data processability: yes, CSV • Georeferencing: yes • Data update frequency/last update: 31 October 2022
Regional source	Vizcaya Cadaster
Source link	https://web.bizkaia.eus/es/catastro-de-bizkaia
Characteristics of the source	• Availability: open data • Data collection method: statistical summaries based on administrative data • Data processability: yes, CSV • Georeferencing: yes • Data update frequency/last update: unspecified
Regional source	*Gipuzkoa Cadaster*

(continued)

Table 14 (continued)

Indicator: Number of existing buildings per climate zone (surface area)	
Source link	https://ssl7.gipuzkoa.net/OgasunaNet/Catastro/porDP.asp
Characteristics of the source	• Availability: open data • Data collection method: statistical summaries based on administrative data • Data processability: yes, CSV • Georeferencing: yes • Data update frequency/last update: unspecified

buildings per climate zone; (e) Number of dwellings per type of residential building; (f) Number of dwellings per type of building (occupancy); (g) Number of dwellings per building age; (h) Number of dwellings per building size (surface area); (i) Number of dwellings per building size (j) Number of dwellings per climate zone; (k) m^2 per building type; (l) m^2 per building age; (m) m^2 per building size; (n) m^2 per climate zone. Of these proposed indicators, 5 are fully developable, 8 are partially developable and one can be developed due to lack of data.

The sources of information to develop these indicators are national and regional. The main source of information is the Population and Housing Census carried out by Spain's National Institute of Statistics. It is a national source whose access is open and allows the download of data in formats that allow its processing. The Population and Housing Census is based on a 'pre-census file' with information from Municipal Census Records and other administrative records, from which a sample was extracted of 12% of the dwellings in the entire country. The percentage varies from 100% for municipalities with less than 200 inhabitants to 9% for municipalities with more than 1,000,000 inhabitants. From there, the total data are obtained by statistical calculations using calibration techniques. In the specific case of the Building Census, there is no data on the sampling volume percentages.

In the characterization of buildings by type, there is a general lack of information on non-residential buildings, while precise information is found for residential buildings. However, the classification made by the Population and Housing Census into single-family and multi-family dwellings is only made for municipalities with more than 2000 inhabitants, which makes it difficult to characterize buildings in rural areas. In order to perform the indicators that group the buildings by climate zone, it has only been possible to perform it for the winter climatic zone and there is not enough data to perform it for the summer climatic zone. The Spanish Cadaster contains complete information about buildings such as surface area, year of construction, location, etc. This information is very valuable to develop the indicators, however it requires advanced computer knowledge to be able to process the data.

It was not possible to develop the indicator m^2 per building size, and it was complex to manage the information to obtain results for the indicator m^2 per climate zone. This may be related to the need to obtain the information on m^2 in the cadaster. The Spanish Cadaster provides the information at the building scale, and downloads municipality by municipality are allowed. This means that, to obtain result at the regional or national scales, it is needed to process the information in order to be analyzed, which is a demanding task that requires further research and advanced computer tools. The Spanish Cadaster does not provide data for the region of the Basque Country. Other sources such as Digital Atlas of Urban Areas and IAEST are extracted from the Spanish Cadaster, so their accuracy depends on the accuracy of the latter. The Cadasters are the only sources of information studied in this chapter that allow for georeferencing. Data georeferencing is currently at a stage where it is poorly defined. If more detailed mapping were undertaken, it would be an important tool for the detection of vulnerable areas.

The regional sources of information have been studied in the cases of Aragon and the Basque Country. The main source of information in Aragon is The Aragon Institute of Statistics (IAEST), and in the case of the Basque Country there are three main sources: the Basque Institute of Statistics (EUSTAT), the long-term intervention strategy for the Basque Country's building stock, and the Basque Government and its provincial Urban Cadasters.

In conclusion, in Spain there are good sources of information to develop some indicators that measure the progress of the general characteristics of buildings. The need to resort to different sources depending on the information required means that the cross-referencing of data does not always coincide and some of the indicators can only be developed partially. Furthermore, the operational system of the Spanish Cadaster holds significant potential for generating results on a regional or national level. However, its use requires further research and the application of advanced tools, which exceeds the scope of this chapter.

Acknowledgements This work was funded by the MINISTRY OF SCIENCE AND INNOVATION OF SPAIN, grant number PID2019-104871RB-C21/AEI/10.13039/501100011033 and by GOBIERNO DE ARAGÓN, grant number T37_23R: Built4Life Lab.

References

Basque Government: Estrategia de intervención a largo plazo en el parque de edificios de Euskadi [Long-term intervention strategy in the building stock of Euskadi] (2020).

Basque Institute of Statistics: Family housing (2023).

Beltran-Velamazan, C., Monzón-Chavarrías, M., López-Mesa, B.: A new approach for national-scale Building Energy Models based on Energy Performance Certificates in European countries: the case of Spain. Heliyon 10(3), e25473 (2024). https://doi.org/10.1016/j.heliyon.2024.e25473

Buildings Performance Institute Europe: EUROPE'S BUILDINGS UNDER THE MICROSCOPE. A country-by-country review of the energy performance of buildings. ISBN: 9789491143014 (2011).

European Commission: COMMISSION RECOMMENDATION (EU) 2019/786 of 8 May 2019 on building renovation. Official Journal of the European Union (2019: L 127), 34–79 (2019).

European Parliament, Council of the European Union: DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Official Journal of the European Union (2012: L 315), 1–56 (2012).

European Parliament, Council of the European Union: DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on energy performance of buildings. Official Journal of the European Union (2003: L 1), 65–71 (2003).

European Parliament, Council of the European Union: 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. Official Journal of the European Union (2018: L 156), 75–91 (2018).

European Parliament: Energy performance of buildings (recast) Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (COM(2021)0802 – C9–0469/2021 – 2021/0426(COD)). Strasbourg (2023).

https://en.eustat.eus/elementos/ele0011300/ti_viviendas-familiares-de-la-ca-de-euskadi-por-ambitos-territoriales-segun-caracteristicas-estructurales-01012022/tbl0011354_i.html, last accessed 2023/09/20.

Institute for Energy Diversification and Savings (IDAE): Zonas Climáticas [Climate zones]. (2020). http://zonasclimaticas.idae.es/, last accessed 2023/09/20.

Jacobs, J.: The Death and Life of Great American Cities. New York: Random House (1961)

Landolfo, R., Formisana, A., Di Lorenzo, G., Di Filippo A.: Classification of european building stock in technological and typological classes. Journal of Building Engineering. 45, 103482 (2022).

Loga, T. (ed.), Diefenbacn, N. (ed.), Stein, B. (ed.): Typology Approach for Building Stock Energy Assessment. Main Results of the TABULA project. Final project report. (2012). https://episcope.eu/fileadmin/tabula/public/docs/report/TABULA_FinalReport.pdf, last accessed 2023/09/20.

Lynch, K.: The image of the city. Cambridge: The M.I.T. Press. ISBN: 0 262 12004 6 (1960).

Ministry of Finance and Public Administration: Cadastral Electronic Site. (2022). https://www.sedecatastro.gob.es/, last accessed 2023/09/20.

Ministry of Transport, Mobility and Urban Agenda: Estimación del parque de viviendas [Housing stock estimate]. (2019). https://apps.fomento.gob.es/BoletinOnline2/?nivel=2&orden=33000000, last accessed 2023/09/20.

Ministry of Transport, Mobility and Urban Agenda: 2020 Update of the long-term strategy for energy renovation in the building sector in Spain (ERESEE). Madrid. (2020)

Nachtigall, f., Milojevic-Dupont, N., Wagner, F., Creutzing, F.: Predicting building age from urban form at large scale. Computers, Environment and Urban Systems. 105, 102010 (2023). https://doi.org/10.1016/j.compenvurbsys.2023.102010, last accessed 2023/09/20.

Spain's National Institute of Statistics: Population and Housing Census (2011). https://www.ine.es/en/censos2011_datos/cen11_datos_resultados_en.htm, last accessed 2023/09/20.

Spain's National Institute of Statistics: Continuous Household Surveys (2023). https://www.ine.es/dyngs/INEbase/en/operacion.htm?c=Estadistica_C&cid=1254736176952&menu=resultados&idp=1254735572981, last accessed 2023/09/20.

Zhou, P., Zhana, T., Zhao, L., Qi, Y., Chana, Y., Bai, L.: Pre-clustering active learning method for automatic classification of building structures in urban areas. Engineering Applications of Artificial Intelligence. 123, Part C, 106382 (2023).

Indicators and Data in Spain for an Overview of the Energy Characteristics of the National Building Stock

Marta Gómez-Gil, Almudena Espinosa-Fernández, Belinda López-Mesa, and Marta Monzón-Chavarrías

Abstract The decarbonization objectives outlined by Europe, coupled with the aging of existing buildings, underscore the importance of evaluating the evolution of energy characteristics of the building stock at both national and regional levels. To facilitate this evaluation in Spain, along with its regions Aragon and the Basque Country, a set of indicators is suggested in this chapter. These indicators aim to offer insights into the evolution of annual final energy consumption by building type and per end use. Additionally, the Energy Performance Certificates (EPCs) are put forth as valuable indicators, with a focus on the number and energy class derived from these certificates. In the case of the former indicators, Spain benefits from both national and regional data sources, although enhancements are possible through improved data processing techniques and the extraction of information based on building characteristics. As for EPCs, it is recommended that the information provided by regions undergo a standardization process to ensure a more comprehensive development of the indicators. Furthermore, an additional proposed indicator involves the measurement of the quantity and surface area of nearly zero-energy buildings (nZEB). Unfortunately, the current lack of national or regional sources hampers the development of this particular indicator.

M. Gómez-Gil · A. Espinosa-Fernández · B. López-Mesa · M. Monzón-Chavarrías (✉)
Built4Life Lab, University of Zaragoza-I3A, 50018 Zaragoza, Spain
e-mail: monzonch@unizar.es

M. Gómez-Gil
e-mail: m.gomez@unizar.es

A. Espinosa-Fernández
e-mail: almudenaef@unizar.es

B. López-Mesa
e-mail: belinda@unizar.es

B. López-Mesa and X. Oregi (eds.), *Assessing Progress in Decarbonizing Spain's Building Stock*, Digital Innovations in Architecture, Engineering and Construction,
https://doi.org/10.1007/978-3-031-51829-4_4

1 Introduction

Buildings account for 40% of total energy consumption and 36% of carbon dioxide (CO_2) emissions in the European Union (EU), being the most energy-consuming sector (European Commission 2020). Most of the final energy consumption is used for heating and cooling and it is estimated that 85%-95% of the building stock is energy inefficient, so there is great potential to increase its energy efficiency (Buildings Performance Institute Europe 2017). Therefore, reduction of energy consumption and the use of energy from renewable sources in the buildings sector is an important measure to reduce the EU´s energy dependency and greenhouse gas (GHG) emissions.

Due to the aging of the existing buildings in Europe and their need for upgrading, the renovation of the existing building stock is necessary to obtain real energy savings. In this sense, knowledge of the energy characteristics of the existing building stock can provide a more solid basis for the elaboration of European or national policies. This is an essential element of a data-driven debate on how to improve energy savings in buildings, with other collateral benefits such as boosting the economy.

The European Union began to legislate in relation to this objective in the 1990s. Recognizing the context of growth in the building sector, Directive 93/76/CEE of 13 September 1993 stated that objective information on the energy performance of buildings could promote greater transparency in the real estate market and would encourage investments in energy savings (Council of European Communities 1993). In this sense, the Energy Performance Certification of buildings (EPC) was initially launched, which consists of the description of the energy characteristics of buildings, providing information to those interested in using a building, about its energy efficiency. The energy performance certificate of a building should include reference values such as current regulations and comparative ratings, so that consumers can compare and evaluate the energy performance of the building. The calculation methodology and requirements for EPCs were modified in subsequent directives, such as Directive 2002/91. The latter also introduced the possibility of distinguishing between new and existing buildings, between different categories of buildings, and further developed the indicators to be shown in the certificate. These requirements are reviewed periodically at intervals not exceeding 5 years and, if necessary, updated to adapt them to technical developments in the construction sector. As reflected in subsequent updates, such as the 2010/31/UE Directive, the EPC information may serve to further encourage owners and tenants to improve the energy performance of their building or building unit (European Parliament and the Council of the European Union 2010). The EPBD is currently being reviewed. In the latest version of the revision (European Parliament 2023), not yet approved, referred to in this book as 2023 EPBD Proposal recast, it is established that Member States (MSs) shall make publicly available information on the share of buildings in the national building stock covered by EPC and aggregated or anonymized data on the energy performance, making it available to public and research institutions such as National Statistics Institutes, upon request.

Directive 2002/27/UE on energy efficiency (referred to as 2002 EED in this book) (European Parliament and the Council of the European Union 2002) and its recast 2018/844 (referred to as 2018 EPBD in this book) stipulate that each Member State (MS) shall establish a long-term renovation strategy (LTRS) to support the renovation of the national stock of residential and non-residential buildings, both public and private, into a highly energy efficient and decarbonized building stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly zero-energy buildings (nZEBs). Each LTRS shall be submitted in accordance with the applicable planning and reporting obligations and shall encompass, among other things:

(A) an overview of the national building stock, based, as appropriate, on statistical sampling and expected share of renovated buildings in 2020;
(B) an evidence-based estimate of expected energy savings and wider benefits, such as those related to health, safety and air quality.

In its LTRS, each MS shall set out a roadmap with measures and domestically established measurable progress indicators, with a view to the long-term 2050 goal of reducing GHG emissions in the Union by 80–95% compared to 1990, in order to ensure a highly energy efficient and decarbonized national building stock and in order to facilitate the cost-effective transformation of existing buildings into nearly zero-energy buildings. The roadmap shall include indicative milestones for 2030, 2040 and 2050, and specify how they contribute to achieving the Union's energy efficiency targets in accordance with Directive 2012/27/EU.

In Spain, the first LTRS (whose acronym in Spanish is ERESEE) was submitted in 2014 and updated in 2017 and 2020. In the 2020 ERESEE, the assessment comprises two separate parts. The first involves an overview analysis of the Spanish building stock and, in the light of the above analysis, the second part segments this stock into typological clusters to reflect different renovation scenarios and objectives.

The second chapter of the first part covers the diagnosis of energy consumption in the building sector and its evolution between 2014 and 2020. Other relative issues are reflected in a third chapter of the same part, as the evolution of building renovation. In the light of the above analysis, the second part segments this residential stock into typological clusters, which are used throughout the 2020 ERESEE to propose renovation approaches within the clusters and to economically assess the different options, while at the same time taking into account the different climate zones and energy consumption.

The achievement of the Union's energy and climate goals is linked to the Union's efforts to renovate its building stock by giving priority to energy efficiency, making use of the 'energy efficiency first' principle as well as considering deployment of renewable energies. Therefore, this is aligned with the 2030 Agenda for Sustainable Development, which includes 17 Sustainable Development Goals (SDGs), with the United Nations New Urban Agenda and the Urban Agenda for the European Union.

The Buildings Performance Institute Europe (BPIE) is a Europe's leading independent think tank on energy performance of buildings, with a vision of climate-neutral built environment. This association published in 2011 the report 'Europe's buildings under the microscope' (Buildings Performance Institute Europe 2011). As there was a lack of comprehensive data on buildings at European level, the BPIE analyzed Europe's building stock (EU 27 plus Switzerland and Norway) including building characteristics, building codes and other regulatory measures. The collected data allowed to determine the energy and CO_2 saving potential of Europe's buildings and to model a variety of scenarios for the systematic renovation of the European building stock until 2050.

The objective of the European research Project TABULA is the national typological classification of residential buildings. According to the report of this project (Loga et al. 2012) the typological classification of a country consists of a classification system of the building stock according to its size, age, and other parameters. The classification is presented through a set of example buildings representing the different building types established. As a result, each participating country publishes a "catalog of residential building typology". Another result of this project is a web tool that provides an online calculation of example buildings in all participating countries, showing their energy characteristics and the possible energy savings achieved through the application of energy renovation measures.

The final report of the Sech-Spahousec Project, named 'Analysis of the Energy Consumption in the Spanish Households' (IDAE 2011), provides an approach to the energy consumptions of the building sector in Spain, explaining in depth the consumptions by climatic zone and type of housing. The project's findings provided valuable insights into residential equipment and actual energy consumption, confirming the country's elevated consumption levels and the necessity to influence policies promoting responsible energy use in homes. In a second part of this project, called 'SPAHOUSEC II: Statistical analysis of natural gas consumption in primary homes with individual heating' (IDAE 2019), focusing on the stock of primary homes equipped with individual heating systems based on natural gas, the study allowed to deepen the knowledge about the availability and behaviour associated with the equipment of these homes. According to this report, an upward in tenants'energy consumption is detected explained by several factors such as the increase in the number of homes, the greater comfort required by them and, consequently, the increase in equipment. All of this, together with increases in purchasing power and an improvement in the standard of living, leads us to foresee future upward trends in the representativeness of the residential sector in terms of energy demand.

Recent scientific literature has addressed the study of the diagnosis of the energy characteristics of buildings. These studies differ, among other things, in the scale at which they are applied. Some studies allow to obtain information at building level, others allow a diagnosis at larger scales, by means of the so-called Urban Building Energy Models (UBEMs). In the first group, some studies are centred on determining the U-value of the envelope of existing buildings (e.g. Byun et al. 2023) or on Building Energy Modelling (BEM) with automated inputs, such as age prediction (Benz et al., 2023). UBEMS are energy models at district, city, or national scale (Ali et al., 2021) and have been identified as useful tools to know the energy consumption of urban areas or cities for urban energy planning (Johari et al., 2020).

Measuring progress in the energy performance of existing buildings is important to achieve the proposed decarbonization targets goals. This chapter proposes some indicators in this sense for the case of Europe and develops them for the case of Spain and two of its regions, Aragon and the Basque Country.

2 Methodology

To develop the indicators that allow an overview of the energy characteristics of the building stock in Aragon, the Basque Country and Spain, the process indicated in Fig. 1 was followed.

The first step consisted in the development of a common template for these indicators based on:

- Indicator:
  - Definition of the indicator.
  - Variables to quantify it and their unit of measurement.
  - Purpose and advantages of implementing this indicator.

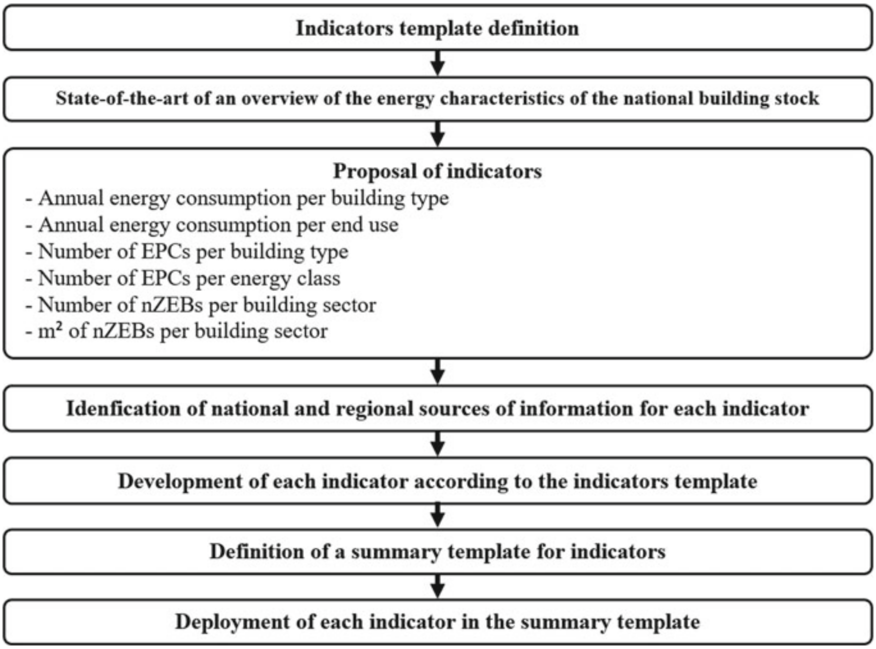


Fig. 1 Methodology implemented to develop indicators on an overview of the energy characteristics of the building stock in Aragon, the Basque Country and Spain. *Source* own creation

- Alignment of the indicator with the directives, agendas, action plans and strategies, covering the European and international, national, and regional scales.
- Relationship of this indicator with other similar ones.

- Information sources:
  - Availability of information to generate this indicator at different scales.
  - Entity responsible for providing this information.

- Measurement:
  - Measurement method.
  - Methodology.
  - Current possibilities of obtaining it.
  - Information necessary to generate it.
  - Availability and quality of data.

A state of the art of indicators related to the study of an overview of the energy characteristics of the national building stock was undertaken and, in conclusion, the following indicators were proposed:

- Annual energy consumption per building type.
- Annual energy consumption per end use.
- Number of EPCs per building type.
- Number of EPCs per energy class.
- Number of nZEBs per building sector.
- m^2 of nZEBs per building sector.

Once the key indicators to cover this topic were identified, the available sources of information were studied and the standard template for each indicator was developed and generated.

Subsequently, a summary file was defined for each indicator with the main points covered in the complete file.

3 Indicators

3.1 Annual Energy Consumption Per Building Type

The purpose of this indicator is to know the evolution of final energy consumption, which makes it possible to assess fluctuations—upward and downward trends—in energy consumption. This could be used to detect the cluster with the highest consumption, the greatest savings, and the greatest potential for intervention towards responsible consumption and a decarbonized building stock. The information sources to obtain this indicator can be divided in national sources and regional ones (Table 1).

The variables of this indicator are the type of the buildings according to:

Table 1 Sources for indicator Annual energy consumption per building type. *Source* own creation

Indicator: Annual energy consumption per building type	
Variables	Final annual energy consumption (ktoe) of the building sector by type of building: – Single family – Multi-family building – Non-residential building
Indicator developability	– Data availability: partially available – Processing method from source: direct from some sources. Indirect. In the case of Eustat, where the non-residential sectors must be added up as they are disaggregated – Data processability: yes
National source	Institute for Energy Diversification and Savings—IDAE
Source link	https://www.idae.es/informacion-y-publicaciones/estudios-informes-y-estadisticas
Characteristics of the source	– Availability: open data – Data collection method: records or data collection – Data processability: yes – Georeferencing: not applicable – Data update frequency/last update: annually. Last update in 2019
National source	Ministry of Transport, Mobility and Urban Agenda. Long-term Strategy for Energy Renovation in the Spanish Building Sector—LTRS 2020
Source link	https://www.mitma.gob.es/recursos_mfom/paginabasica/recursos/es_ltrs_2020.pdf
Characteristics of the source	– Availability: open data – Data collection method: records or data collection – Data processability: no – Georeferencing: not applicable – Data update frequency/last update: updated every 3 years. Last update in 2020
Regional source	Basque Institute of Statistics—EUSTAT
Source link	https://www.eustat.eus/elementos/ele0000300/consumo-final-de-energia-de-la-ca-de-euskadi-por-sectores-ktep/tbl0000396_c.html
Characteristics of the source	– Availability: open data – Data collection method: records or data collection – Data processability: yes – Georeferencing: not applicable – Data update frequency/last update: annually. Last update in May 2020

- Single family buildings.
- Multi-family buildings.
- Non-residential buildings.

The national information sources indicated in Table 1 provide the annual energy consumption of buildings, categorized as residential and non-residential buildings. However, there is no information about the annual energy consumption in single family buildings and multi-family ones. In the case of Eustat, the indicators are obtained indirectly. There are no regional information sources for Aragon. Figure 2 shows the evolution of the annual energy consumption in residential and non-residential buildings at national scale, and Fig. 3 shows the evolution of the annual energy consumption in residential and non-residential buildings in the Basque Country.

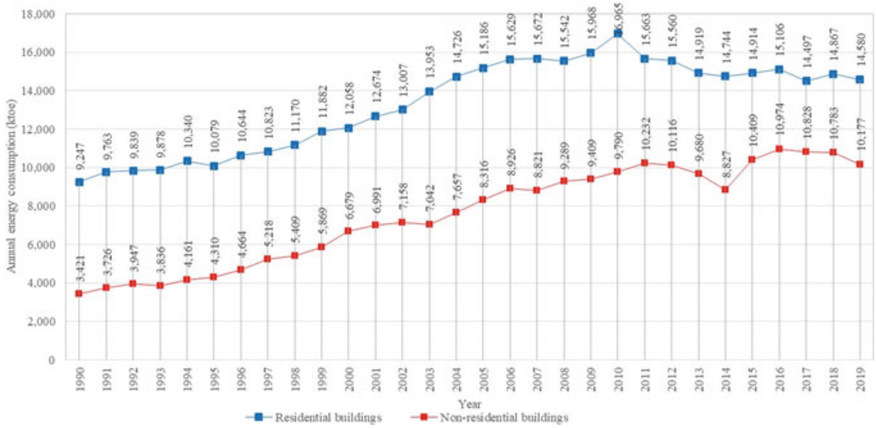


Fig. 2 National annual energy consumption (ktoe) in residential and non-residential buildings. *Source* own creation from data in (Institute for Energy Diversification and Savings 2023)

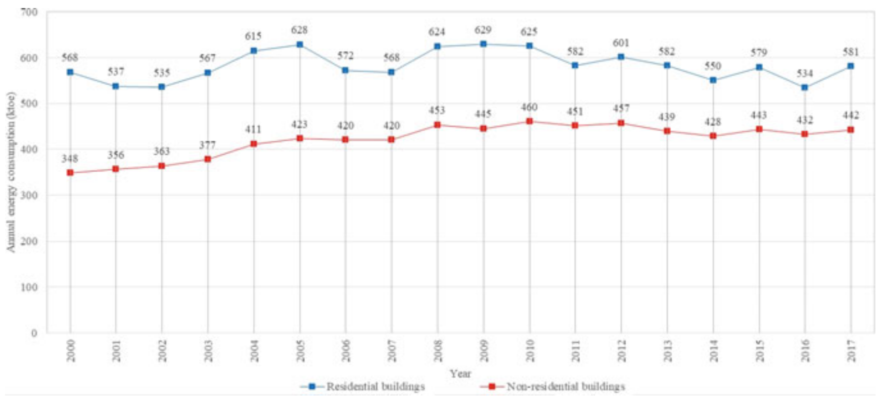


Fig. 3 Annual energy consumption (ktoe) in the Basque Country in residential and non-residential buildings. *Source* own creation from data in (Basque Institute of Statistics, 2023)

3.2 Annual Energy Consumption Per End Use

The purpose of this indicator is to measure the evolution of the energy consumption for each type of end-use in buildings. This information can be used to assess fluctuations—upward and downward trends—of consumption in relation to each of these end-uses. This could be used to detect the end-use with the highest consumption, the greatest savings, and the greatest potential for intervention towards responsible consumption and a decarbonized building stock. This information is only available in national sources, which are detailed in Table 2.

The variables chosen to measure the annual energy consumption per end use are: heating, domestic hot water (DHW), cooling, kitchen, lighting and, electrical

Table 2 Sources for indicator annual energy consumption per end use. *Source* own creation

Indicator: Annual energy consumption per end use	
Variables	Final annual energy consumption (ktoe) of buildings by type of energy end-use: – Heating – Domestic Hot Water (DHW) – Cooling – Kitchen, – Lighting – Electrical appliances
Indicator developability	– Data availability: partially available – Processing method from source: direct, but only for the residential sector – Data processability: yes, XLSX, CSV
National source	Institute for Energy Diversification and Savings—IDAE
Source link	https://www.idae.es/en/information-and-notifications/studies-reports-and-statistics
Characteristics of the source	– Availability: open data – Data collection method: records or data collection – Data processability: yes – Georeferencing: not applicable – Data update frequency/last update: annually. Last update in 2021
National source	Ministry of Transport, Mobility and Urban Agenda. Long-term Strategy for Energy Renovation in the Spanish Building Sector—LTRS 2020
Source link	https://www.mitma.gob.es/recursos_mfom/paginabasica/recursos/es_ltrs_2020.pdf
Characteristics of the source	– Availability: open data – Data collection method: records or data collection – Data processability: no – Georeferencing: not applicable – Data update frequency/last update: updated every 3 years. Last update in 2020

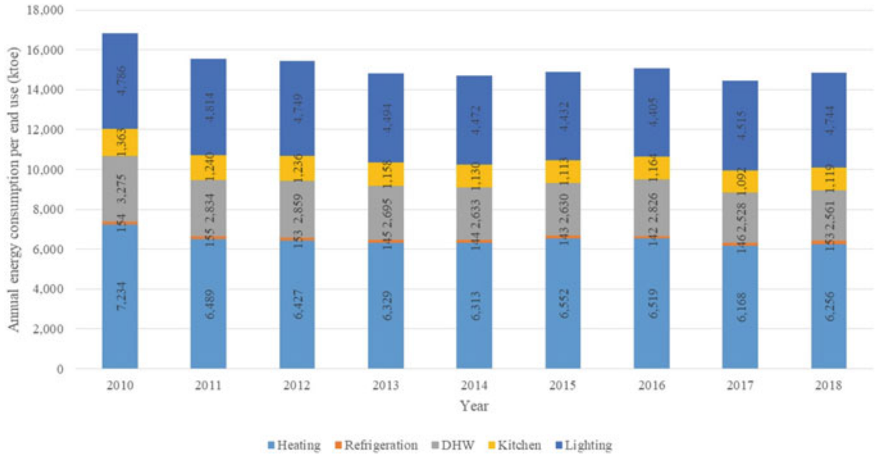


Fig. 4 Annual energy consumption per end use in residential buildings of Spain between 2010 and 2018 (ktoe). *Source* own creation from data in (Institute for Energy Diversification and Savings, 2023)

appliances. The data is only partially available, as detailed data is only available for residential buildings. Moreover, the sources present data at national level, and there is no regional information. Figure 4 shows the evolution on annual energy consumption per end use in Spain, between 2010 and 2018.

3.3 Number of Energy Performance Certificates (EPCs) Per Building Type

The purpose of this indicator is to know to what extent the energy performance of the building stock is certified. This makes it possible to have a general overview of the energy performance of the building stock and, also to evaluate the strategies for the promotion of the improvement of the energy efficiency of buildings. The sources of information to develop this indicator in Spain are national and regional (Table 3).

The variables needed to measure the number of EPCs emitted per year are:

- New buildings, differentiating by residential buildings and non-residential buildings.
- Existing buildings, differentiating by residential buildings, non-residential buildings.

The national source is a report made by the Ministry of Ecological Transition and Demographic Challenge published in pdf, which shows the number of EPCs by region differentiating between news and existing buildings. This report also publishes the number of EPCs in residential and non-residential buildings per year. However,

Table 3 Sources for indicator Number of energy performance certificates (EPCs) per building type. *Source* own creation

Indicator: Number of energy performance certificates (EPCs) per building type	
Variables	Number of energy performance certificates (EPCs) per year and per type of building: – New buildings: residential buildings, non-residential buildings – Existing buildings: residential buildings, non-residential buildings
Indicator developability	– Data availability: partially available – Processing method from source: direct – Data processability: no
National source	Ministry of Ecological Transition and Demographic Challenge
Source link	https://energia.gob.es/desarrollo/EficienciaEnergetica/CertificacionEnergetica/Documentos/Documentos%20informativos/2022_Informe-seguimiento.pdf
Characteristics of the source	– Availability: open data but insufficient to fully collect the indicator – Data collection method: data related to energy performance certificates come from the regional registers where they are registered by the corresponding technicians – Data processability: no, PDF report – Georeferencing: no – Data update frequency/last update: annually. Last update in December 2021
Regional source	Government of Aragon Open Data
Source link	https://opendata.aragon.es/datos/catalogo/dataset/registro-de-certificacion-de-eficiencia-energetica-de-edificios-de-aragon
Characteristics of the source	– Availability: open data – Data collection method: database of the regional register – Data processability: yes, data available in XLS and CSV formats – Georeferencing: no – Data update frequency/last update: continually
Regional source	Basque Government
Source link	https://www.euskadi.eus/certificado-eficiencia-energetica/web01-a2indust/es/index.shtml#7971
Characteristics of the source	– Availability: open data but insufficient to fully collect the indicator – Data collection method: regional register – Data processability: no, PDF report – Georeferencing: no – Data update frequency/last update: twice a year. Last update in June 2022

updated data are not provided nor is it possible to process data directly or consult more detailed information on the EPCs. Aragon provides sufficient information to develop the indicator. Regarding data from the Basque Country, there is a compilation of the EPC registry that can be consulted by express request; but not having immediate processable open data is a limitation.

Figure 5 shows the number of EPCs registered annually by type of building (new and existing buildings, and residential and non-residential buildings) in Spain according to national information. Figure 6 shows the number of EPCs registered annually by type of building (new and existing buildings, and residential and non-residential buildings) in Aragon according to regional data.

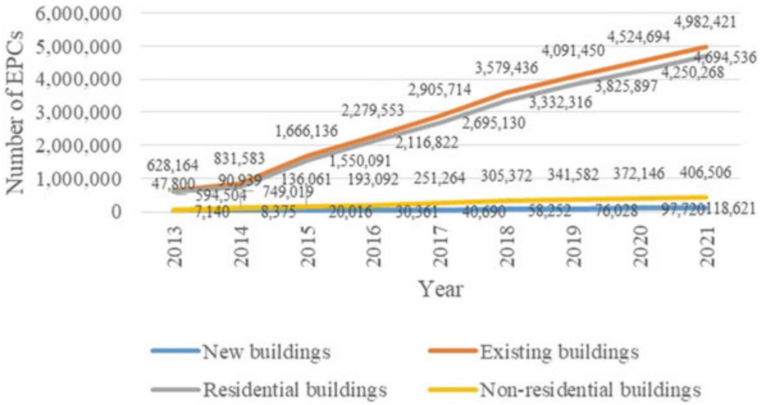


Fig. 5 Number of EPCs registered per year in Spain per type of building (new and existing buildings, and residential and non-residential buildings). *Source*: own creation from data in (Ministry for Ecological Transition and the Demographic Challenge and Ministry of Transport, Mobility and Urban Agenda, 2021)

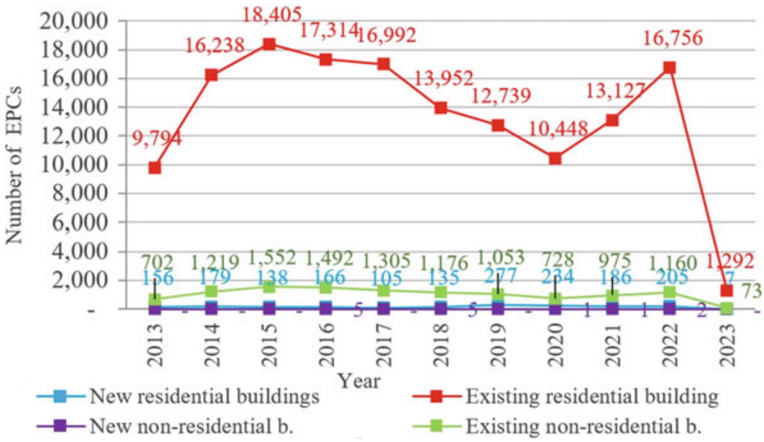


Fig. 6 Number of EPCs registered per year in Aragon by type of building (new and existing buildings, and residential and non-residential buildings). *Source* own creation from data in (Government of Aragon, 2023)

3.4 Number of Energy Performance Certificates (EPCs) Per Energy Class

The purpose of this indicator is to track the evolution of the number of EPCs registered in each energy class. This enables tracking the changes in energy efficiency within a country's buildings and evaluating their prevalence in the national building stock. Ultimately, it helps gauge the progress toward decarbonization goals. This can also be useful to know the number of buildings certified.

The energy rating of buildings in Spain is expressed through two main indicators, which are annual carbon dioxide (CO_2) emissions and annual consumption of non-renewable primary energy (NRPEC). The national-scale source in Table 4 provides energy classification data, so the variables proposed to this indicator are:

- Number of EPCs per year by energy class regarding CO_2 emissions:
  - Number of EPCs class A.
  - Number of EPCs class B.
  - Number of EPCs class C.
  - Number of EPCs class D.
  - Number of EPCs class E.
  - Number of EPCs class F.
- Number of EPCs per year by energy class regarding NRPEC:
  - Number of EPCs class A.
  - Number of EPCs class B.
  - Number of EPCs class C.
  - Number of EPCs class D.
  - Number of EPCs class E.
  - Number of EPCs class F.

This indicator is directly derived from the national source of information. The results are shown in Figs. 7, 8 and 9 based on the data found in the national source, which includes the EPCs registered as of December 31, 2021. Figure 7 shows the percentage of buildings of each energy class (A–G) with respect to CO_2 emissions in new buildings. Figures 8 and 9 show the percentage of existing buildings of each energy class, with respect to emissions and NRPEC, respectively. To obtain the number of registered EPCs of energy class with respect to NRPEC in new buildings, the regional sources should be consulted because this information is not provided by the national source. In Aragon's case, the available sources offer the raw data from EPCs, which could potentially facilitate the development of the comprehensive set of variables at the regional level. Nonetheless, this task is beyond the scope of this chapter, as it necessitates additional research and advanced data management.

Table 4 Sources for indicator Number of energy performance certificates (EPCs) per energy class. *Source* own creation

Indicator: Number of energy performance certificates (EPCs) per energy class	
Variables	– Number of EPCs per year by energy class regarding CO_2 emissions: energy class A, B, C, D, E, F – Number of EPCs per year by energy class regarding NRPEC: energy class A, B, C, D, E, F
Indicator developability	– Data availability: partially available – Processing method from source: indirect – Data processability: no, except for the case of Aragon
National source	Ministry of Ecological Transition and Demographic Challenge
Source link	https://energia.gob.es/desarrollo/EficienciaEnergetica/CertificacionEnergetica/Documentos/Documentos%20informativos/2022_Informe-seguimiento.pdf
Characteristics of the source	– Availability: open data – Data collection method: data relating to energy performance certificates come from the regional registers where they are registered by the corresponding technicians – Data processability: no – Georeferencing: no – Data update frequency/last update: annually. Last update in December 2021
Regional source—Aragon	Government of Aragon Open Data
Source link	https://opendata.aragon.es/datos/catalogo/dataset/registro-de-certificacion-de-eficiencia-energetica-de-edificios-de-aragon
Characteristics of the source	– Availability: open data but insufficient to fully collect the indicator – Data collection method: regional register – Data processability: yes, CSV and Json formats – Georeferencing: no – Data update frequency/last update: continuously updated
Regional source—The Basque Country	Basque Government
Link	https://www.euskadi.eus/certificado-eficiencia-energetica/web01-a2indust/es/index.shtml#7971
Characteristics of the source	– Availability: open data – Data collection method: regional register – Data processability: no, PDF report – Georeferencing: no – Data update frequency/last update: twice a year. Last update in June 2022
Regional source—The Basque Country	GeoEuskadi

(continued)

Table 4 (continued)

Indicator: Number of energy performance certificates (EPCs) per energy class	
Link	https://www.geo.euskadi.eus/visor-areas-vulnerables-de-la-capv/webgeo00-geoapps/es/
Characteristics of the source	– Availability: open data – Data collection method: directly – Data processability: no – Georeferencing: partially georeferenced, although only at section level, not at building level – Data update frequency / last update: unspecified

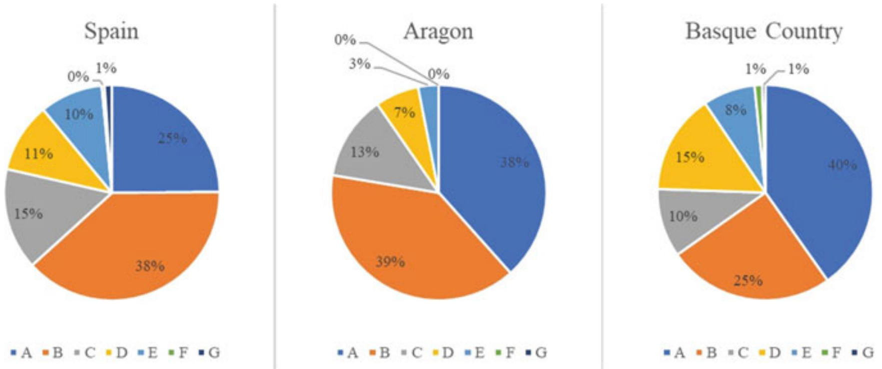


Fig. 7 Number of EPCs registered per year in Spain, and the regions of Aragon and the Basque Country, by energy class regarding CO_2 emissions in new buildings, as of end of year 2021. *Source* own creation from data in (Ministry for Ecological Transition and the Demographic Challenge and Ministry of Transport, Mobility and Urban Agenda, 2021)

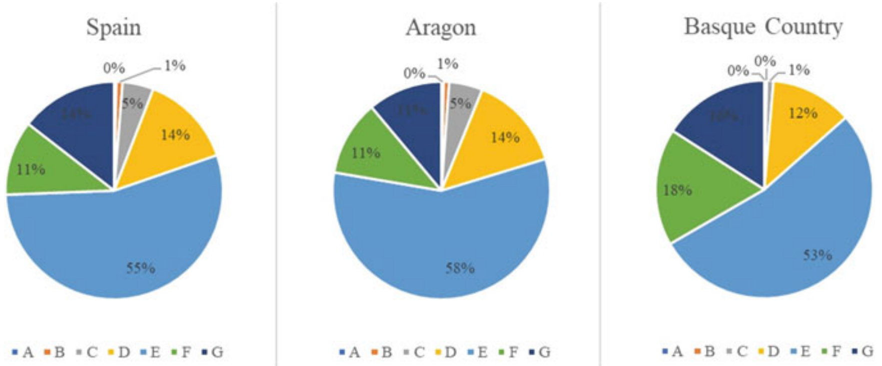


Fig. 8 Number of EPCs registered per year in Spain, and the regions of Aragon and the Basque Country, by energy class regarding CO_2 emissions in existing buildings, as of end of year 2021. *Source* own creation from data in (Ministry for Ecological Transition and the Demographic Challenge and Ministry of Transport, Mobility and Urban Agenda, 2021)

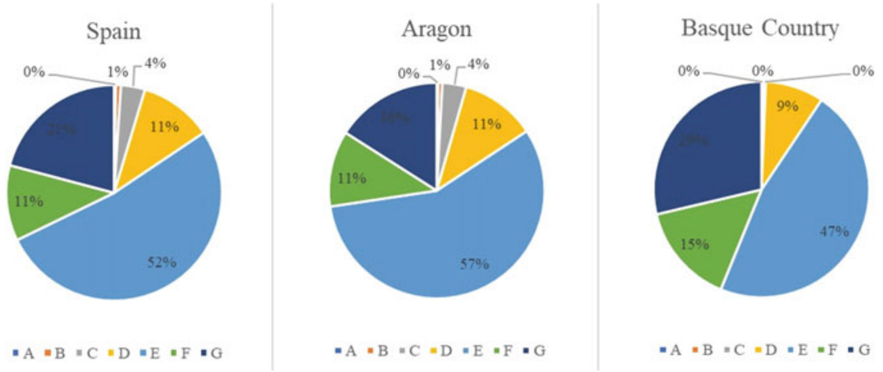


Fig. 9 Number of EPCs registered per year in Spain, and the regions of Aragon and the Basque Country by energy class regarding NRPEC in existing buildings, as of end of year 2021. *Source* own creation from data in (Ministry for Ecological Transition and the Demographic Challenge and Ministry of Transport, Mobility and Urban Agenda, 2021)

3.5 Number of Nearly Zero-Energy Buildings (nZEBs) Per Building Sector

The purpose of this indicator is to understand the evolution of building construction towards decarbonization and nearly-zero consumption. There is no national nor regional sources to develop this indicator in the case of Spain, so Table 5 shows an international source.

The variables proposed to develop this indicator are the number of nearly zero-energy buildings (nZEB) per year by building sector (residential and non-residential). At the European Community level, there is an official definition to define what an nZEB is. In the European Union, nZEB means a building that has a very high energy performance, while the nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby (European Parliament and the Council of the European Union 2018). Member States are responsible to define what specifically constitutes an nZEB in their national contexts. In Spain, a nZEB is considered to be a building that complies with the Basic Document on Energy Savings from the Technical Building Code updated on 20 December 2019.

The data found regarding this indicator belong to a finished research project and have not been updated subsequently (Zebra 2020: 2016). Therefore, comprehensive data are lacking, and it is unfeasible to develop this indicator.

Table 5 Sources for indicator Number of nearly zero-energy buildings (nZEBs) per building sector. *Source* own creation

Indicator: Number of nearly zero-energy buildings (nZEBs) per building sector	
Variables	Number of nearly zero-energy buildings per year by building sector – Residential sector – Non-residential sector
Indicator developability	– Data availability: partially available – Processing method from source: direct – Data processability: no
International source	– Zebra 2020-Data Tool
Source link	https://zebra-monitoring.enerdata.net/nzeb-activities/panel-distribution.html
Characteristics of the source	– Availability: open data with limitations – Data collection method: through a research project – Data processability: no – Georeferencing: partially, European maps differentiated by country – Data update frequency/last update: unspecified. The last update was in 2020

3.6 Square Meters of Nearly Zero-Energy Buildings (nZEBs) Per Building Sector

The purpose of this indicator is to understand the evolution of building construction towards decarbonization and near-zero consumption. This indicator measures the surface area, in number of m^2, of nZEBs per year by building sector. However, no sources were found that compile this indicator.

The reader is referred to Sect. 3.5, where further details about the few data available linked to this indicator are given.

4 Conclusions

In this chapter, we proposed indicators to measure the energy characteristics of the national buildings stock in Spain, at national level and regional level to the cases of Aragon and the Basque Country. We studied the sources of information available for the development of these indicators and developed them when data were found. To measure the energy characteristics of buildings, we proposed some indicators. The indicators on annual energy consumption per building type and per end use measure the final annual energy consumption (ktoe). National sources provide information by residential and non-residential buildings, but do not differentiate the type of residential buildings. In addition, they provide information per use (heating, cooling, DHW, kitchen and lighting) in the case of residential building. In the case of the Basque

Country, energy consumption per type of building can be obtained indirectly, but there is no data per end use. In the case of Aragon, there is no data for any of them.

Other proposed indicator is Number of EPCs registered annually by building type and energy class. National data can be obtained from a national source, but it is necessary to consult regional sources to obtain results at this scale. In this case, while Aragon provides open data, the Basque Country only provides data upon express request. In most regions in Spain, such as in the case of Aragon, there are open sources providing the raw data of the EPCs, however, according to Beltran-Velamazan et al. (2024), the EPC information published by the different regions differs both in the data and the format, giving rise to multiple incompatibilities and information gaps.

To know the evolution of the energy performance of buildings towards decarbonization, the last proposed indicators focus on the number and m^2 of nearly zero-energy buildings (nZEBs) per building sector. There are no national or regional sources that collect those data, and only an international source which collects partial data was found.

In conclusion, Spain has sources of information that provide national data on energy consumption and number of EPCs and energy ratings, however, this information can often only be obtained on a national scale and not broken down by region or building characteristics. These data are not processable and are difficult to collect. As for regional sources, the information they provide is heterogeneous. There is no data on nZEB buildings constructed, which is relevant to the country's decarbonization goals.

Acknowledgements This work was funded by the MINISTRY OF SCIENCE AND INNOVATION OF SPAIN, grant number PID2019-104871RB-C21/AEI/10.13039/501100011033 and by GOBIERNO DE ARAGÓN, grant number T37_23R: Built4Life Lab.

References

Ali, U., Shamsi, M.H., Hoare, C., Mangina, E., O´Donnell, J.: Review of urban building energy modeling (UBEM) approaches, methods and tools using qualitative and quantitative analysis. Energy and Buildings. 246, 111073 (2021). https://doi.org/10.1016/j.enbuild.2021.111073

Basque Institute of Statistics: Family housing (2023). https://www.eustat.eus/elementos/ele0011300/viviendas-familiares-de-la-ca-de-euskadi-por-ambitos-territoriales-segun-caracteristicas-estructurales/tbl0011354_c.html, last accessed 2023/09/20.

Beltran-Velamazan, C., Monzón-Chavarrías, M., López-Mesa, B.: A new approach for national-scale Building Energy Models based on Energy Performance Certificates in European countries: the case of Spain. Heliyon 10(3), e25473 (2024). https://doi.org/10.1016/j.heliyon.2024.e25473.

Benz, A., Voelker, C., Daubert, S., Rodehorst, V.: Towards an automated image-based estimation of building age as input for Building Energy Modeling (BEM). Energy and Buildings. 292, 113166 (2023). https://doi.org/10.1016/j.enbuild.2023.113166

Buildings Performance Institute Europe: EUROPE'S BUILDINGS UNDER THE MICROSCOPE. A country-by-country review of the energy performance of buildings. ISBN: 9789491143014 (2011).

Buildings Performance Institute Europe: 97% of buildings in the EU need to be upgraded. Brussels (2017a). https://www.bpie.eu/wp-content/uploads/2017/12/State-of-the-building-stock-briefing_Dic6.pdf, last accessed 2023/09/20.

Byun, J., Baek, J., Shim, J., Park, S., Sona, D.: Proposal of a correction factor for predicting the thermal transmittance of building envelopes in existing buildings accounting for aging and environmental conditions. Buildings and Environment. 243, 110658 (2023). https://doi.org/10.1016/j.buildenv.2023.110658

Council of European Communities: COUNCIL DIRECTIVE 93/76/EEC of 13 September 1993 to limit carbon dioxide emissions by improving energy efficiency (SAVE). Official Journal of the European Union (1993: L 237), 28–30 (1993).

European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. COM(2020) 662 final. Brussels (2020).

European Parliament, Council of the European Union: DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on energy performance of buildings. Official Journal of the European Union (2003: L 1), 65–71 (2003).

European Parliament, the Council of the European Union: DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast). Official Journal of the European Union (2010: L 153), 13–35 (2010).

European Parliament, Council of the European Union: 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. Official Journal of the European Union (2018: L 156), 75–91 (2018).

European Parliament: Energy performance of buildings (recast) Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (COM(2021)0802 – C9–0469/2021 – 2021/0426(COD)). Strasbourg (2023).

Government of Aragon: Registro de Certificación de Eficiencia Energética de Edificios de Aragón. (2023) https://opendata.aragon.es/datos/catalogo/dataset/registro-de-certificacion-de-eficiencia-energetica-de-edificios-de-aragon, last accessed 2023/09/20.

Institute for Energy Diversification and Savings (IDAE): Project Sech-Spahousec. Analyses of the energy consumption of the household sector in Spain. Final report. (2011). https://cros-legacy.ec.europa.eu/system/files/SECH_Spain.pdf, last accessed 2023/09/20.

Institute for Energy Diversification and Savings (IDAE): SPAHOUSEC II: Análisis estadístico del consumo de gas natural en las viviendas principales con calefacción individual. (2019). https://www.idae.es/sites/default/files/documentos/publicaciones_idae/estudio_spahousec-ii_270619.pdf, last accessed 2023/09/20.

Institute for Energy Diversification and Savings (IDAE): Studies, reports and statistics. Statistics and energy balances. (2023). https://www.idae.es/informacion-y-publicaciones/estudios-informes-y-estadisticas, last accessed 2023/09/20.

Johari, F., Peronato, G., Sadeghian, P., Zhao, X., Widén, J.: Urban building energy modeling: State of the art and future prospects. Renewable and Sustainable Energy Reviews, 128, 109902 (2020). https://doi.org/10.1016/j.rser.2020.109902

Loga, T. (ed.), Diefenbacn, N. (ed.), Stein, B. (ed.): Typology Approach for Building Stock Energy Assessment. Main Results of the TABULA project. Final project report. (2012). https://episcope.eu/fileadmin/tabula/public/docs/report/TABULA_FinalReport.pdf, last accessed 2023/09/20.

Ministry for Ecological Transition and the Demographic Challenge, Ministry of Transport, Mobility and Urban Agenda: Estado de la certificación energética de los edificios (10º Informe). (2021). https://energia.gob.es/desarrollo/EficienciaEnergetica/CertificacionEnergetica/Documentos/Documentos%20informativos/2022_Informe-seguimiento.pdf , last accessed 2023/09/20.

Zebra 2020: Data tool. Energy efficiency trends in buildings. (2016). https://zebra-monitoring.enerdata.net/, last accessed 2023/09/20.

Indicators and Data in Spain for an Overview of Deep Renovation of Buildings

Markel Arbulu, Marta Gómez-Gil, Francisco J. González-González, and Almudena Espinosa-Fernández

Abstract Indicators are necessary to measure whether the European Union Member States' long-term renovation strategies deliver the necessary progress towards the transformation of the building stock into a decarbonized one. Deep renovation of buildings has been identified as a key issue to be addressed in the decarbonization of the building sector. In this chapter, we propose progress indicators to measure the evolution in Spain of the deep renovation of buildings following the European Commission recommendations and directives. We also studied the sources of information available in Spain for the development of these indicators and developed them when there were data. This study allowed us to conclude that in this country, there are not enough sources of data to develop an overview of deep renovation of buildings. The consulted data sources do not categorize renovations based on energy savings depth, creating challenges in distinguishing between deep renovations and other types. Moreover, there is a need to centralize data collection to prevent discrepancies among sources.

M. Arbulu
Department of Architecture, University of the Basque Country UPV/EHU, 20018 Donostia-San Sebastian, Spain
e-mail: markel.arbulu@ehu.eus

M. Gómez-Gil · A. Espinosa-Fernández (✉)
Built4Life Lab, University of Zaragoza-I3A, 50018 Zaragoza, Spain
e-mail: almudenaef@unizar.es

M. Gómez-Gil
e-mail: m.gomez@unizar.es

F. J. González-González
Department of Architecture and Civil Engineering, Universidad Europea, Madrid, Spain
e-mail: franciscojavier.gonzalez@universidadeuropea.es

B. López-Mesa and X. Oregi (eds.), *Assessing Progress in Decarbonizing Spain's Building Stock*, Digital Innovations in Architecture, Engineering and Construction,
https://doi.org/10.1007/978-3-031-51829-4_5

1 Introduction

The European Union (EU) has strategically pursued the development of environmental, social, and economic policies and directives that affect buildings. Europe wants to be the first climate-neutral continent in 2050, promoting decarbonization and the transition of the production system, within the Paris Agreement. In December 2019, the European Green Deal was presented, which is the EU strategy to achieve the goal of climate neutrality by 2050. Among the initiatives that make up the Green Deal, Objective 55 proposes the review of directives such as the Energy Performance of Buildings Directive (EPBD) and the Energy Efficiency Directive (EED), as well as the creation of new initiatives, such as the Clean, Affordable and Safe Energy initiative, which includes the Renovation Wave. The strategy´s aim, presented by the European Commission (EC), is for the construction sector to contribute to the objective of carbon neutrality.

It will not be possible to achieve climate neutrality in 2050 without a complete decarbonization of the building sector. If the building sector fails to deliver its share of greenhouse gas (GHG) emission cuts, it will leave a GHG reduction gap of 10 to 14%, i.e., GHG emissions could only be reduced up to 86%-90% below the 1990 level (Buildings Performance Institute Europe 2021b). This gap cannot be filled even if other sectors were fully decarbonized (European insulation Manufacturers Association 2018).

The EU needs to increase both the rate and depth of building renovation. Deep renovation should become the default approach to renovation, accounting for most refurbishment works carried out. The 75% European building stock is energy inefficient (European Commission 2020b) and 95% of the actual building stock will still be standing in 2050 (European Commission 2020c). In Spain, according to data from the latest Spain's National Institute of Statistics (INE) Census, from 2011, 61% of the buildings stock were built before the first thermal conditions regulations of buildings in Spain, 1980. Without a deep renovation of the building stock, the sector will not completely be decarbonized by 2050.

By 2030, the Renovation Wave aims to at least double the annual energy renovation rate, as well as to encourage deep energy renovations (European Commission 2020a). The Buildings Performance Institute Europe (BPIE) calculated that to contribute to the reduction of GHG emissions by at least 55% by 2030, GHG emissions from buildings sector would need to decrease by 60% by 2030 compared to 2015. This means that the deep energy renovation rate renewal should reach 3% per year as soon as possible, even before 2030, and be maintained until 2050. These numbers contrast with the current situation, where the annual average of EU deep energy rate is 0.2%. By 2030, 70% of renovations should be deep (estimating 60–90% energy savings to calculate the impacts of deep renovations on reducing GHG emissions). The remaining 30% of renovation activities should result in a medium depth renovation (Buildings Performance Institute Europe 2020). Overall, all renovation scenarios should consider deep renovations to be the majority.

The Directive 2010/31/EU on energy performance of buildings, and the last version of its on-going revision (which in this book is referred to as 2023 EPBD Proposal recast define the concept of major renovation. A building renovation is considered ‘major’ when either the total cost of the renovation related to the building envelope or the technical systems of the building are greater than 25% of the value of the building, or when more than 25% of the surface of the building envelope is renovated in the process (European Parliament 2010; European Parliament 2023). Both directives give freedom to Member States (MSs) to choose between the two options to establish their own definition.

According to the staff working document accompanying the Commission’s 2013 report on financial support for energy efficiency in buildings, deep renovation can be considered as renovation that leads to significant efficiency improvements, typically exceeding 60% (European Commission 2013).

The Commission Recommendation (EU) 2019/786 (European Commission 2019) indicates that a deep renovation should result in both energy efficiency and greenhouse gas reduction. Furthermore, deep renovations involve refurbishments that reduce both the delivered and final energy consumption of a building by a significant percentage compared to pre-renovation levels, resulting in a very high level of energy performance. The Commission Recommendation also refers to a classification used in the context of the EU Building Stock Observatory (EU BSO) which classifies renovations according to the volume of primary energy savings (light means less than 30%, medium between 30 and 60%, and deep more than 60%) (EU Building Stock Observatory 2013). The Commission recommends that MSs use these categories as indicators in the context of their long-term renovation strategies (LTRSs) when reporting on the transformation of their building stock. The EC also adds that the transformation into nearly zero-energy building (nZEB) could be another indicator (European Commission 2019).

The 2023 EPBD Proposal recast defines deep renovation as a standard of excellence for building renovation and suggests conducting deep renovation in stages to facilitate its implementation. Deep renovation is defined as the renovation that transforms a building or a building unit into nZEB before 2030, or into zero emissions building from 2030. This definition is designed to enhance the energy efficiency of existing buildings. Both terms are important, because deep renovation is considered as a renovation that transforms buildings into nZEB or zero emissions buildings, depending on the deadline, with a long-term view.

The LTRSs for energy renovation in the building sector aim to establish a roadmap to transform the current built stock into a highly energy efficient and decarbonized stock before 2050, in compliance with Directive 2010/31/EU, relating to the energy efficiency of buildings. The 2023 EPBD Proposal recast goes further and sets out national building renovation plans to ensure the renovation of their national building stocks into highly energy efficient and decarbonized buildings by 2050, with the aim of transforming existing buildings into zero emissions buildings.

Spain’s LTRS (better known by its acronym in Spanish ERESEE) includes an analysis of buildings in Spain and future renovation scenarios in the country to decarbonize buildings by 2030. Deep renovation is a concept driven by the goal of climate neutrality by 2050 and the need to prepare buildings for the future. Therefore, in the building analysis metric in Spain, deep renovations are measured either as buildings renovated under the nZEB, zero emissions criterion (European Commission 2023) or with the objective of reducing final energy consumption more than 60% (European Commission 2019). The ERESEE is based on these three indicators to categorize the current analysis of the building and future refurbishment scenarios on a national scale.

BUILD UPON^2 (Green Building Council Spain 2021), a project funded by the EU within the framework of the Horizon 2020 program, addressed one of the priority issues in relation to the building energy renovation, the adequate monitoring of its impact and benefits. BUILD UPON^2 proposed a framework of indicators to make it easier for local governments to measure the benefits of building renovation through thirteen common indicators at the European scale and 4 additional indicators at the national scale in Spain. One of the common proposed indicators is the energy renovation rate (Green Building Council Spain 2021).

BUILD UPON^2's framework defines energy renovation rate as the percentage of the building stock that undergoes energy renovation per year (Green Building Council Spain 2021). The calculation methodology proposes a percentage breakdown according to deep energy renovation. In this case, deep renovation is considered to be that which achieves a reduction of more than 60%, using as reference the Commission Recommendation (EU) 2019/786, on the renovation of buildings, referred as to 2019 EPBD-based Recommendation in this book.

The ERESEE also indicates that, in an energy renovation, the order in which the actions are carried out has a great importance in the results. In the useful life of a building there is a time when energy costs make it profitable to deeply renovate the building, achieving a reduction in consumption that can reach 80% of the initial consumption. This does not imply that no other intervention is carried out until that moment. On the contrary, the identification of this critical moment should be the starting point to consider the opportunity to advance certain actions to improve energy efficiency and assess their consequences, as well as to take advantage of the opportunities and synergies offered by other interventions.

Deep renovation for reasons of energy efficiency is also an excellent opportunity to address other aspects, such as the living conditions of vulnerable households, increasing resilience to climate change, fire safety, the elimination of harmful substances and accessibility for people with disabilities (Lynn et al. 2021).

This chapter aims to develop indicators to measure the status of deep renovation in European countries, which will contribute to measure the effectiveness of building renovation policies and the progress of decarbonization. The indicators will be developed for Spain as case study. This will also allow us to draw conclusions about its evolution in this country.

2 Methodology

To develop the indicators that allow an overview of deep renovation of buildings we followed the methodology shown in Fig. 1.

The first step consisted in the development of a common template for these indicators based on the following scheme:

- Indicator:
  - Definition of the indicator.
  - Variables to quantify it and their unit of measurement.
  - Purpose and advantages of implementing this indicator.
  - Alignment of the indicator with the directives, agendas, action plans and strategies, covering the European and international, national, and regional scales.
  - Relationship of this indicator with other similar ones.
- Information sources:

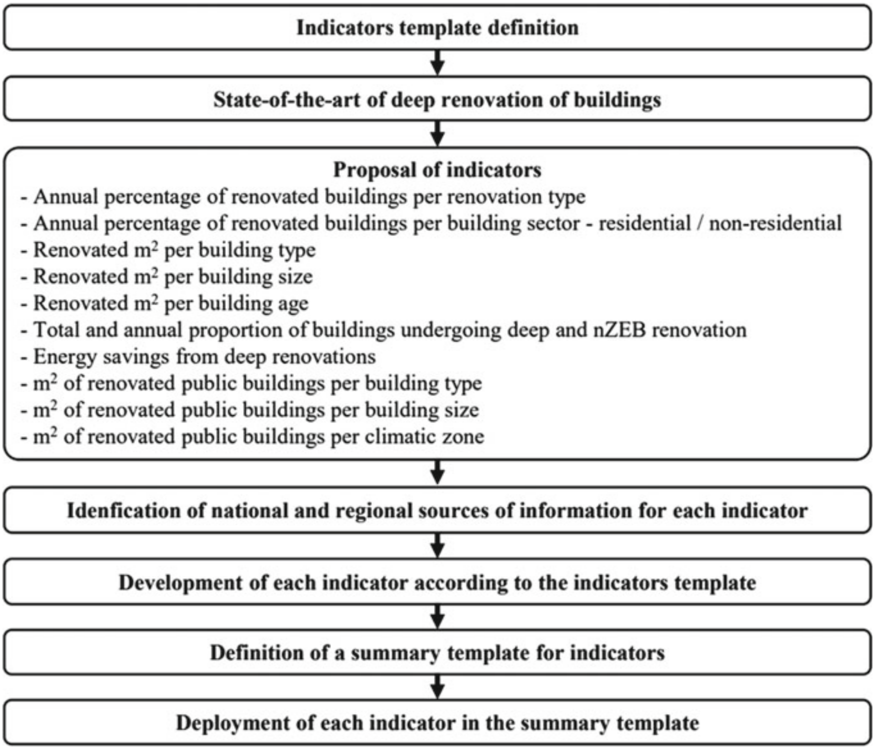


Fig. 1 Methodology implemented to generate indicators on deep renovation of buildings in Spain and two of its regions. *Source* own creation

- Availability of information to generate this indicator at different scales.
- Entity responsible for providing this information.

- Measurement:
  - Measurement method.
  - Methodology.
  - Current possibilities of obtaining it.
  - Information necessary to generate it.
  - Availability and quality of data.

In order to select the deep renovation of buildings indicators to develop, we considered the indicators which have been suggested in European directives and related documents. For this study, we considered two documents. On one hand, we studied the indicators included in the 2019 EPBD-related Recommendation (European Commission 2019), which was the first document in which a framework of progress indicators to measure the European building stock decarbonization was proposed. On the other hand, we analyzed the indicators included in the 2023 EPBD Proposal recast, which is the document with the last version of the framework of progress indicators. In Table 1, the indicators in both documents for deep renovation of buildings can be seen.

The proposed indicators are grouped into two blocks related to renovation rates and policies and actions. As can be seen in Table 1, in the 2019 EPBD-related Recommendation there is the same number of renovation rates indicators than in the 2023 EPBD Proposal recast. They are not exactly the same but quite similar changing only units and ways of grouping the information. For example, the 2019 EPBD-related Recommendation includes indicator named in Table 1 as S1, measured in percentage, which is split into two indicators in the 2023 EPBD Proposal recast (S1a, S1b in Table 1), which are measured in number and total floor area. The indicators within policies and actions are different in the 2019 EPBD-related Recommendation and the 2023 EPBD Proposal recast, however, in both cases they focus on the promotion of deep renovation (P1, P2, P6) and the improvement of public buildings (P3–P5, P7).

Given the similarities between the two sets of indicators and that the indicators in the 2023 EPBD Proposal recast are not yet definitive, we decided to further study the indicators in the 2019 EPBD-based Recommendation. Thus, the following indicators were proposed for development:

- Annual percentage of renovated buildings per renovation type.
- Annual percentage of renovated buildings per building sector—residential/non-residential.
- Renovated m^2 per building type.
- Renovated m^2 per building size.
- Renovated m^2 per building age.
- Total and annual proportion of buildings undergoing deep and nZEB renovation.
- Energy savings from deep renovations.
- Square meters (m^2) of renovated public buildings per building type.

Table 1 Deep renovation of buildings indicators included in selected European directive and related document. *Source* own creation from data in (European Commission 2019) (European Parliament 2023)

Document	Renovation rates	Policies and actions
2019 EPBD-related Recommendation	– S1. Annual percentage of renovated buildings per renovation type – S2. Annual percentage of renovated buildings per building sector—residential/non-residential – S3. Renovated m^2 per building type – S4. Renovated m^2 per building size – S5. Renovated m^2 per building age	– P1. Total and annual proportion of buildings undergoing deep and nZEB renovation – P2. Energy savings from deep renovations – P3. m^2 of renovated public buildings per building type – P4. m^2 of renovated public buildings per building size – P5. m^2 of renovated public buildings per climatic zone
2023 EPBD Proposal recast	– S1a. Annual renovation rates: number and total floor area (m^2) per renovation depth (weighted average renovation) – S1b. Annual renovation rates: number and total floor area (m^2) of deep renovations – S3. Annual renovation rates: number and total floor area (m^2) per building type – S6. Annual renovation rates: number and total floor area (m^2) to nearly zero-energy building levels – S7. Annual renovation rates: number and total floor area (m^2) of public buildings	– P6. Policies and measures with regard to the promotion of deep renovation of buildings, including staged deep renovation – P7. Policies and measures with regard to the improvement of buildings owned by public bodies

- Square meters (m^2) of renovated public buildings per building size.
- Square meters (m^2) of renovated public buildings per climatic zone.

These indicators cover the aspects related to the renovation rates and policies and actions. Once the key indicators to cover this topic were identified, the available sources of information were studied. Since in Spain a good deal of the promotion and aid management of building renovation is delegated to regions, we used as regional case studies the regions of Aragon and the Basque Country. The previously defined indicator template was used to develop each indicator.

For the sake of transmitting all the information of each indicator in a user-friendly way, we also developed a summary template, which was used to deploy in a summarized way the information we got for each indicator.

3 Indicators

3.1 Annual Percentage of Renovated Buildings Per Renovation Type

The purpose of this indicator is to compile the available data on the percentage of renovated buildings, which can be used to analyze the rate at which renovations are carried out and the corresponding trend, with a view to meeting the decarbonization targets for building stock in 2030, 2040 and 2050. The sources of information to develop this indicator in Spain are national and regional (Table 2).

Data on annual percentage of renovated buildings per renovation type is not published directly by any institution. Data to calculate the indicator can be found in the above-mentioned sources (Table 2). The proportion of buildings renovated each year per renovation type in relation to the total building stock is calculated based on the number of existing buildings and the number of renovated buildings.

The indicator is developed at the national scale below, showing the number of existing buildings according to the 2011 INE census and the data on municipal building permits collected from the Ministry of Transport, Mobility and Urban Agenda (Fig. 2). Among the proposed variables (Table 2), the most important one (deep renovation) cannot be developed since the data sources do not distinguish between different levels of energy depth of renovations.

It should be noted that there is a difference in the trend shown by the data obtained from building permits (this indicator) and construction permits (next indicator) at the national scale but not at the regional scale. According to the building permits, the national trend in renovations is downwards since 2017; however, there is an upward trend for the same period according to construction permits.

It is not possible to develop the indicator at a scale other than the national scale, as data disaggregated by type of renovation is non-available. Only the data provided by the same sources as in the previous case can be used to analyze the annual percentage of fully renovated buildings (Fig. 3).

3.2 Annual Percentage of Renovated Buildings Per Building Sector—Residential/Non-residential

The purpose of this indicator is to compile the available data on the percentage of buildings renovated, depending on whether they are residential or non-residential, to analyze the rate at which renovations are carried out and the corresponding trend, with a view to meeting the decarbonization targets for building stock in 2030, 2040 and 2050. It is important to know the percentage of renovation works per building sector, as residential and non-residential buildings have very different characteristics that require a different approach when planning renovation processes. On the

Table 2 Sources for indicator Annual percentage of renovated buildings per renovation type. *Source* own creation

Indicator: Annual percentage of renovated buildings per renovation type	
Variables	Annual percentage of buildings renovated (%) according to the type of intervention carried out: – Deep renovation – Foundations renovated – Roofs renovated – Commercial venues renovated
Indicator developability	– Data availability: partially available – Processing method from source: indirect – Data processability: yes
National source	Spain's National Institute of Statistics (INE)
Link	https://www.ine.es/jaxiPx/Tabla.htm?path=/t20/e244/edificios/p03/l0/&file=01001.px&L=1 https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/e244/edificios/p04/&file=pcaxis&L=0
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes – Georeferencing: not applicable – Data update frequency/last update: updated every ten years. Last update in 2021
National source	Ministry of Transport, Mobility and Urban Agenda (MITMA)
Link	https://apps.fomento.gob.es/BoletinOnline/?nivel=2&orden=10000000
Characteristics of the source	– Availability: open data – Data collection method: collection of the number of building – permits through administrative surveys of municipalities – Data processability: yes Georeferencing: not applicable – Data update frequency/last update: updated monthly, but with a delay of approximately one year
Regional source—Aragon	Aragon Institute of Statistics (IAEST)

(continued)

Table 2 (continued)

Indicator: Annual percentage of renovated buildings per renovation type	
Link	https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/03/02010301/030090TP&Action=Navigate&Options=df&NQUser=granpublico&NQPassword=granpublic https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/03/02010301/030090TC&Action=Navigate&Options=df&NQUser=granpublico&NQPassword=granpublic https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/03/02010301/030090TM&Action=Navigate&Options=df&P0=1&P1=eq&P2=Territorio.%22Provincia%20codigo%22&P3=&NQUser=granpublico&NQPassword=granpublico https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/01/010026TM&Action=Navigate&Options=df&NQUser=granpublico&NQPassword=granpublico
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes – Georeferencing: not applicable – Data update frequency/last update: Census is updated every ten years whereas data on municipal building permits collected by the IAEST are updated for each year with a delay of approximately one year. Last update in 2021
Regional source—The Basque Country	Basque Institute of Statistics (EUSTAT)
Link	https://www.eustat.eus/elementos/ele0016000/edificios-de-viviendas-de-la-ca-de-euskadi-por-ambitos-territoriales-por-ano-de-construccion-del-edificio/tbl0016035_c.html https://www.eustat.eus/elementos/ele0011100/edificios-de-viviendas-de-la-ca-de-euskadi-por-ambitos-territoriales-por-ano-de-construccion-del-edificio/tbl0011180_c.html
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes – Georeferencing: not applicable – Data update frequency/last update: unspecified. The most up-to-date data from the Eustat correspond to November 2016

one hand, the diversity of non-residential buildings requires practically case-by-case approaches. On the other hand, it is easier to establish clusters or similar groups of buildings in the residential sector, although different issues arise such as those related to horizontal property. It is important to take these issues into account when designing renovation strategies and public policies.

The sources of information to develop this indicator in Spain are national and regional. The indicator for the national level and for the region of Aragon indicator

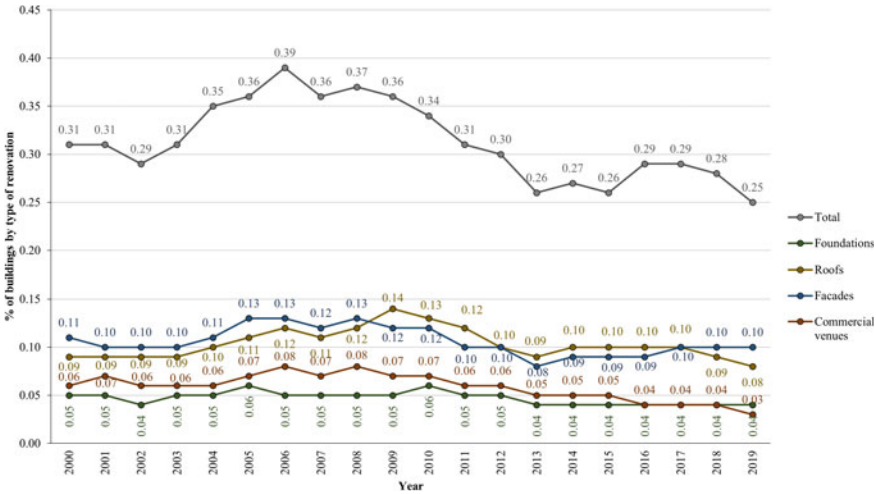


Fig. 2 Annual percentage of buildings renovated according to the type of intervention carried out in Spain, between 2000 and 2019. *Source* own creation from data in (Ministry of Transport, Mobility and Urban Agenda 2023a)

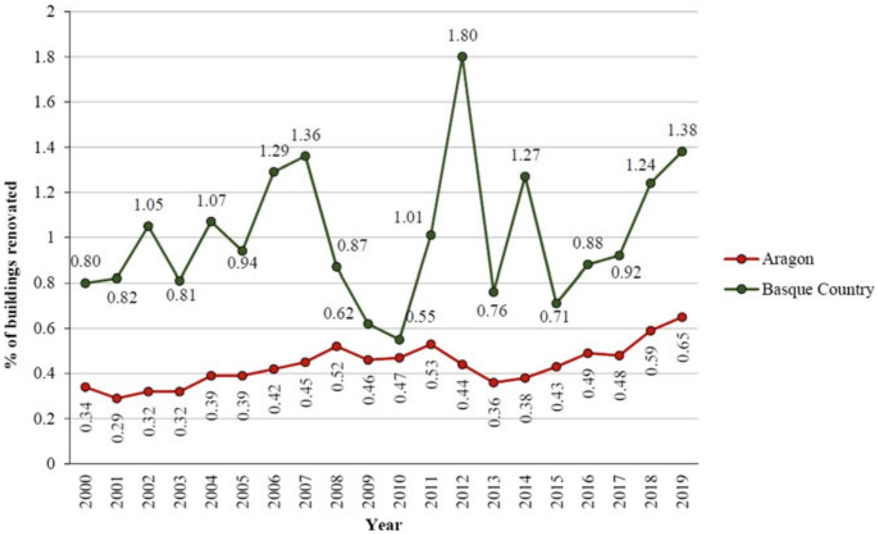


Fig. 3 Annual percentage of buildings renovated in the regions of Aragon and Basque Country (both of them in Spain), from 2000 to 2019. *Source* own creation from data in (Aragon Institute of Statistics 2021) (Basque Institute of Statistics, 2016a)

is developed with national information sources. The Basque Country's sources of information only allow the development of this indicator for the residential building (Table 3).

Data on annual percentage of renovated buildings per building sector (residential/ non-residential) are not directly published by any institution, but the data required to calculate the indicator are available. The proportion of buildings renovated each year in relation to the total building stock is calculated based on the number of existing building and the number of each type of construction permit building renovations or refurbishments granted each year.

The data available in the sources cited above were sufficient for the elaboration of Fig. 4, according to the method previously described. A chart of this indicator at the national scale is displayed below, distinguishing between the residential and non-residential sector (Fig. 4).

Three sources of information were used to obtain national and Aragon total number of existing buildings: Spain's National Institute of Statistics (INE), Ministry of Transport, Mobility and Urban Agenda (MITMA) and Ministry of Finance and Civil Service (MHAP). Data obtained from the three sources differs from 4 to 11%.

For national annual percentage of residential renovated buildings, this variation in sources of information is reflected in annual percentage (Fig. 4). The trend of the renovation rate (%) is the same for the data obtained in the three information sources. From 2006 to 2010 the rate increases between 8 and 13% depending on the source of information. From 2010 to 2012, renovation rate decreases between 29 and 43% according to the source of information. The period 2012–2022 shows a slight increase in the first three years and then remains stable until 2018. The average value of the annual percentage of residential renovated buildings, between 2012 and 2022, ranges between 0.095% and 0.10% depending on the source of information.

National annual percentage of renovated non-residential buildings overall trend is very similar to the behavior of the national residential renovated rate. From 2006 to 2009 the annual percentage remains stable at 0.08%. Between 2009 and 2012 the renovated rate decreased by 52% and starting in 2012, it increases and decreases slightly. The average value of the national annual percentage of non-residential renovated buildings was 0.047% between 2012 and 2022.

The same happens to data produced at the regional scale for the case of Aragon (Fig. 5). For Aragon annual percentage of residential renovated buildings, the variation in sources of information is reflected in annual percentage. The data obtained from the three sources of information differs from 3 to 7%. The trend of the renovation rate (%) is the same for the three information sources. From 2006 to 2010 the rate increases between 5 and 10% depending on the source of information. From 2010 to 2012, renovation rate decreases between 44 and 45% according to the source of information. The period 2012–2022 shows a slight increase in the first five years. The average value of the annual percentage of residential renovated buildings, between 2012 and 2022, ranges between 0.094% and 0.095%5 depending on the source of information.

Aragon annual percentage of renovated non-residential buildings overall trend is very similar to the behavior of the Aragon residential renovated rate. From 2006 to

Table 3 Sources for indicator Annual percentage of renovated buildings per building sector—residential/non-residential. *Source* own creation

Indicator: Annual percentage of renovated buildings per building sector—residential/non-residential	
Variables	Annual percentage of buildings renovated (%) according to the type of building: – Residential sector – Non-residential sector
Indicator developability	– Data availability: fully available for Spain and Aragon. Partially for Basque Country – Processing method from source: indirect – Data processability: yes
National source	Spain's National Institute of Statistics (INE)
Link	https://www.ine.es/censo/es/seleccion_ambito.jsp https://www.ine.es/censos2011/tablas/Inicio.do https://www.ine.es/Censo2021/Inicio.do
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes – Georeferencing: not applicable – Data update frequency/last update: updated every ten years. Last update in 2021
National source	Ministry of Transport, Mobility and Urban Agenda (MITMA)
Link	https://apps.fomento.gob.es/BoletinOnline2/?nivel=2&orden=33000000 https://apps.fomento.gob.es/BoletinOnline/?nivel=2&orden=09000000
Characteristics of the source	– Availability: open data – Data collection method: information collected through forms that Quantity Surveyors and Technical Architects fill in at professional associations to approve construction permits and obtain end-of-construction certifications – Data processability: yes – Georeferencing: not applicable – Data update frequency / last update: updated monthly, but with a delay of approximately one year
Regional source—The Basque Country	Basque Institute of Statistics (EUSTAT)
Link	https://www.eustat.eus/estadisticas/opt_0/id_All/temalista.html
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes – Georeferencing: not applicable – Data update frequency/last update: updated every five years

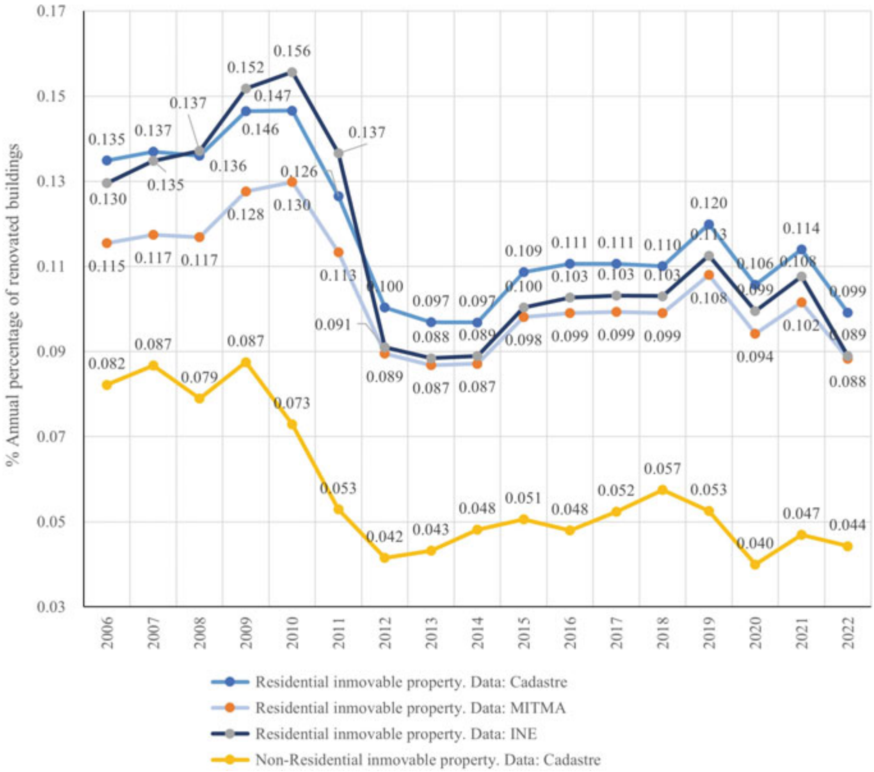


Fig. 4 Annual percentage of renovated buildings according to the type of building: residential or non-residential in Spain, from 2006 to 2022. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics, 2011; 2021), using open data from the MITMA website: (Ministry of Transport, Mobility and Urban Agenda, 2023b; 2023c), and from (Ministry of Finance and Civil Service, 2023)

2009 the annual percentage increases by 36%. Between 2009 and 2012 the renovated rate decreased by 43%. The average value of the Aragon annual percentage of non-residential renovated buildings is 0.075% between 2012 and 2022. In the period 2007–2009, non-residential renovated rate was higher than residential renovated rate.

In National and Aragon annual percentage of renovated buildings (residential and non-residential), it was not possible to obtain data prior to 2006 because they are unavailable in the cadaster.

Three sources of information were used to obtain Basque Country total number of existing buildings: Spain's National Institute of Statistics (INE), Ministry of Transport, Mobility and Urban Agenda (MITMA) and Basque Institute of Statistics (EUSTAT). Data obtained from the three sources differs from 1 to 6%.

In the case of the Basque Country, annual percentage of residential renovated buildings, this variation in sources of information is reflected in annual percentage

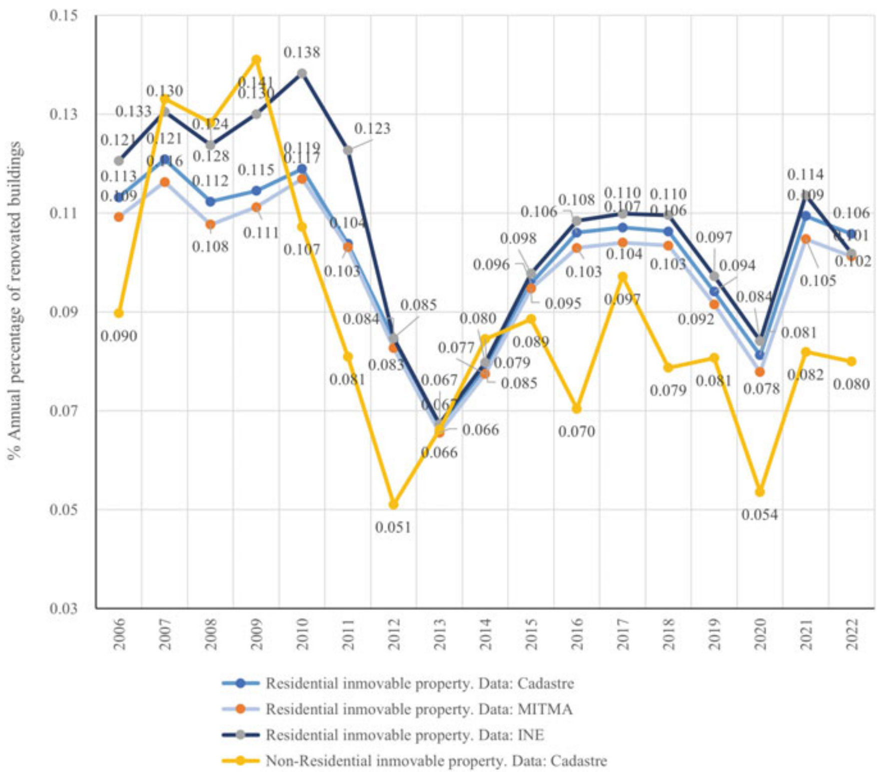


Fig. 5 Annual percentage of buildings renovated according to the type of building: residential or non-residential in the region of Aragon (Spain) from 2006 to 2022. *Source*: own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011; 2021), using open data from the MITMA website: (Ministry of Transport, Mobility and Urban Agenda 2023b; 2023c), and from (Ministry of Finance and Civil Service 2023)

(Fig. 6). The trend of the renovation rate (%) is the same for the data obtained in the three information sources. From 2006 to 2018 the rate decreases between 61 and 64% depending on the source of information. From 2018 to 2021, renovation rate increases between 48 and 51% depending on the source of information. The period 2021–2022 shows a slight decrease. No sources were found that compile annual percentage of non-residential buildings renovated in the Basque Country.

3.3 *Renovated m^2 Per Building Type*

The purpose of this indicator is to quantify the renovated surface area of each type of building to analyze the rate at which renovations are carried out and to establish strategies and roadmaps to achieve the targets set.

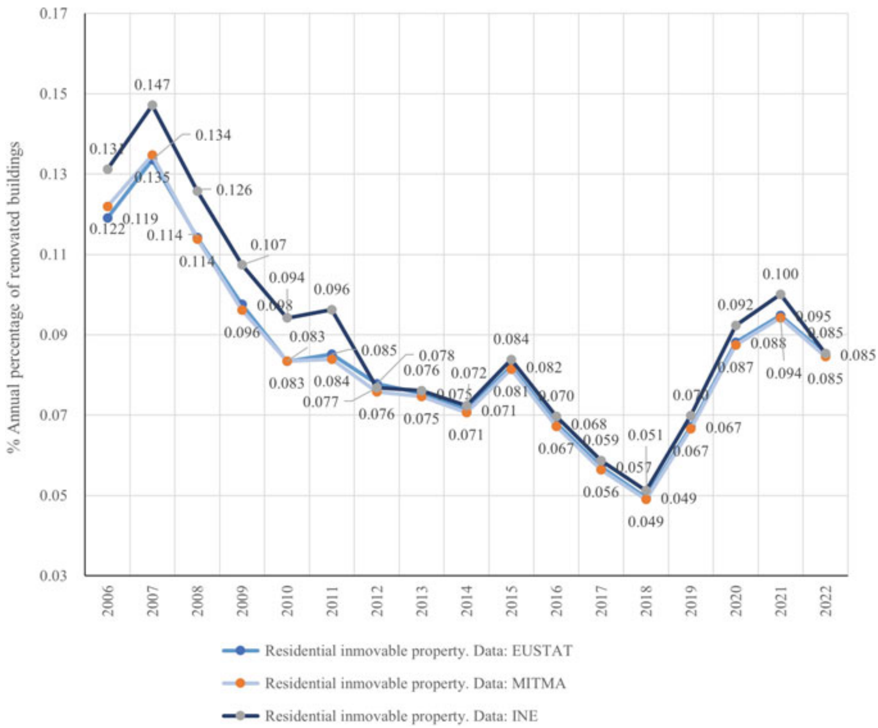


Fig. 6 Annual percentage of buildings renovated according to the type of building: residential or non-residential in the Basque Country (Spain) from 2006 to 2022. *Source* own creation from data in (Basque Institute of Statistics 2016b), using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011; 2021), and using open data from the MITMA website: (Ministry of Transport, Mobility and Urban Agenda 2023c)

No entities were identified that compile this indicator or provide data that could be used to calculate it (Table 4). The Ministry of Transport, Mobility and the Urban Agenda publishes statistics on municipal building permits and construction permits, which provide data on renovation activities. However, the information collected is not sufficient to compile the indicator. The data on renovated surface area from building permits are not broken down by type of building and are non-available at the regional or provincial scale. Furthermore, while construction permits classify buildings as residential or non-residential, they do not provide the renovated surface area, only the number of renovated buildings (Figs. 8, 9 and 10).

Although not requested in this indicator, it is interesting to point out that it is possible to collect data on the intervened building area over the last two decades based on data from municipal building permits, compiled by the Ministry of Transport, Mobility and Urban Agenda. This information is broken down into full renovations, extensions, and emptying activities (Fig. 7).

Table 4 Variables and indicator developability for indicator Renovated m^2 per building type indicator. *Source* own creation

Indicator: Renovated m^2 per building type	
Variables	The variables that this indicator should at least include are: – Number of m^2 renovated by use and typology for residential use: • Single-family building • Multi-family building • Other residential purposes – Number of m^2 renovated for non-residential use Given the previous variables cannot be developed, alternative variables considered are: -Number of m^2 intervened: • Extension • Emptying activities • Renovation
Indicator developability	– Data on partially aligned indicators: – Data availability: non-available – Processing method from source: not applicable for the necessary— variables. For alternative variables the method is indirect – Data processability: not applicable for the necessary variables. For alternative variables data are processable
National source	Ministry of Transport, Mobility and Urban Agenda (MITMA)
Link	https://apps.fomento.gob.es/BoletinOnline/?nivel=2&orden=10000000
Characteristics of the source	– Availability: open data – Data collection method: statistics on municipal building permits and construction permits, which provide data on renovation activities – Data processability: yes – Georeferencing: no – Data update frequency/last update: updated monthly, but with a delay of approximately one year

The number of total residential and non-residential buildings renovated from 1992 to 2020 is displayed in the charts below, based on the construction permits as compiled by the Ministry of Transport, Mobility and Urban Agenda. This data aligns with this indicator, as it disaggregates renovations by building type, but it is not identical as it does not include surface area, only the number of buildings. National data are represented in Fig. 8, regional data for Aragon, in Fig. 9 and Basque Country's data in Fig. 10.

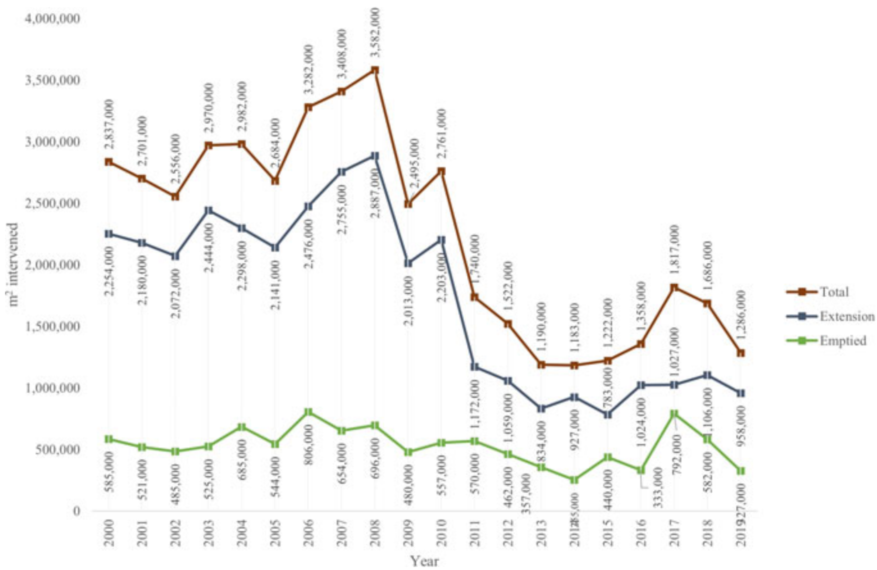


Fig. 7 Number of m^2 intervened per type of intervention: extension, emptying activities and total including the previous ones plus renovations in Spain, from 2000 to 2019. *Source* own creation using open data from the MITMA website: www.mitma.es (Ministry of Transport, Mobility and Urban Agenda 2023a)

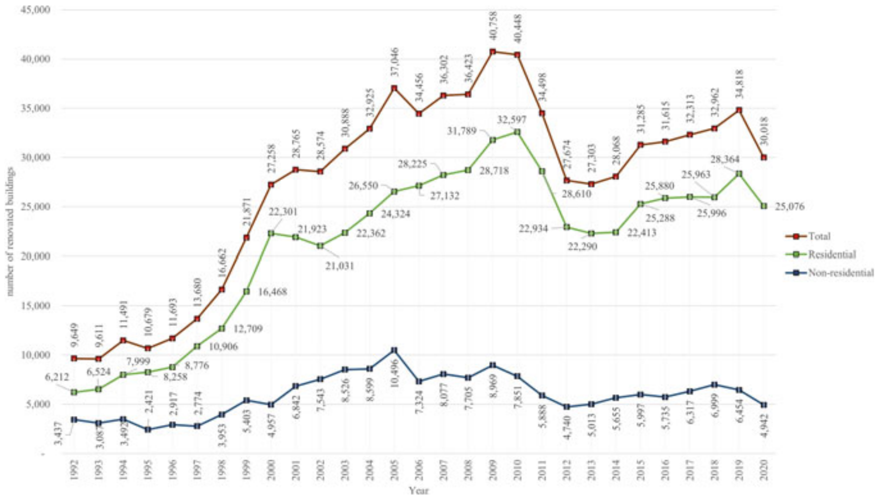


Fig. 8 Number of buildings renovated per sector in Spain, from 1992 to 2020. *Source* own creation using open data from the MITMA website: www.mitma.es (Ministry of Transport, Mobility and Urban Agenda 2023a)

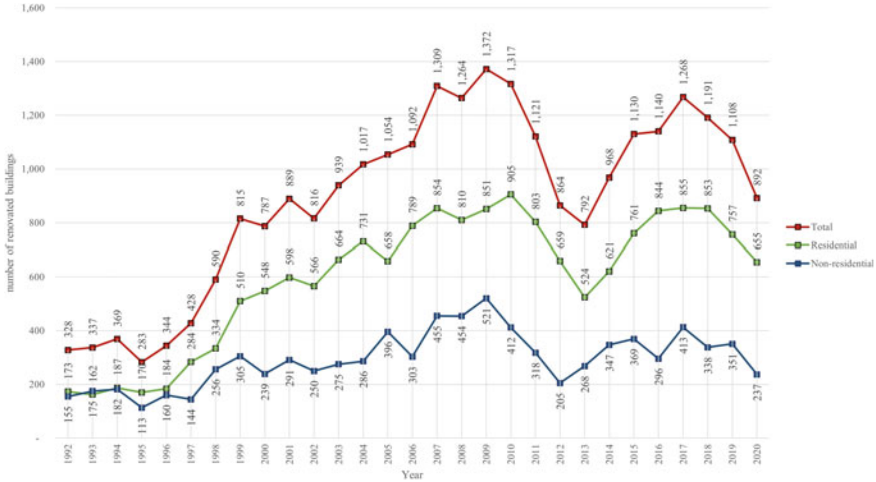


Fig. 9 Number of buildings renovated per sector in the region of Aragon (Spain) from 1992 to 2020. *Source* own creation using open data from the MITMA website: www.mitma.es (Ministry of Transport, Mobility and Urban Agenda 2023a)

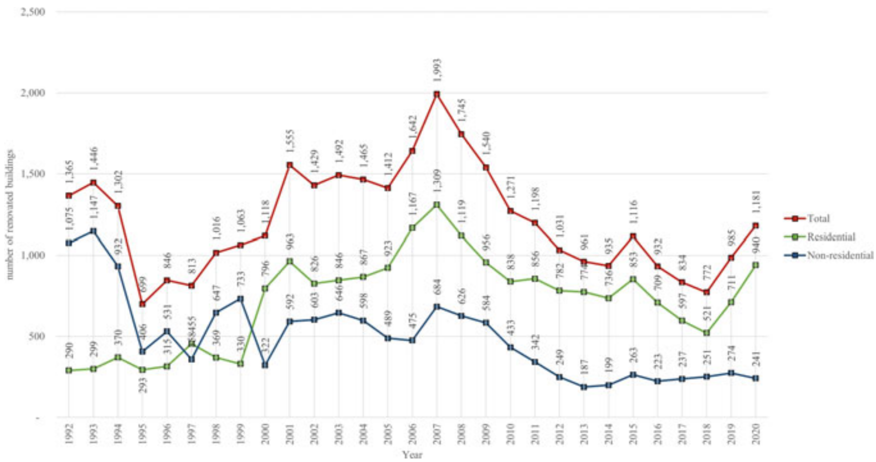


Fig. 10 Number of buildings renovated per sector in the Basque Country (Spain) from 1992 to 2020. *Source* own creation using open data from the MITMA website: www.mitma.es (Ministry of Transport, Mobility and Urban Agenda 2023a)

3.4 Renovated m² Per Building Size

The purpose of this indicator is to quantify the renovated surface area of each type of building based on building size to analyze the rate at which renovations are carried

Table 5 Sources for indicator Renovated m^2 per building size. *Source* own creation

Indicator: Renovated m^2 per building size	
Variables	Number of m^2 renovated according to the number of properties in residential buildings or their area in the case of non-residential buildings: – 1 property – 2 properties – 3 properties – 4 properties – 6 to 9 properties – 10 to 19 properties – 20 to 29 properties – 30 to 39 properties – 40 or more properties
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

out and to establish strategies and roadmaps to achieve the targets set. No sources were found that compile this indicator (Table 5).

3.5 Renovated m^2 Per Building Age

The purpose of this indicator is to quantify the renovated surface area of each age group of buildings to analyze the rate at which renovations are carried out and to establish strategies and roadmaps to achieve the targets set. The classification according to age is important, as age is a determining factor in the energy performance of buildings. However, no sources were found that compile this indicator (Table 6).

3.6 Total and Annual Proportion of Buildings Undergoing Deep and nZEB Renovation

The purpose of this indicator is to know the percentage of major renovation interventions or actions to reach the deep renovation or nearly zero-energy building (nZEB) standard. This would make it possible to compare the current percentages with the values recommended by the EC in order to meet the decarbonization targets for the building stock by 2050. The sources of information to develop this indicator in Spain are international, national, and regional (Table 7) for one of the variables considered: percentage of buildings subject to major renovation that reach the nZEB standard in total and on an annual basis. For the variable regarding deep renovation standard there are no sources available to fully develop the indicator.

Table 6 Sources for indicator Renovated m^2 per building age. *Source* own creation

Indicator: Renovated m^2 per building age	
Variables	Renovated surface area, in m^2, broken down by building age: – < 1900 – 1900–1920 – 1921–1940 – 1941–1950 – 1951–1960 – 1961–1970 – 1971–1980 – 1981–1990 – 1991–2001 – 2002–2011 – > 2011
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

The annual percentage of buildings subject to major and nZEB renovation can only be found directly in one of the sources, the Zebra2020 platform, although only for the year 2014 and on a national scale. For the remaining years, the number of buildings in which these types of interventions are undertaken should be collected year by year and the proportion of these buildings compared to the total building stock should be calculated using the sources indicated in Table 7. However, the data on the number of nZEB renovations in Spain is non-available, and therefore the indicator cannot be developed.

On the other hand, while it is slightly outside the scope of this indicator, it is worth mentioning that the number of dwellings in which comprehensive renovations are carried out can be partially compiled for some regions included in the State Housing Plan 2013–2017 (Rubio del Val et al. 2020).

3.7 Energy Savings from Deep Renovations

The purpose of this indicator is to know the amount of energy saved through deep renovations of the building stock. This is important for planning policies and strategies to decarbonize the housing stock to meet the 2050 targets. No sources were found that compile this indicator (Table 8).

Table 7 Sources for indicator Total and annual proportion of buildings undergoing deep and nZEB renovation. *Source* own creation

Indicator: Total and annual proportion of buildings undergoing deep and nZEB renovation	
Variables	– Percentage of buildings subject to major renovation that reach the deep renovation standard in total and on an annual basis – Percentage of buildings subject to major renovation that reach the nearly zero-energy building standard in total and on an annual basis
Indicator developability	– Data availability: partially available – Processing method from source: direct from the Zebra 2020 project viewer. Data correspond only to 2014 – Data processability: yes, data in XLS format
International source	Zebra 2020 project viewer
Link	https://zebra-monitoring.enerdata.net/nzeb-activities/nzeb-definitions-by-country.html
Characteristics of the source	– Availability: partially open data – Data collection method: not specified – Data processability: yes, data available in XLS format – Georeferencing: only cartographic viewer – Data update frequency/last update: data from 2014, not updates expected
National source	Spain's National Institute of Statistics (INE)
Link	https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/edificios/p03/l0/&file=01001.px&L=0 https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/e244/edificios/p04/&file=pcaxis&L=0
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, data in CSV, XLS, Json, plain text, PDF, PPT formats – Georeferencing: no – Data update frequency/last update: decennial. Last update November 2011
Regional source—Aragon	Aragon Institute of Statistics (IAEST)
Link	https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/01/010023TP&Action=Navigate&Options=df&NQUser=granpublico&NQPassword=granpublico https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/01/010023TC&Action=Navigate&Options=df&NQUser=granpublico&NQPassword=granpublico https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/01/010023TM&Action=Navigate&Options=df&P0=1&P1=eq&P2=%22Territorio%22.%22Provincia%20codigo%22&P3=&NQUser=granpublico&NQPassword=granpublico

(continued)

Table 7 (continued)

Indicator: Total and annual proportion of buildings undergoing deep and nZEB renovation	
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, data in CSV, XLS, Json, plain text, PDF, PPT formats – Georeferencing: no – Data update frequency/last update: not specified. Last update in 2019
Regional source—The Basque Country	Basque Institute of Statistics (EUSTAT)
Link	https://www.eustat.eus/elementos/ele0018900/edificios-de-la-ca-de-euskadi-por-ambitos-territoriales-segun-tipo-de-edificio-p/tbl0018925_c.html
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, data in CSV, XLS, Json, plain text, PDF, PPT formats – Georeferencing: no – Data update frequency/last update: decennial. Last update in June 2021

Table 8 Sources for indicator energy savings from deep renovations. *Source* own creation

Indicator: Energy savings from deep renovations	
Variables	Savings in energy demand and/or consumption (kWh per year/kWh/m^2, ktoe (cumulative final energy savings)) achieved through deep renovation interventions. There are no variables to this indicator
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

3.8 Square Meters of Renovated Public Buildings Per Building Type

The purpose of this indicator is to monitor the surface of national and local public building renovations. This information aids in prioritizing and allocating resources based on the size and type of public buildings. No sources were found that compile this indicator (Table 9).

Table 9 Sources for indicator m^2 of renovated public buildings per building type. *Source* own creation

Indicator: m^2 of renovated public buildings per building type	
Variables	Renovated surface area (m^2) of public buildings, classified according to building type: – Administrative buildings – Educational buildings – Welfare buildings – Sports buildings – Healthcare buildings – Cultural buildings – Public service buildings – Other buildings
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

3.9 Square Meters of Renovated Public Buildings Per Building Size

The purpose of this indicator is to monitor national and local public building renovations depending on the building size. This information helps ensure that renovation efforts are proportionate to the actual size of the buildings. No sources were found that compile this indicator (Table 10).

Table 10 Sources for indicator m^2 of renovated public buildings per building size. *Source* own creation

Indicator: m^2 of renovated public buildings per building size	
Variables	Renovated surface area (m^2) of public buildings, classified according to building size: – Buildings up to 500 m^2 – Buildings between 500 and 3 500 m^2 – Buildings between 3 500 and 9 000 m^2 – Buildings between 9 000 and 25 000 m^2 – Buildings between 25 000 and 50 000 m^2 – Buildings over 50 000 m^2
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

Table 11 Sources for indicator m^2 of renovated public buildings per climate zone. *Source* own creation

Indicator: m^2 of renovated public buildings per climate zone	
Variables	Renovated surface area (m^2) of public buildings, classified according to the climate zone in which they are located: – Winter Climate Severity (SCI): A, B, C, D, E, α – Summer Climate Severity (SCV): 1, 2, 3, 4
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

3.10 Square Meters (m^2) of Renovated Public Buildings Per Climatic Zone

The purpose of this indicator is monitoring national and local public building renovations depending on the climate zone in which they are situated. Climate directly influences the comfort and well-being of building occupants. By monitoring renovations per climatic zone, authorities can assess whether renovations are being carried out across all climate zones and especially in the most severe climates. No sources were found that compile this indicator (Table 11).

4 Conclusions

In this chapter, we proposed indicators designed to assess the progress of deep building renovations in Spain. We examined the available sources of information in Spain essential for developing these indicators and constructed them whenever pertinent data were available.

For the overview of the national building stock about deep renovation we studied five indicators: (a) Annual percentage of renovated buildings per renovation type; (b) Annual percentage of renovated buildings per building sector—residential/non-residential; (c) Renovated m^2 per building type; (d) Renovated m^2 per building size; (e) Renovated m^2 per building age.

No published data were found that can be used to compile the indicator renovated m^2 per building type, size, and age. Data partially aligned with the indicator renovated m^2 per building type are available, but they do not allow for its full development.

Classifying the annual percentage of renovated buildings according to the type of renovation also provides an insight into the relative weight of energy efficiency in these processes, which is usually much lower than renovations focused on accessibility or conservation. The Ministry of Transport, Mobility and Urban Agenda publishes data disaggregated by type of renovation at national scale only, meaning the indicator cannot be fully developed at lower scales, such as regional or local.

Furthermore, the variables into which the data are classified do not allow a distinction to be made between light, medium and deep renovations, what is a necessary distinction to be made in the future in line with the EC's decarbonization goals.

Moreover, the fact that the data on municipal building permits are collected monthly and annually and the data on existing buildings are collected by the censuses on a ten-yearly basis (five-yearly in the case of EUSTAT) leads to inaccuracies in the calculations, as the annual variation in the number of buildings is not reflected, influencing the results.

Sources such as the IAEST have mentioned the difficulty of collecting data on municipal building permits from all municipalities, as some do not respond to the corresponding administrative surveys. Only data from the year 2000 onwards were found in the sources, and the situation in previous years is unknown.

For the indicator 'Annual percentage of renovated buildings per building sector—residential/non-residential', one of the first limitations is that only the data from the Official Association of Quantity Surveyors (in Spanish named *Colegio Oficial de Aparajadores y Arquitectos Técnicos*) include the distinction between residential and non-residential buildings. Other documents collected by Associations of Architects and Engineers, could substantially be improved if they included this distinction.

For the overview of the policies and actions about deep renovation we studied five indicators: (a) Total and annual proportion of buildings undergoing deep and nZEB renovation; (b) Energy savings from deep renovations; (c) m^2 of renovated public buildings per building type; (d) m^2 of renovated public buildings per building size; (e) m^2 of renovated public buildings per climatic zone.

No published data were available to compile indicator m^2 of renovated public buildings per building type, size, and climatic zone.

In the case of the indicator 'Total and annual proportion of buildings undergoing deep and nZEB renovation', the limitations set out for previous indicators apply. On the one hand, the Ministry of Transport, Mobility and Urban Agenda publishes data disaggregated by type of renovation at national scale only, meaning the indicator cannot be developed at lower scales. Furthermore, the variables into which the data are classified do not allow deep or nZEB renovation to be identified. On the other hand, the fact that data on municipal building permits are collected on a monthly and annual basis and data on existing buildings are mostly collected every ten years leads to inaccuracies in the calculations.

As previously mentioned, the IAEST recognizes the difficulty of collecting data on municipal building permits from all localities, as some do not respond to administrative surveys. Furthermore, the IAEST does not provide a breakdown of the different types of renovation, making it impossible to identify deep renovations and nZEB.

The project permit files are a great opportunity to collect information regarding the renovation processes, including the energy depth of the operations carried out. Therefore, a simple and effective option would be to expand the use of these files to have an additional source of information to those already here analyzed.

Regarding indicator 'Energy savings from deep renovations', scarce information was possible to compile. The only available one is based on the Evaluation Report on Public Residential Renovation Policies in Spain (2013–2017) (Rubio del Val et al.

2019), prepared by the 3R City Observatory. This document is based on a series of data sheets that the observatory provided to regions and institutions at the national scale to fill in with their collected renovation data so that they could be put together, studied, and compared. However, the tables prepared by the observatory for the homogeneous collection of information did not ask for renovation interventions to be classified according to their depth, so no data was collected that can be used to develop this indicator.

On the other hand, the type of data disaggregation applied in other sources, such as municipal building permits, also fails to address the depth of renovations. It is disaggregated according to other parameters.

In conclusion, in Spain, there are not enough data sources to develop an overview of deep renovation of buildings. The data sources consulted do not record renovations according to the depth of energy savings, making it difficult to distinguish deep renovations from other types. Additionally, there is a need to centralize data collection to mitigate the observed discrepancies among various sources.

Acknowledgements This work was founded by the MINISTRY OF SCIENCE AND INNOVATION OF SPAIN, grant number PID2019-104871RB-C21/AEI/10.13039/501100011033 and by GOBIERNO DE ARAGÓN, grant number T37_23R: Built4Life Lab.

References

Aragon Institute of Statistics (IAEST): Open Data (2021). https://opendata.aragon.es/datos/catalogo/busqueda/siu?org=ORG16617, last accessed 2023/09/20.

Basque Institute of Statistics (EUSTAT): Residential housing in the Basque Country by territorial scope and year of building construction. (2016). https://en.eustat.eus/elementos/ele0016000/ti_edificios-de-viviendas-de-la-ca-de-euskadi-por-ambitos-territoriales-por-ano-de-construccion-del-edificio-01112016/tbl0016035_i.html, last accessed 2023/09/20.

Basque Institute of Statistics (EUSTAT): Buildings and premises census. (2016). https://en.eustat.eus/estadisticas/tema_445/opt_0/tipo_1/temas.html, last accessed 2023/09/20.

Buildings Performance Institute Europe (BPIE): On the way to a climate-neutral Europe. (2020). https://www.bpie.eu/wp-content/uploads/2020/12/On-the-way-to-a-climate-neutral-Europe-_Final.pdf, last accessed 2023/09/20.

Buildings Performance Institute Europe (BPIE): Deep Renovation: Shifting from exception to standard practice in EU Policy (2021b). https://www.bpie.eu/wp-content/uploads/2021/11/BPIE_Deep-Renovation-Briefing_Final.pdf, last accessed 2023/09/20.

European Commission: COMMISSION STAFF WORKING DOCUMENT Accompanying the document REPORT FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL Financial support for energy efficiency in buildings {COM(2013) 225 final}. Brussels (2013).

European Commission: COMMISSION RECOMMENDATION (EU) 2019/786 of 8 May 2019 on building renovation. Official Journal of the European Union (2019: L 127), 34–79 (2019).

European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS. A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives. COM(2020) 662 final. Brussels (2020a).

European Commission: Energy efficiency in buildings. Brussels (2020b). https://commission.europa.eu/system/files/2020-03/in_focus_energy_efficiency_in_buildings_en.pdf, last accessed 2023/09/20.
European insulation Manufacturers Association: The key role of energy renovation in the net-zero GHG emission challenge. (2018). https://www.eurima.org/uploads/files/modules/articles/1584371842_C&E%20climact_role-of-energy-renovation-in-net-zero-ghg-emission_2050-final.pdf, last accessed 2023/09/20.
European Parliament: DIRECTIVE 2010/31/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 May 2010 on the energy performance of buildings (recast). Strasbourg (2010).
European Parliament: Energy performance of buildings (recast) Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (COM(2021)0802 – C9–0469/2021 – 2021/0426(COD)). Strasbourg (2023).
EU Building Stock Observatory: EU Building Stock Observatory (2013). https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/eu-building-stock-observatory_en, last accessed 2023/09/20.
Green Building Council Spain (GBCe): BUILD UPON Framework: The framework for measuring benefits of renovation of buildings (2021). https://gbce.es/documentos/BUILD-UPON-Framework-Spain.pdf, last accessed 2023/09/20.
Lynn T, Rosati P, Egli A, Krinidis S, Angelakoglou K, Sougkakis V, Tzovaras D, Kassem M, Greenwood D, Doukari O. RINNO: Towards an Open Renovation Platform for Integrated Design and Delivery of Deep Renovation Projects. Sustainability. 13(11):6018. https://doi.org/10.3390/su13116018 (2021).
Ministry of Finance and Civil Service (MHAP): Urban Real Estate Cadastre Statistics. (2023). https://www.catastro.minhafp.es/esp/estadistica_1.asp, last accessed 2023/09/20.
Ministry of Transport, Mobility and Urban Agenda (MITMA): Construcción de edificios (licencias municipales de obra) [Construction of buildings (municipal construction licenses)]. (2023a). https://apps.fomento.gob.es/BoletinOnline/?nivel=2&orden=10000000, last accessed 2023/09/20.
Ministry of Transport, Mobility and Urban Agenda (MITMA): Visados de dirección de obra de los Colegios de Arquitectos Técnicos (Obras en edificación) [Visas for site management from the Building Surveyor' Associations (Construction Works)]. (2023b). https://apps.fomento.gob.es/BoletinOnline/?nivel=2&orden=09000000, last accessed 2023/09/20.
Ministry of Transport, Mobility and Urban Agenda (MITMA): Estimación del parque de viviendas [Housing stock estimate]. (2023c). https://apps.fomento.gob.es/BoletinOnline2/?nivel=2&orden=33000000, last accessed 2023/09/20.
Rubio del Val, J., Espinosa-Fernández, A., Monzon, M., López-Mesa, B.: Evaluation of public residential renovation policies in Spain 2013–2017. Anales de Edificación. 6 (3), 6–12. (2020). https://doi.org/10.20868/ade.2020.4609.
Rubio del Val, J. (coord.), López-Mesa, B., Monzon-Chavarrías, M., Espinosa, A., García-Pérez, S.: Evaluation Report on Public Residential Renovation Policies in Spain (2013–2017). Reflections on Challenge 2020/2030. 3R City Observatory. (2020). ISBN 978–84–09–19847–4.
Spain's National Institute of Statistics (INE): Censos de Población y Viviendas 2011. Edificios. Resultados Municipales [Population and Housing Census 2011. Buildings. Municipal Results]. (2011). https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/e244/edificios/p04/&file=pcaxis&L=0, last accessed 2023/09/20.
Spain's National Institute of Statistics (INE): Censos de Población y Viviendas 2021. [Population and Housing Census 2021]. (2021). https://www.ine.es/Censo2021/Inicio.do, last accessed 2023/09/20.

Indicators and Data in Spain Regarding an Overview of Worst Performing Segments of the National Building Stock, Rented Properties and Energy Poverty

Carlos Beltrán-Velamazán, Markel Arbulu, Marta Gómez-Gil, Markel Rueda-Esteban, Almudena Espinosa-Fernández, and Belinda López-Mesa

Abstract Indicators are necessary to assess the effectiveness of building renovation policies and to know whether the European Union Member States' long-term renovation strategies deliver the necessary progress towards the transformation of the building stock into a decarbonized one. Worst performing segments, rental properties, and energy poverty have been identified as key issues to be addressed in the decarbonization of the building sector in Europe. In this chapter, we propose indicators to measure the evolution in Spain of the worst performing segments of the building stock regarding energy, the energy performance of rented properties, and energy poverty following the European Commission recommendations and directives. We also studied the sources of information available in Spain for the development of these indicators and developed them when there were data. This study allowed us to conclude that in this country, there are good sources of data to develop energy poverty indicators, which could be improved by systematically collecting information on the percentage of population living in inadequate housing thermal conditions in summer.

C. Beltrán-Velamazán · M. Gómez-Gil · A. Espinosa-Fernández · B. López-Mesa (✉)
Built4Life Lab, University of Zaragoza-I3A, 50018 Zaragoza, Spain
e-mail: belinda@unizar.es

C. Beltrán-Velamazán
e-mail: cbeltran@unizar.es

M. Gómez-Gil
e-mail: m.gomez@unizar.es

A. Espinosa-Fernández
e-mail: almudenaef@unizar.es

M. Arbulu · M. Rueda-Esteban
Department of Architecture, University of the Basque Country UPV/EHU, 20018 Donostia-San Sebastian, Spain
e-mail: markel.arbulu@ehu.eus

M. Rueda-Esteban
e-mail: markel.rueda@ehu.eus

B. López-Mesa and X. Oregi (eds.), *Assessing Progress in Decarbonizing Spain's Building Stock*, Digital Innovations in Architecture, Engineering and Construction,
https://doi.org/10.1007/978-3-031-51829-4_6

It is necessary to improve and unify the information from the energy performance certificates of buildings published by the different regions of Spain in order to better develop indicators relating to the worst segments of the building stock. There is a lack of data to develop indicators on the energy efficiency of rented properties.

1 Introduction

All European Union (EU) Member States (MS) must have since 2014 a long-term renovation strategy (LTRS) to support the renovation of their national building stock into a highly energy efficient and decarbonized building stock by 2050. The LTRS must include, among other things, an overview of policies and actions to target the worst performing segments of the national building stock, split-incentive dilemmas and market failures, and an outline of relevant national actions that contribute to the alleviation of energy poverty. Worst performing segments, rental housing, and energy poverty have been identified as key issues to be addressed for various reasons:

(A) Poorly performing buildings have great potential for improvement.
(B) People living in inefficient buildings and facing energy poverty are more exposed to cold and heat waves, as well as to other impacts of climate change (European Environment Agency 2018).
(C) Inadequate comfort and sanitary conditions in housing and work environments contribute to lower productivity, health problems, and increased mortality and morbidity (Krieger and Higgins 2002; Visher 2007; Wang et al. 2022). These inadequate conditions include aspects such as inadequate indoor temperatures, deficient air quality and exposure to harmful chemicals and materials.
(D) Economic constraints have been found to further aggravate barriers to housing renovation (Listokin and Listokin 2001). This is because the size of household income plays an important role on the willingness to pay for renovation (Christensen et al. 2011).
(E) Rented properties are exposed to the dilemma of split-incentives. Split incentives occur when those responsible for paying energy bills (the tenant) are not the same as those making the capital investment decisions (the landlord). In these circumstances, the landlord may underinvest in energy efficiency measures (Melvin 2018).

The requirement for EU countries to adopt a LTRS was first set out in the Directive 2012/27/EU (European Parliament and the Council of the European Union 2012). However, the need to include an overview of policies for the worst performing segments, split incentives dilemma and market failures, and national actions contributing to the alleviation of energy poverty was not reflected in the regulations until the Energy Performance of Buildings Directive (EPBD) was revised in 2018 (European Parliament and the Council of the European Union 2018). In said revision, it was specified that to achieve a highly energy efficient and decarbonized building stock and to ensure that the LTRSs deliver the necessary progress towards the transformation of existing buildings into nearly zero-energy buildings, MSs should provide clear guidelines and outline measurable, targeted actions as well as promote equal access to financing, including for the worst performing segments of the national building stock, for energy-poor consumers, for social housing and for households subject to split-incentive dilemmas, while taking into consideration affordability. Additionally, to further support the necessary improvements in their national rental stock, MSs should consider introducing or continuing to apply requirements for a certain level of energy performance for rental properties, in accordance with the energy performance certificates.

In October 2020, the Commission presented its Renovation wave strategy, as part of the European Green Deal. Its objective is to at least double the annual energy renovation rate of buildings by 2030 and to foster deep renovation. A revision of the Energy Performance of Buildings Directive (EPBD) is one of its key initiatives. In December 2021, the Commission proposed a revision of the directive (European Commission 2021). It sets out how Europe can achieve a zero-emission and fully decarbonize the building stock by 2050. The proposed measures aim to increase the rate of renovation, particularly for the worst-performing buildings in each country, and to facilitate more targeted financing to investments in the building sector, complementing other EU instruments supporting vulnerable consumers and fighting energy poverty. Homes facing energy poverty, rented housing and worst-performing segments would benefit from renovated and better buildings and from reduced energy costs and be buffered from further market price increases and volatility.

Energy poverty is a household situation in which energy bills represent a high percentage of consumers' income, or in which the consumers must reduce their household's energy consumption to a degree that negatively impacts their health and well-being. As can be seen by the definition, this phenomenon can materialize in different ways, and a single metric will always miss an important part of the story (Rademaekers et al. 2016). For this reason, energy poverty is proposed to be measured by multiple indicators. There are four main approaches in the literature to define energy poverty metrics (Rademaekers et al. 2016):

(A) Expenditure-based metrics define energy poverty based on information about the household's expenditure in energy, and often compares it with the household's income.
(B) Consensual-based metrics are metrics that identify those households that declare to face difficulties in order to meet basic energy services ('perceived deprivation').
(C) Temperature-based metrics rely on internal temperature measurement. However, there is a lack of data on this regard (Thomson 2013).
(D) Outcome-based metrics are those based on the outcomes associated with energy poverty e.g. disconnections, arrears, cold-related mortality.

The scientific literature on metrics calls for indicators that represent contextualized energy use issues, including energy access and quality, expenditure in relation to income, built environment related aspects and thermal comfort levels, while retaining simplicity and comparability for policy traction (Sareen et al. 2020).

Worst performing buildings have been recently defined in the Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (European Parliament 2023). This document is referred to as 2023 EPBD Proposal recast in this book, and it is the last version of the ongoing revision of the EPBD, not yet approved. According to the 2023 EPBD Proposal recast, the worst performing buildings in Europe in each of their MSs are those with Energy Performance Certificate (EPC) classes E, F and G. The EPCs are a rating scheme to summarize the energy efficiency of buildings in Europe. Each building is given a rating between A (Very efficient) and G (Very inefficient). The 2023 EBPD Proposal recasts also proposes the revision of the EPC scheme, so that the G rating will correspond to the 15% worst performing buildings in each MS, with the remaining buildings in the country distributed proportionately among the other classes between G and A, which corresponds to zero-emission buildings. A main novelty of the EPBD revision is the introduction of Minimum Energy Performance Standards (MEPSs), designed with the aim to mitigate possible negative social effects and maximize their social benefits, notably as regards to improving living conditions in worst-performing buildings and rented properties and alleviating or even preventing energy poverty. The introduction of the EU MEPS will require the renovation of the worst energy-performing buildings. In particular, non-residential buildings with class F and G will need to be renovated to at least class E by 2027 and at least class D by 2030. Meanwhile, all class F and G residential buildings will need to reach class E by 2030 and class D by 2033. MSs will be required to support compliance with MEPS with an appropriate support framework that includes financial support, technical assistance, removal of barriers and monitoring of social impacts, in particular on the most vulnerable segments.

According to the EPBD revision, each MS shall establish a national building renovation plan (NBRP) to ensure the renovation of the national stock into a highly energy efficient and decarbonized building stock by 2050. The NBRP will include the definition of a roadmap with nationally established targets and measurable progress indicators, and specific timelines for all existing buildings to achieve higher energy performance classes by 2030, 2040 and 2050. MSs are also empowered to set national MEPS, in line with their NBRP.

This chapter aims to propose and develop indicators to track the situation of worst performing segments, rented properties and energy poverty in the MSs. The indicators will be developed for the case study of Spain. This will also allow us to draw the main conclusions on their evolution in this country.

2 Methodology

To develop the indicators that allow an overview of the worst performing segments of the national building stock, rented properties, and energy poverty we followed the methodology shown in Fig. 1.

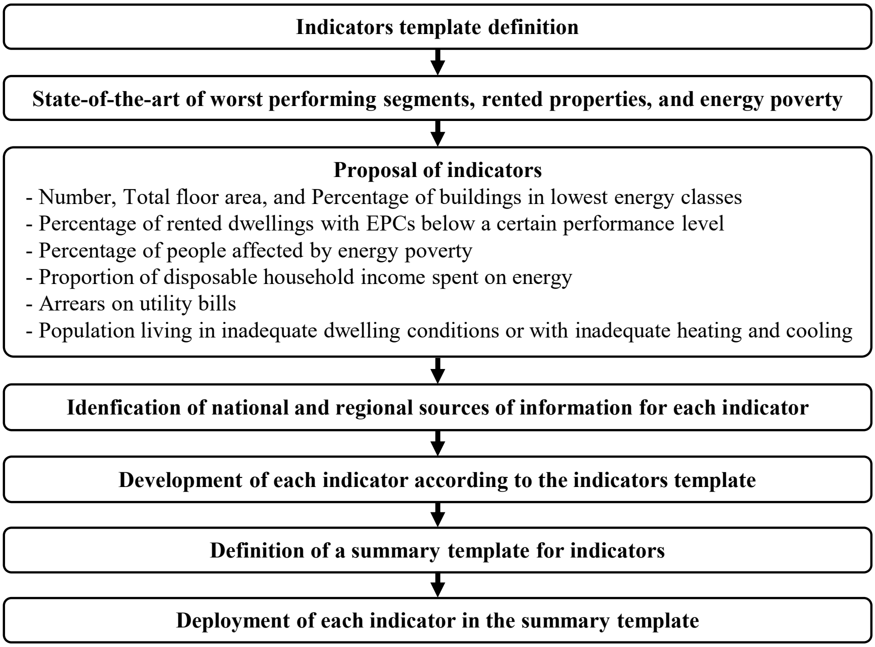


Fig. 1 Methodology implemented to generate indicators on worst performing segments, rented properties and energy poverty in Spain and two of its regions, Aragon and the Basque Country. *Source* own creation

The first step consisted in the development of a common template for these indicators based on the following scheme:

- Indicator:
  - Definition of the indicator
  - Variables to quantify it and their unit of measurement
  - Purpose and advantages of implementing this indicator
  - Alignment of the indicator with the directives, agendas, action plans and strategies, covering the European and international, national, and regional scales.
  - Relationship of this indicator with other similar ones
- Information sources:
  - Availability of information to generate this indicator at different scales
  - Entity responsible for providing this information
- Measurement:
  - Measurement method
  - Methodology

– Current possibilities of obtaining it
– Information necessary to generate it
– Availability and quality of data

In order to select the worst performing segments, rented properties, and energy poverty indicators to develop, we considered the indicators which have been suggested in European directives and related documents. For this study, we considered two documents. On one hand, we studied the indicators included in the Commission Recommendation (EU) 2019/786 (European Commission 2019), which was the first document in which a framework of progress indicators to measure the European building stock decarbonization was proposed. This document is referred to as 2019 EPBD-based Recommendation in this book. On the other hand, we analyzed the indicators included in the 2023 EPBD Proposal recast, which is the document with the last version of the framework of progress indicators. In Table 1, the indicators in both documents for worst-performing segments and rented properties, and for energy poverty can be read. As can be seen in Table 1, in the 2019 EPBD-related Recommendation, there is one energy poverty indicator more than in the 2023 EPBD Proposal recast, and three indicators (E1, E2, and E3) which are exactly the same. Regarding the worst-performing segments and rented properties indicators, the 2019 EPBD-related Recommendation includes two indicators (W1, W2a), whereas the 2023 EPBD Proposal recast has only one (W2b). One of the two indicators in the Recommendation (W2a) is similar to the one in the 2023 EPBD revision (W2b), except for the proposed units of measurement.

We decided to study the availability of data and develop the widest set of indicators possible. For this reason, we propose to consider all the indicators among the two documents, and all the units of measurement of the two indicators that were similar. Thus, the following indicators were proposed for development:

- Number, Total floor area, and Percentage of buildings in lowest energy classes
- Percentage of rented dwellings with EPCs below a certain performance level
- Percentage of people affected by energy poverty
- Proportion of disposable household income spent on energy
- Arrears on utility bills
- Population living in inadequate dwelling conditions or with inadequate heating and cooling

These indicators cover the aspects related to the worst energy performance, rented housing, and the homes with energy poverty problems.

Once the key indicators to cover this topic were identified, the available sources of information were studied. Since in Spain a good deal of the promotion and aid management of building renovation is delegated to regions, we used as case studies the regions of Aragon and the Basque Country. The previously defined indicator template was used to develop each indicator.

For the sake of transmitting all the information of each indicator in a user-friendly way, we also developed a summary template, which was used to deploy in a summarized way the information we got for each indicator.

Table 1 Worst-performing segments, rented properties, and energy poverty indicators included in selected European directives and related documents. *Source* own creation from data in (European Commission 2019; European Parliament 2023)

Document	Worst-performing segments and rented properties indicators	Energy poverty indicators
Commission recommendation (EU) 2019/786	– W1. Percentage of rented houses with EPCs below a certain performance level – W2a. Percentage of buildings in lowest energy classes	– E1. Percentage of people affected by energy poverty – E2. Proportion of disposable household income spent on energy – E3. Population living in inadequate dwelling conditions (e.g. leaking roof) or with inadequate thermal conditions – E4. Arrears on utility bills
2023 EPBD revision	– W2b. Number of buildings and total floor area of worst-performing (including a definition classes E, F, G)	– E1. Percentage of people affected by energy poverty – E2. Proportion of disposable household income spent on energy – E3. Population living in inadequate dwelling conditions (e.g. leaking roof) or with inadequate thermal conditions

3 Indicators

3.1 Number, Total Floor Area, Percentage of Buildings in Lowest Energy Classes

The purpose of this indicator is to identify the buildings that are less energy efficient in a country and their level of representation in the national building stock in order to measure the progress of the building stock decarbonization targets. The sources of information to develop this indicator in Spain are national and regional (Table 2).

The energy rating of buildings in Spain is expressed through two main indicators, which are annual carbon dioxide (CO_2) emissions and annual consumption of non-renewable primary energy (NRPEC). The national-scale source in Table 2 provides energy classification data, differentiating between new and existing buildings. For these reasons, the variables proposed for this indicator were:

- Number of new buildings in lowest energy classes (energy rating letters E, F, G) regarding CO_2 emissions.
- Number of new buildings in lowest energy classes (energy rating letters E, F, G) regarding NRPEC.

Table 2 Sources for indicator Number, Total floor area, Percentage of buildings in lowest energy classes. *Source* own creation

Indicator: Number, total floor area, Percentage of buildings in lowest energy classes	
Variables	– Number of new/existing buildings in lowest energy classes regarding CO_2 emissions/non-renewable primary energy consumption (NRPEC) – Total floor area of new/existing buildings in lowest energy classes regarding CO_2 emissions/NRPEC – Percentage of new/existing buildings in lowest energy classes regarding CO_2 emissions/NRPEC
Indicator developability	– Data availability: partially available – Processing method from source: indirect – Data processability: no, except for the case of Aragon
National source	Ministry of Ecological Transition and Demographic Challenge
Source link	https://energia.gob.es/desarrollo/EficienciaEnergetica/CertificacionEnergetica/Documentos/Documentos%20informativos/2022_Informe-seguimiento.pdf
Characteristics of the source	– Availability: partially available – Data collection method: data relating to energy performance certificates come from the regional registers where they are registered by the corresponding technicians – Data processability: no, PDF report – Georeferencing: no – Data update frequency/last update: annually. Last update in December 2021
Regional source—Aragon	Government of Aragon Open Data
Source link	https://opendata.aragon.es/datos/catalogo/dataset/registro-de-certificacion-de-eficiencia-energetica-de-edificios-de-aragon
Characteristics of the source	– Availability: open data but insufficient to fully collect the indicator – Data collection method: regional register – Data processability: Yes, CSV and Json formats – Georeferencing: no – Data update frequency/last update: Continuously updated
Regional source—The Basque Country	Basque Government
Link	https://www.euskadi.eus/certificado-eficiencia-energetica/web01-a2indust/es/index.shtml#7971
Characteristics of the source	– Availability: open data but insufficient to fully collect the indicator – Data collection method: regional register – Data processability: no, PDF report – Georeferencing: no – Data update frequency/last update: Twice a year. Last update in June 2022
Regional source—The Basque Country	GeoEuskadi

(continued)

Table 2 (continued)

Indicator: Number, total floor area, Percentage of buildings in lowest energy classes	
Link	https://www.geo.euskadi.eus/visor-areas-vulnerables-de-la-capv/webgeo00-geoapps/es/
Characteristics of the source	– Availability: open data but insufficient to fully collect the indicator – Data collection method: directly – Data processability: no – Georeferencing: partially georeferenced, although only at section level, not at building level – Data update frequency/last update: Unspecified

- Number of existing buildings in lowest energy classes (energy rating letters E, F, G) regarding CO_2 emissions.
- Number of existing buildings in lowest energy classes (energy rating letters E, F, G) regarding NRPEC.
- Total floor area of new buildings in lowest energy classes (energy rating letters E, F, G) regarding CO_2 emissions.
- Total floor area of new buildings in lowest energy classes (energy rating letters E, F, G) regarding NRPEC.
- Total floor area of existing buildings in lowest energy classes (energy rating letters E, F, G) regarding CO_2 emissions.
- Total floor area of existing buildings in lowest energy classes (energy rating letters E, F, G) regarding NRPEC.
- Percentage of new buildings in lowest energy classes (energy rating letters E, F, G) regarding CO_2 emissions.
- Percentage of new buildings in lowest energy classes (energy rating letters E, F, G) regarding NRPEC.
- Percentage of existing buildings in lowest energy classes (energy rating letters E, F, G) regarding CO_2 emissions.
- Percentage of existing buildings in lowest energy classes (energy rating letters E, F, G) regarding NRPEC.

However, when we tried to develop the indicators from these sources at the national and regional levels, we found that only three of them were available, whose data we deploy in Figs. 2, 3 and 4. The available variables are percentage of new buildings in lowest energy classes regarding CO_2 emissions, percentage of new buildings in lowest energy classes regarding NRPEC, and percentage of existing certified buildings in lowest energy classes regarding CO_2 emissions. There are no data published regarding number of buildings nor total floor area. In some regions, such as in the case of Aragon, the existing sources provide the raw data of the EPCs, what would allow to develop the full set of variables at a regional scale. On the contrary, in other regions, such as the Basque Country, the access to raw data is not open, and only statistical data can be found. According to Beltran-Velamazan et al. (2024), the EPC information published by the different regions of Spain differs both in the data

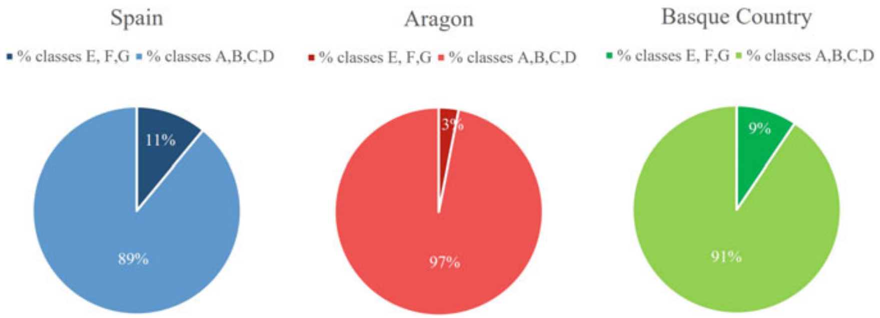


Fig. 2 Percentage of new buildings in lowest energy classes (energy rating letters E, F, G) regarding CO_2 emissions in Spain, certified in 2021. *Source* own creation from data in (Ministry for Ecological Transition and the Demographic Challenge and Ministry of Transport, Mobility and Urban Agenda 2021)

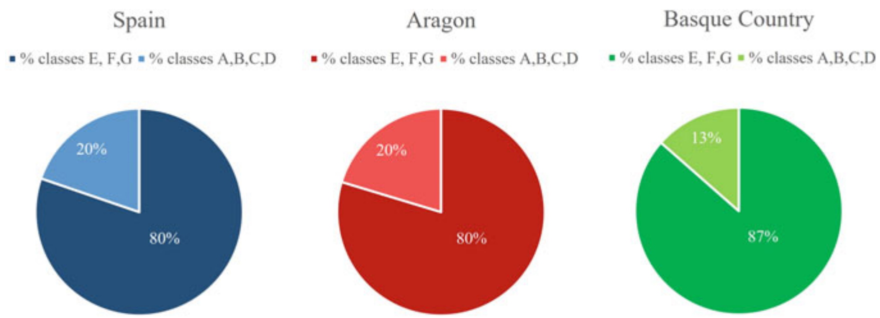


Fig. 3 Percentage of existing buildings in lowest energy classes (energy rating letters E, F, G) regarding CO_2 emissions in Spain, certified between 2013 and 2021. *Source* own creation from data in (Ministry for Ecological Transition and the Demographic Challenge and Ministry of Transport, Mobility and Urban Agenda 2021)

and the format, giving rise to multiple incompatibilities and information gaps. Thus, collecting and unifying the data for the whole of Spain requires further research beyond the scope of this chapter.

3.2 Percentage of Rented Dwellings with EPCs Below a Certain Performance Level

The purpose of this indicator is to know the energy status of rented dwellings to measure the evolution of split incentives as a barrier to the deployment of energy efficiency measures in housing.

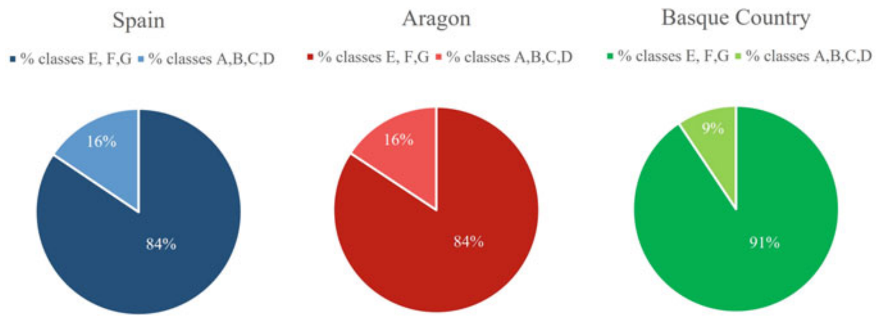


Fig. 4 Percentage of existing buildings in lowest energy classes (energy rating letters E, F, G) regarding NRPEC, certified between 2013 and 2021. *Source* own creation from data in (Ministry for Ecological Transition and the Demographic Challenge and Ministry of Transport, Mobility and Urban Agenda 2021)

In Spain there is no regulation regarding performance level of rented dwellings. Even if there are several sources that publish data on EPCs at national and regional levels (Table 3), none of them include data on the type of property ownership. On the other hand, in the Basque Country there are other sources that publish data on the social housing stock and on its energy renovation and accessibility (Table 3). However, these sources only provide EPC information about the rented housing stock owned by public bodies, and there is no data on the private rental sector, which is the majority in the Basque Country and the rest of Spain. Therefore, in Spain there is no available data to develop this indicator.

The only data that could be generated was the percentage of public rental dwellings with energy rating letters E, F or G out of the total public rental housing stock in the Basque Country, which is of 34.9% (Table 4). The public rental housing stock in this region of Spain represents the 0.8% of the housing stock and the 9.9% of the rental housing stock. There is no EPC information regarding the private rental housing stock, which is the one with higher risk of suffering the split incentives dilemma.

3.3 Energy Poverty Indicators: Percentage of People Affected by Energy Poverty

The purpose of this indicator is to raise awareness on the extent of existing risk and the evolution of energy poverty and vulnerability of the population. The only source of information to develop this indicator in Spain is the National Fuel Poverty Strategy (Table 5).

According to Spain's National Fuel Poverty Strategy, energy poverty is the situation in which a household energy supply needs cannot be met as a result of an insufficient level of income and which may be aggravated by having energy inefficient housing. Additionally, this strategy defines a vulnerable consumer as a consumer of

Table 3 Sources for indicator number, Total floor area, percentage of buildings in lowest energy classes. *Source* own creation

Indicator: Percentage of rented dwellings with EPCs below a certain performance level	
Variables	– Percentage of rented dwellings with energy rating letters E, F or G out of the total public rental housing stock
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator Data processability: not applicable to this indicator
Regional source—The Basque Country	Alokabide—Plan ZERO Plana
Link	https://www.alokabide.euskadi.eus/contenidos/recurso_tecnico/aa10_comun/es_def/adjuntos/eje5/Zero_plana_Tomo_3_CAST_BAJA.pdf
Characteristics of the source	– Availability: open but insufficient for the indicator development – Data collection method: not specified – Data processability: no – Georeferencing: no – Data update frequency/last update: unique publication in February 2021
Regional source—The Basque Country	Etxebide: The Basque Government agency
Link	https://apps.euskadi.eus/x39-appcont/es/x91aEtxebideWar/geo/maint?locale=es
Characteristics of the source	– Availability: open data but insufficient for the indicator development – Data collection method: directly – Data processability: no – Georeferencing: yes, partially georeferenced, although only at census section level, not at building level – Data update frequency/last update: Unspecified

Table 4 Percentage of rented dwellings with energy rating letters E, F or G out of the total public rental housing stock in the Basque Country. *Source* own creation from data in (Alokabide 2021)

Energy rating letter	A	B	C	D	E	F	G	Total
% of dwellings	4.4(%)	8.5	11.8	40.4	34.3	0.4	0.2	100
No. of dwellings	365	702	974	3335	2826	35	13	8250

electricity or thermal energy who is in a situation of energy poverty and can benefit from the support measures established by the administrations. These definitions are in line with the ones given in the introduction section.

The variables used in Spain's National Fuel Poverty Strategy to measure the indicator are:

Table 5 Sources for indicator percentage of people affected by energy poverty. *Source* own creation

Indicator: Percentage of people affected by energy poverty	
Variables	– Disproportionate expenditure (2 M) – Hidden Energy Poverty (HEP)
Indicator developability	– Data availability: fully available – Processing method from source: direct – Data processability: no
National source	Ministry for Ecological Transition and the Demographic Challenge. National Energy Poverty Strategy 2019–2024 report
Source link	https://www.miteco.gob.es/es/prensa/estrategianacionalcontralapobrezaenergetica2019-2024_tcm30-496282.pdf
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: not directly, data provided in PDF format – Georeferencing: no – Data update frequency/last update: the indicator has been published directly twice, in 2019 and 2020

- Disproportionate expenditure (2 M), defined as the percentage of households whose energy expenditure in relation with their income is more than double the national median.
- Hidden Energy Poverty (HEP), defined as the percentage of households whose energy expenditure absolute is less than half the national median.

We can directly take the data from the mentioned source to develop our proposed indicator. Thus, in Fig. 5 we can see the evolution of 2 M and HEP in Spain from 2008 to 2021. Additionally, we can also extract regional data from this source, as can be seen in Fig. 6 for the case of the region of Aragon, and the Fig. 7 for the case of the Basque Country.

Since the data are provided in PDF format, they have to be treated manually. However, it must be mentioned that part of the data in the National Energy Poverty

Fig. 5 Evolution in the percentage of population affected by energy poverty in Spain from 2008 to 2021. *Source* own creation from data in (Ministry for Ecological Transition and the Demographic Challenge 2019)

Fig. 6 Evolution in the percentage of population affected by energy poverty in the region of Aragon (Spain) from 2016 to 2021. *Source* own creation from data in (Ministry for Ecological Transition and the Demographic Challenge 2019)

Fig. 7 Evolution in the percentage of population affected by energy poverty in the Basque Country (Spain) from 2016 to 2020. *Source* own creation from data in (Ministry for Ecological Transition and the Demographic Challenge 2019)

Strategy 2019–2024 report is obtained from the National Statistics Institute of Spain, which offers access to processable data in XLS, CSV, Pc-Axis, Json and plain text formats. Therefore, the indicator could also be developed based on these processable data and other big data technologies, what would require further and specific research in the field.

3.4 Energy Poverty Indicators: Proportion of Disposable Household Income Spent on Energy

The purpose of this indicator is to measure the evolution of the average economic weight of expenditure on energy services in households as a proportion of disposable income. The increase on the proportion of households' income on utility bills

Table 6 Sources for indicator proportion of disposable household income spent on energy. *Source* own creation

Indicator: Proportion of disposable household income spent on energy	
Variables	– Share of average household income spent on energy (electricity, gas and other fuels)
Indicator developability	– Data availability: fully available – Processing method from source: direct – Data processability: yes, XLS, CSV, Pc-Axis, Json
National source	Household Budget Survey. Spain's National Institute of Statistics (INE)
Source links	https://www.ine.es/jaxiT3/Tabla.htm?t=24964&L=0 https://www.ine.es/jaxiT3/Datos.htm?t=25144
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, XLS, CSV, Pc-Axis, Json – Georeferencing: no – Data update frequency/last update: Annually. The latest full year update is from 2021

imply significant declines in households' purchasing power and a greater risk of fuel poverty.

The only source of information to develop this indicator in Spain is the Household Budget Survey of the National Institute of Statistics (INE) (Table 6). The variable used in the INE is the share of average household income spent on energy (electricity, gas and other fuels).

Figure 8 shows the evolution of share of disposable household income spent on energy in Spain from 2006 to 2021. The data are easily processable from the source and can be depicted for the whole of Spain and for each of its regions.

3.5 *Energy Poverty Indicators: Arrears on Utility Bills*

The purpose of this indicator is to understand the evolution of the situation of households in terms of energy poverty by means of the analysis of the difficulties in paying for the costs of utilities.

There is only one source of information to develop this indicator in Spain, the National Energy Poverty Strategy 2019–2024 report of the Ministry for Ecological Transition (Table 7). The variable used in this report is the percentage of population that has arrears in household utility bills. Figure 9 shows the evolution of the percentage of population with arrears in utility bills from 2008 to 2020 in Spain and from 2016 to 2020 in the regions of Aragon and the Basque Country. The data have to be treated manually, since they are published through a pdf and there is not a clear update frequency defined.

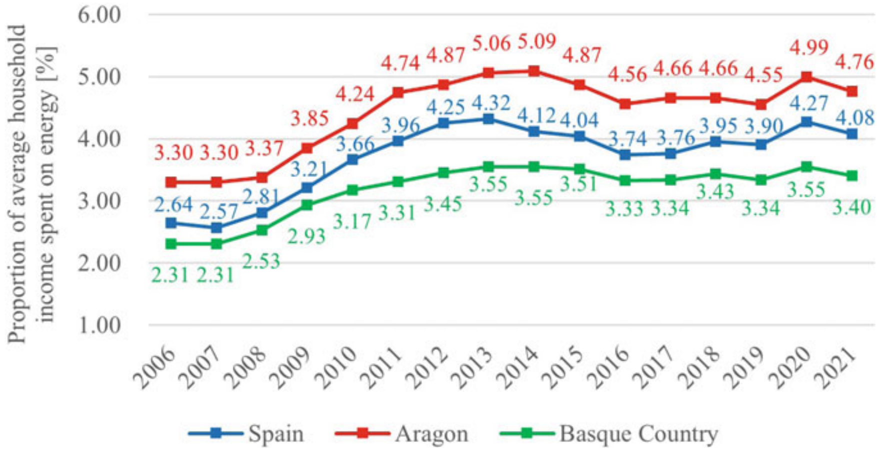


Fig. 8 Evolution of share of disposable household income spent on energy in Spain and the regions of Aragon and the Basque Country from 2006 to 2021. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2021a)

Table 7 Sources for indicator Arrears on utility bills. *Source* own creation

Indicator: Arrears on utility bills	
Variables	– Percentage of population that has arrears in household utility bills
Indicator developability	– Data availability: fully available – Processing method from source: direct – Data processability: not directly, data provided in PDF format
National source	Ministry for Ecological Transition and the Demographic Challenge. National Energy Poverty Strategy 2019–2024 report
Source link	https://www.miteco.gob.es/es/prensa/estrategianacionalcontralapobrezaenergetica2019-2024_tcm30-496282.pdf
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: not directly, data provided in PDF format – Georeferencing: no – Data update frequency/last update: the indicator has been published directly twice, in 2019 and 2020

3.6 Energy Poverty Indicators: Population Living in Inadequate Dwelling Conditions or with Inadequate Heating and Cooling

The purpose of this indicator is to understand the evolution of the situation of households in terms of energy poverty by means of the analysis of the population living in inadequate dwelling conditions or with inadequate heating and cooling.

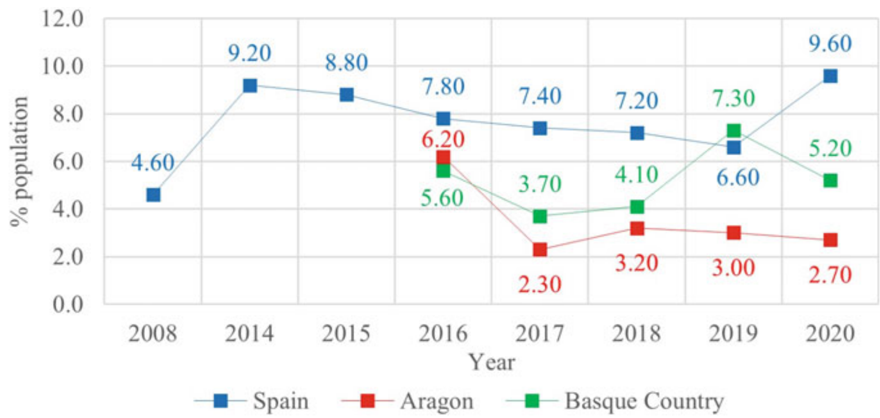


Fig. 9 Evolution of the percentage of population with arrears in utility bills from 2008 to 2020 in Spain and from 2016 to 2020 in the regions of Aragon and the Basque Country. *Source* own creation from data in (Ministry for Ecological Transition and the Demographic Challenge 2019)

There are two sources of information to develop this indicator in Spain: The National Institute of Statistics (INE), and the National Energy Poverty Strategy 2019–2024 report of the Ministry for Ecological Transition (Table 8). The variable used in the INE is the percentage of population who cannot afford an adequate housing temperature. The variables used in the National Energy Poverty Strategy 2019–2024 report is the percentage of population suffering from inadequate thermal housing conditions in both winter and summer. The variables we have selected for this indicator are these second ones (Table 8). Figure 10 shows the evolution of the percentage of population living in inadequate housing thermal conditions in winter from 2004 to 2021 in Spain and in the regions of Aragon and the Basque Country. These data have been obtained from the INE whose open data is processable, given that it is published in XLS, CSV, Pc-Axis, Json formats. However, the data to obtain the inadequate conditions in summer is incomplete and non-processable. Table 9 shows the only open data available regarding this issue, which results insufficient to study its progress both in Spain and in the case study regions.

4 Conclusions

In this chapter, we proposed indicators to track the evolution in Spain of:

- the worst performing segments of the building stock regarding energy performance,
- the energy performance of rented properties,
- and energy poverty.

Table 8 Sources for indicator population living in inadequate dwelling conditions or with inadequate heating and cooling. *Source* own creation

Indicator: Population living in inadequate dwelling conditions or with inadequate heating and cooling	
Variables	– Percentage of population suffering from inadequate thermal housing conditions in winter – Percentage of population suffering from inadequate thermal housing conditions in summer
Indicator developability	– Data availability: partially available – Processing method from source: direct – Data processability: Yes, XLS, CSV, Pc-Axis, Json
National source	Spain's National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxiT3/Tabla.htm?t=9967&L=0 https://www.ine.es/jaxiT3/Tabla.htm?t=9972&L=0
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, XLS, CSV, Pc-Axis, Json – Georeferencing: no – Data update frequency/last update: annually. Last update 2021
National source	Ministry for Ecological Transition and the Demographic Challenge. National Energy Poverty Strategy 2019–2024 report
Source link	https://www.miteco.gob.es/es/prensa/estrategianacionalcontralapobrezaenergetica2019-2024_tcm30-496282.pdf https://www.miteco.gob.es/content/dam/miteco/es/ministerio/planes-estrategias/estrategia-pobreza-energetica/actualizaciondelosindicadoresdelaestrategianacionalcontralapobrezaenergetica-2022_tcm30-549718.pdf
Characteristics of the source	– Availability: open data – Data collection method: survey – Data processability: no, PDF – Georeferencing: no – Data update frequency/last update: the indicator has been published directly twice, in 2019 and 2020

We studied the sources of information available for the development of these indicators and developed them when there were data.

For the worst performing segments, we proposed one indicator named 'Number, total floor area, and percentage of buildings in lowest energy classes'. We found that there are sources to develop percentage data, but there are no data published regarding number of buildings nor regarding total floor area. In most regions in Spain, such as in the case of Aragon, there are open sources providing the raw data of the EPCs, however, according to Beltran-Velamazan et al. (2024), the EPC information published by the different regions differs both in the data and the format, giving rise to multiple incompatibilities and information gaps. Until these data are collected and unified for the whole of Spain, the only information available is the percentage of buildings in the lowest energy classes. This percentage information is interesting, but it does not allow us to define with great precision the real size of the

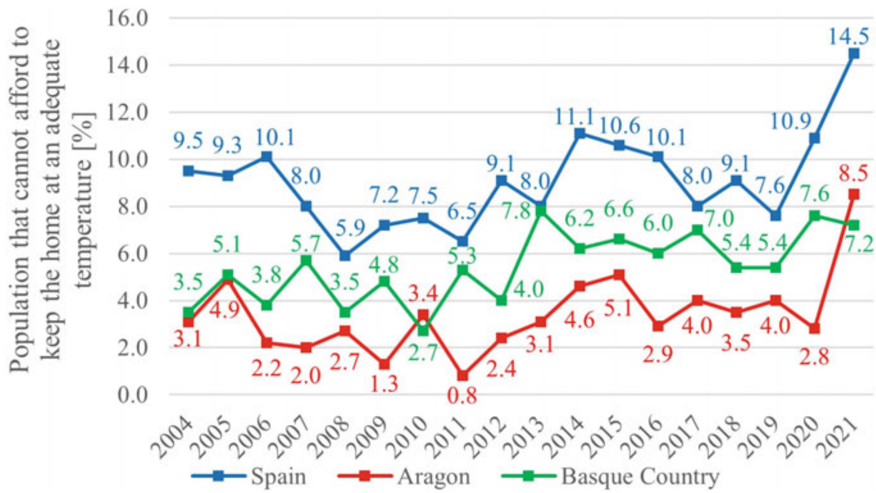


Fig. 10 Percentage of population living in inadequate housing conditions in winter from 2004 to 2021 in Spain and in the regions of Aragon and the Basque Country. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics (INE) 2021b)

Table 9 Percentage of population living in inadequate housing conditions in winter from 2004 to 2021 in Spain and in the regions of Aragon and the Basque Country. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics (INE) 2021b)

Country or region	2007	2012
Spain	26.4(%)	25.6
Aragon	30.2(%)	17.2
Basque Country	25.1(%)	15.1

decarbonization challenge, since for this we would need to know the square meters that should be decarbonized as a priority. In any case, with the data we have, we know that 81–85% of the energy certificates issued for existing buildings in Spain have the letters E, F or G, that is, they are included in what are considered the worst segments. This percentage will vary if the rating scheme is modified as a consequence of the approval of the EPBD revision. For new buildings, this percentage is 12%, that is, the energy performance of new buildings is much better. The major challenge in Spain is, therefore, the decarbonization of the existing building stock. At the regional level, differences are observed between the cases studied and the Spanish average. In the region of Aragon, the size of the worst energy segments of the existing building stock is similar to the Spanish average, however the new buildings have better energy ratings than the Spanish average, with the worst segments representing only the 4%.

In the Basque Country, both existing and new buildings perform worse than the Spanish average, probably due to a more demanding winter climate.

For the energy performance of rented properties, we proposed one indicator named Percentage of rented dwellings with EPCs below a certain performance level. We found that there are no sources in Spain collecting this data. Furthermore, there is no specific regulation in Spain on minimum energy performance for rented properties. This puts our rented housing stock, which is mainly private, at greater risk of suffering from the split-incentives dilemma, which in turn poses a greater risk of underinvestment in energy measures.

For energy poverty, we proposed four indicators: (a) Percentage of people affected by energy poverty; (b) Proportion of disposable household income spent on energy; (c) Arrears on utility bills; and (d) Population living in inadequate dwelling conditions or with inadequate heating and cooling. In general, we can say that the availability of data to measure the evolution of energy poverty is high in Spain. The first three indicators can be fully developed, and only the fourth allows partial collection. From the fourth indicator, information regarding the percentage of population suffering from inadequate thermal housing conditions in winter can be collected, but not in summer. We consider that this lack of data associated with the summer period is disadvantageous for the case of Spain, as it is a country with high temperatures in summer, which are expected to get further intensified due to the phenomenon of climate change. In relation to the available data on energy poverty in Spain, it is observed that the percentage of households with disproportionate expenditure (2 M) remains stable with a value of 16.4% in 2021 and the percentage of households with hidden energy poverty (HEP) is decreasing each year presenting a value of 9.3% in 2021. However, between 2006 and 2014 the proportion of disposable household income spent on energy rose to levels that have not decreased significantly in the following years, presenting a value of 4.76% in 2007. This meant an increase in the percentage of households with arrears on utility bills until 2014, which has been decreasing little by little except in the year of the COVID pandemic, in which, with a value of 9.60%, the peak of the year 2014 was exceeded. Finally, it is worth mentioning that the percentage of population that cannot heat their homes to an adequate temperature grew significantly in 2020 and in 2021, reaching a value of 14.5% in that second year.

In conclusion, in Spain, there are good sources of data to develop energy poverty indicators, which could be improved by systematically collecting information on the percentage of population living in inadequate housing thermal conditions in summer. It is necessary to improve and unify the publication of information from the energy certificates of buildings by the different regions of Spain in order to better develop indicators relating to the worst segments of the building stock, in such a way that the provided information allows to know not only the data in percentage format but also in total area and number of buildings. There is a lack of data to develop indicators on the energy efficiency of rented properties.

Acknowledgements This work was funded by the MINISTRY OF SCIENCE AND INNOVATION OF SPAIN, grant number PID2019-104871RB-C21/AEI/10.13039/501100011033 and by GOBIERNO DE ARAGÓN, grant number T37_23R: Built4Life Lab.

References

Alokabide: Plan ZERO Plana. Alokabide, Vitoria-Gasteiz (2021). https://www.alokabide.euskadi.eus/contenidos/recurso_tecnico/aa10_comun/es_def/adjuntos/eje5/Zero_plana_Tomo_3_CAST_BAJA.pdf, last accessed 2023/09/20.

European Commission: COMMISSION RECOMMENDATION (EU) 2019/786 of 8 May 2019 on building renovation. Official Journal of the European Union (2019: L 127), 34–79 (2019).

European Commission: Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast). COM/2021/802. Brussels (2021).

European Environment Agency: Unequal exposure and unequal impacts: social vulnerability to air pollution, noise and extreme temperatures in Europe. EEA Report No 22/2018. ISBN: 978–92–9248–048–0. ISSN: 1977–8449. doi:https://doi.org/10.2800/324183 (2018).

European Parliament: Energy performance of buildings (recast) Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (COM(2021)0802 – C9–0469/2021 – 2021/0426(COD)). Strasbourg (2023).

Melvin, M.: The split incentives energy efficiency problem: Evidence of underinvestment by landlords. Energy Policy 115, 342–352. Doi: https://doi.org/10.1016/j.enpol.2017.11.069 (2018).

Ministry for Ecological Transition and the Demographic Challenge: ESTRATEGIA NACIONAL CONTRA LA POBREZA ENERGÉTICA 2019–2024 [NATIONAL STRATEGY AGAINST ENERGY POVERTY 2019–2024]. Madrid (2019). https://www.miteco.gob.es/content/dam/miteco/es/prensa/estrategianacionalcontralapobrezaenergetica2019-2024_tcm30-496282.pdf, last accessed 2023/09/20.

Spain's National Institute of Statistics (INE): Household Budget Survey (2021a). https://www.ine.es/dyngs/INEbase/en/operacion.htm?c=Estadistica_C&cid=1254736176806&menu=resultados&idp=1254735976608#!tabs-1254736194790, last accessed 2023/09/20.

Spain's National Institute of Statistics (INE): Total expenditure, average expenditure and distribution of household expenditure (2021b). https://www.ine.es/jaxiT3/Tabla.htm?t=24964&L=1, last accessed 2023/09/20.

Visher, J.: The effects of the physical environment on job performance: towards a theoretical model of workspace stress. Stress and Health 23, 175–184. doi: https://doi.org/10.1002/smi.1134 (2007).

European Parliament, Council of the European Union: DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC. Official Journal of the European Union (2012: L 315), 1–56 (2012).

European Parliament, Council of the European Union: 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. Official Journal of the European Union (2018: L 156), 75–91 (2018).

Krieger, J., Higgins, DL.: Housing and health: time again for public health action. American Journal of Public Health (AJPH) 92(5), 758-68. doi: 10.2105/ AJPH.92.5.758 (2002).

Listokin, D., Listokin, B.: Barriers to the Rehabilitation of Affordable Housing. Volume I Finding and Analysis. U.S. Department of Housing and Urban Development, Office of Policy Development and Research, United States (2001).

Ministry for Ecological Transition and the Demographic Challenge, Ministry of Transport, Mobility and Urban Agenda: Estado de la certificación energética de los edificios (10º Informe) [Status of Energy Certification for Buildings (10th report)]. (2021). https://energia.gob.es/desarrollo/EficienciaEnergetica/CertificacionEnergetica/Documentos/Documentos%20informativos/2022_Informe-seguimiento.pdf , last accessed 2023/09/20.

Beltran-Velamazan, C., Monzón-Chavarrías, M., López-Mesa, B.: A new approach for national-scale Building Energy Models based on Energy Performance Certificates in European countries: the case of Spain. Heliyon 10(3), e25473 (2024). doi: https://doi.org/10.1016/j.heliyon.2024.e25473.

Christensen, T.H., Gram-Hanssen, K., Adjei, A., de Best-Waldhober, M.: Energy renovation practices in Danish homes: The influence of energy labels on home renovation practices Marjolein de Best. In: Proceedings of the 10th Conference of the European Sociological Association (esa2011): Social relations in turbulent times, Geneva, Switzerland, (2011).

Rademaekers, K., Yearwood, J., Ferreira, A., Pye, S., Hamilton, I., Agnolucci, P., Grover, D., Karásek, J., Anisimova, N.: Selecting Indicators to Measure Energy Poverty. Trinomics B.V., Rotterdam (2016).

Sareen, S., Thomson, H., Tirado-Herrero, S., Gouveia, J., Lippert, I., Lis, A.: European energy poverty metrics: Scales, prospects and limits. Global Transitions 2, 26–36. ISSN 2589–7918. doi: https://doi.org/10.1016/j.glt.2020.01.003 (2020).

Thomson H.: Fuel poverty measurement in Europe: A rapid review of existing knowledge and approaches conducted for Eaga Charitable Trust. Technical report, York, University of York. (2013).

Wang, C., Wang, J., Norbäck, D.: A Systematic Review of Associations between Energy Use, Fuel Poverty, Energy Efficiency Improvements and Health. International Journal of Environmental Research and Public Health 19(12), 7393. doi: https://doi.org/10.3390/ijerph19127393 (2022).

Indicators and Data in Spain Regarding an Overview of the Capacities in the Construction, Energy Efficiency and Renewable Energy Sector

Marta Gómez-Gil, Markel Arbulu, Markel Rueda-Esteban, Marta Monzón-Chavarrías, Carlos Beltrán-Velamazán, and Francisco J. González-González

Abstract Capacities of the construction sector are an important vector for a transition towards improving energy efficiency and the broader use of renewable energy in buildings. This affects not only the conventional renovation activity, but also the design and maintenance of buildings with advanced digital features to control their energy behavior. The present study aims to assess the data available on this topic in Spain at the national and regional scales (taking the regions of Aragon and the Basque Country as case studies) in order to be able to develop indicators to assess the building renovation policies effectiveness. The results show that Spain possesses ample data to assess the professional capacity of its sector, and the rough estimates shows existing skills are aligned with requirements, although it is crucial to ensure that university studies adapt to evolving sector needs. Yet emphasis on gathering data on smart technology adoption, engagement with energy communities, and administrative capacity is needed.

M. Gómez-Gil · M. Monzón-Chavarrías · C. Beltrán-Velamazán
Built4Life Lab, University of Zaragoza-I3A, 50018 Zaragoza, Spain
e-mail: m.gomez@unizar.es

M. Monzón-Chavarrías
e-mail: monzonch@unizar.es

C. Beltrán-Velamazán
e-mail: cbeltran@unizar.es

M. Arbulu · M. Rueda-Esteban
Department of Architecture, University of the Basque Country UPV/EHU, 20018 Donostia - San Sebastian, Spain
e-mail: markel.arbulu@ehu.eus

M. Rueda-Esteban
e-mail: markel.rueda@ehu.eus

F. J. González-González (✉)
Department of Architecture and Civil Engineering, Universidad Europea, Madrid, Spain
e-mail: franciscojavier.gonzalez@universidadeuropea.es

B. López-Mesa and X. Oregi (eds.), *Assessing Progress in Decarbonizing Spain's Building Stock*, Digital Innovations in Architecture, Engineering and Construction,
https://doi.org/10.1007/978-3-031-51829-4_7

1 Introduction

Achieving a wide degree of development in the capacities in the construction, energy efficiency and renewable energy sector is key to meeting the challenge of the energy transition in the Europe Union (EU) and all its Member States (MSs), including Spain, on which this chapter focuses.

This matter has been addressed in the so-called Energy Performance Directives (EPBDs) over time in Europe. The EPBD currently in force, Directive (EU) 2018/844 of the European Parliament and the Council, referred to as 2018 EPBD in this book, says that Member States (MSs) "should take into account the need for a clear link between their long-term renovation strategies and pertinent initiatives to promote skills development and education in the construction and energy efficiency sectors" (European Parliament and Council of the European Union 2018). These skills are crucial, as they are part of a broader vision that seeks to share knowledge among all the stakeholders involved in the process of the building stock decarbonization.

To understand the importance of knowledge transfer and technical training in the EU, it is necessary to look at how the issue has been dealt with in the last EPBD proposals. All of them consider this issue as part of the work of a LTRS or National building renovation plan (NBRP) to be developed by the MSs.

Over time, the approach in the EPBDs and related documents has evolved regarding this issue. In Article 2a of the Commission Recommendation (EU) 2019/786 of 8 May 2019 on building renovation (European Commission 2019) (referred to in this book as the 2019 EPBD-related Recommendation) emphasis is placed on enhancing technical and knowledge-related skills within the LTRSs of each MS. However, the scope of the topic is restricted to providing an overview of national initiatives promoting smart technologies, interconnected buildings and communities, as well as skills and education in the construction and energy efficiency sector. The idea is, therefore, to enable technological innovation in relation to the performance of energy issues in buildings, and to promote technical training in these fields to achieve this objective (Table 1).

In the successive versions of the ongoing revision of the EPBD of years 2021, 2022 and 2023 (European Commission 2021; European Commission 2022; European Parliament 2023), the vision is broader encountering points in common with other objectives to be developed by the NBRPs. These documents are referred to in this book as 2021, 2022, and 2023 EPBD Proposal recasts, respectively. Thus, Article 3 1.a of the 2021 EPBD Proposal recast states that the NBRPs should develop "an overview of the national building stock for different types of buildings, building periods and climate zones, based, as appropriate, on statistical surveys and the national database of energy performance certificates in accordance with Article 19, an overview of market barriers and gaps, *and an overview of capacities in the building, energy efficiency and renewable energy sectors*" (European Commission 2021). It can be observed that the diagnosis related to technical capacities extends in a general way to any process of improvement of the building stock, not only limited

Table 1 Capacities in the construction, energy efficiency and renewable energy sector indicators included in selected European directives and related documents. *Source* own creation from data in (European Commission 2019; European Parliament 2023)

Document	Capacities in the construction, energy efficiency and renewable energy sector
2019 EBPD-related Recommendation	– Number of buildings equipped with building energy management systems (BEMSs) or similar smart systems: • Per building type (focus on non-residential) – Public and private investments in smart technologies (including smart grids) – Citizens participating in energy communities – Number of graduated students: • University courses with focus on energy efficiency and related smart technologies • Professional/technical training (EPC certifiers, HVAC inspectors, etc.) – Number of installers skilled in new technologies and working practices – Budget of national research programs in the field of building energy efficiency – Participation of national universities in international scientific research projects (e.g., H2020) on energy efficiency in buildings related topics
2023 EPBD Proposal recast (Articles 3a and 3c)	– Number of Energy service companies – Number of construction companies – Number of architects and engineers – Number of skilled workers – Number of microenterprises and SMEs in the construction/renovation sector – Number of training programs and facilities focused on energy renovation – Number of one-stop-shops per 45,000,000 inhabitants – Architects/engineers/skilled workers retired – Architects/engineers/skilled workers entering the market – Installers and/or installation companies of heating systems – Maintenance personnel of heating systems – Young people on the sector – Women in the sector – Overview and forecast of the evolution of prices of construction materials and national market developments – Number of people being trained within the construction industry in their Member State – Geographic coverage of vocational education and training (VETs) – Number of companies that provide training and apprenticeships – Participation of women and youth in VET and apprenticeships programs – Apprenticeship and VET programs started and completed – Number of awareness raising campaigns for VET opportunities completed – Administrative resources and capacities for: – worst-performing – minimum energy performance standards – energy poverty, social housing – public buildings – residential (single-family, multi family) – non-residential – industry – renewable energy sources – phase-out of fossil fuels in heating and – cooling – whole life-cycle greenhouse gas emissions – circular economy and waste – one-stop shops – renovation passports – smart technologies – sustainable mobility in buildings – district and neighborhood approaches – skills, training – awareness campaigns and advisory tools

to the implementation of advanced digital technologies. Furthermore, the debate on capacity in the construction and energy sectors involves different levels of training for the various actors involved, encompassing both formal training and the specific competencies of these actors. In conclusion, the need for specific professionalization of the technicians and other participants involved in this process is highlighted.

A contribution of the 2021 EPBD Proposal recast is to define specific indicators on skills in its Annex II. The following optional indicators are included in the template provided:

- Number of:
  - Energy service companies.
  - Construction companies.
  - Architects and engineers.
  - Skilled workers.
  - One-stop-shops.
  - Small and medium-sized enterprises (SMES) in the construction/renovation sector.
- Projections of the construction workforce:
  - Architects/engineers/skilled workers retired.
  - Architects/engineers/skilled workers entering the market.
  - Young people in the sector.
  - Women in the sector.

In summary, the instruments developed in the 2019 EPBD-related Recommendation and the 2021 EPBD Proposal recast for the future NBRPs allow for the continuous evaluation of the technicians and companies directly involved in the renovation and implementation of renewable energy installations, as well as the stable availability of human capital sufficiently trained to carry out the necessary work.

In the 2023 EPBD Proposal recast, reference to capacities and skills are included in Art 9., in which it is indicated that MSs shall support compliance with minimum energy performance standards by, among others, "setting the framework to ensure that there is a sufficient and qualified workforce to enable the timely implementation of the minimum energy performance standards in accordance with the national building renovation plans, including by means of a strategy to facilitate the professional education of young people and requalification of workers and creation of more attractive employment opportunities" (European Parliament 2023, Art 9 3.ea). Also, in Art 15. 6, it is stated that MSs "shall monitor the availability of skills and skilled professionals in accordance with Article 3 and develop measures and financing to promote education and training programs, including in digital technologies, to facilitate the professional requalification of workers and creation of employment opportunities to ensure that there is a sufficient workforce with the appropriate level of skills corresponding to the needs in the building sector. Member States shall put in place measures to promote participation in such programs, in particular by microenterprises as well as small and medium sized enterprises (SMEs) and with due regard to the gender dimension. One-stop-shops established pursuant to Article 15a may facilitate access to such programs and the professional reskilling of workers".

In line with these guidelines, in the 2023 EPBD Proposal recast, the previous set of indicators is enlarged with the following additions:

- Number of:
  - Training programs and facilities focused on energy renovation.
  - Renewable energy communities and citizen energy communities.
- Projections of the construction workforce:
  - Installers and/or installation companies of heating systems.
  - Maintenance personnel of heating systems.
- Overview of implemented and planned policies and measures:
  - addressing skills gaps and mismatches in human capacities, and promoting education, training, upskilling and reskilling in the construction, sector and energy efficiency and renewable energy sectors including with a gender dimension.

The indicators that start with 'Number of' and those related to the overview of implemented and planned policies and measures are mandatory, whereas the indicators regarding projections of the construction workforce are optional. Furthermore, the 2023 EPBD Proposal recast also highlights the importance of strengthening the administrative capacity and proposes optional indicators for the areas of worst-performing, minimum energy performance standards, energy poverty, social housing, public buildings, residential (single-family, multi-family), non-residential, industry, renewable energy sources, phase-out of fossil fuels in heating and cooling, whole life-cycle greenhouse gas emissions, circular economy and waste, one-stop shops, renovation passports, smart technologies, sustainable mobility in buildings, district and neighborhood approaches, skills, training, awareness campaigns and advisory tools.

In order to understand the development of these guidelines in the Spanish context, an interesting participatory process was carried out that took place between December 2022 and May 2023 to evaluate the development of the Spain's 2020 LTRS named Long-term strategy for energy renovation in the building sector in Spain (whose acronym in Spanish is ERESEE) (Ministry of Transport, Mobility and Urban Agenda 2020). In this participatory process, the Ministry of Transport, Mobility and Urban Agenda (MITMA), in charge of developing the ERESEE, set up four working groups (inter-ministerial technicians, technicians with the regional authorities, technicians with local authorities and technicians with sector agents), whose conclusions were summarized in a report (Ministry of Transport, Mobility and Urban Agenda 2023).

In the 2020 ERESEE (Ministry of Transport, Mobility and Urban Agenda 2020), capacities in the construction, energy efficiency and renewable energy sector are included in strategic axis 9, under the category of 'supply side measures'. This approach is integrated with the aim of professionalizing the economic stakeholders involved in renovation, with the capacity to offer comprehensive solutions. This is aligned with the measures aimed at promoting industrialization, digitalization, and monitoring of retrofitting activity. Specifically, Sects. 3.3, 3.4 and 3.5 refer to training and capacity building processes. Therefore:

- The initial and continuous training of professionals in the renovation sector regarding new needs (industrialization, digitalization, monitoring, renewable energy installations, etc.) is considered both for initial training and for updating knowledge for already trained technicians. The proposal is to review the intermediate and higher professional training courses and the use of digital courses (MOOCs), public courses and, employment platforms in parallel to formal education. In this section, the experts consider some legislative progress in the incorporation of content in professional training cycles through Royal Decree 921/2022, of October 31, which establishes the Higher Degree Professional Training Specialization Course in Energy Audit and establishes the basic aspects of the curriculum. (Ministry of Education and Vocational Training 2022).
- The need to more effectively incorporate content related to renovation and energy efficiency into university courses is highlighted. Ensuring that graduates are able to carry out Energy Certifications, Building Assessment Reports and other procedures added to the update in renovation techniques, including energy efficiency, and incorporation of renewable energies into the building.

The recommendations point to the importance of professional associations in the organization of training courses, highlighting that progress has been made in the training of university graduates or professionals undergoing retraining and not so much in the incorporation of improvements in university curricula. It is interesting to note the development of professional and scientific conferences that have been promoted by associations, foundations and other non-educational institutions that give greater transversality to the corporate work of the professional associations (National Environmental Congress, CONAMA Foundation, NATURGY Foundation, Spanish Technical Association of Air Conditioning and Refrigeration, for example). The interest of some regional governments in promoting conferences, courses and conferences is also noteworthy.

Finally, the drafting of support guides for technicians and the promotion of demonstrative pilot actions are proposed as a way of reinforcing the training of technicians. Few are the actions reviewed in the recommendations in this sense (FENERCOM guide, guide for the request of public aid in the PIREP program, which stimulates the renovation of public buildings) (Ministry of Transport, Mobility and Urban Agenda and Green Building Council Spain 2021).

In the case of the open digital tools, are remarkable examples in line with the 2020 ERESEE objectives uch as URBAN 3R (Building Institute of Valencia (IVE) 2022), focused on promoting decision-making support for the design of regeneration plans and strategies on an urban scale, and renUEva: Know and improve your Home (Ministry of transport, Mobility and Urban Agenda (2022b)), which allows the approximate calculation of a building's energy consumption, including building improvement options compatible with the set of grants, tax incentives and financing implemented in the context of the Next Generation EU funds for residential renovation. Both tools are promoted by the MITMA. Another case is the Guide to Local Urban Regeneration Strategies developed by MITMA and the 3R City Observatory, which objective is to help local authorities in the drafting of local renovation strategies within the framework of the Spanish Urban Agenda and to contribute to the promotion of regeneration activity in Spain (Ministry of Transport, Mobility and Urban Agenda and 3R City Observatory 2022).

The objective of this chapter is to develop a set of indicators on an overview of the capacities in the construction, energy efficiency and renewable energy sector. The aim is to adjust the intentions of the EPBD directive and of Spain's 2020 ERESEE to the real availability of data and the particular conditions of the sector in the country and in two regions used as case study, Aragon and the Basque Country. Next, the methodological steps that were taken for this purpose are presented.

2 Methodology

To develop the indicators that allow an overview of the capacities in the construction, energy efficiency and renewable energy sector in Aragon, the Basque Country and Spain, the process indicated in Fig. 1 was followed.

The first step consisted in the development of a common template for these indicators based on:

- Indicator:
  - Definition of the indicator.
  - Variables to quantify it and their unit of measurement.
  - Purpose and advantages of implementing this indicator.
- Information sources:
  - Availability of information to generate this indicator at different scales.
  - Entity responsible for providing this information.
- Measurement:
  - Measurement method.
  - Methodology.
  - Current possibilities of obtaining it.
  - Information necessary to generate it.

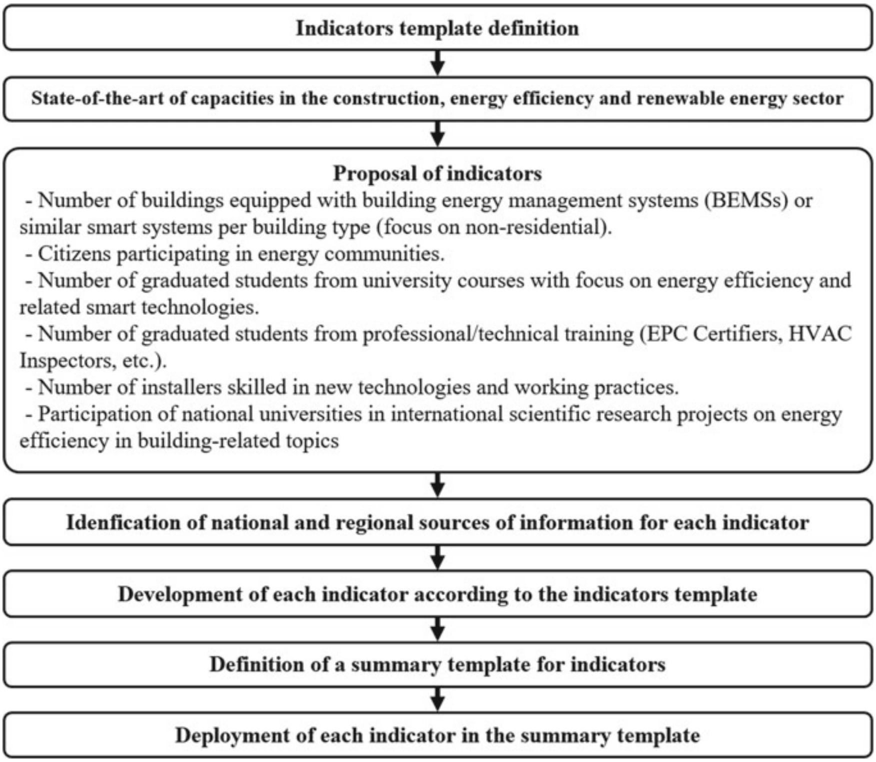


Fig. 1 Methodology implemented to generate indicators on an overview of the capacities in the construction, energy efficiency and renewable energy sector in Spain, and the regions of Aragon and the Basque Country. *Source* own creation

– Availability and quality of data.

In order to select the capacities in the construction, energy efficiency and renewable energy sector indicators to develop, we considered those which have been suggested in European directives and related documents. For this study, we mainly considered two documents. On one hand, we studied the indicators included in the 2019 EPBD-related Recommendation (European Commission 2019), which was the first document in which a framework of progress indicators to measure the European building stock decarbonization was proposed. On the other hand, we analyzed the indicators included in the 2023 EPBD Proposal recast (European Parliament 2023), which is the document with the last version of the framework of progress indicators. In Table 1, the indicators in both documents for capacities in the construction, energy efficiency and renewable energy sector can be compared. As can be seen in the table, indicators included in the 2023 EPBD Proposal recast are more specific and detailed than those in the 2019 EPBD-related Recommendation.

Because of the extensive array of indicators in the 2023 recast of the EPBD Proposal, we opted to create a simplified version based on the 2019 EPBD-related Recommendation, and in conclusion the following indicators were proposed:

- Number of buildings equipped with building energy management systems (BEMSs) or similar smart systems per building type (focus on non-residential).
- Citizens participating in energy communities.
- Number of graduated students from university courses with focus on energy efficiency and related smart technologies.
- Number of graduated students from professional/technical training (EPC Certifiers, HVAC Inspectors, etc.).
- Number of installers skilled in new technologies and working practices.
- Participation of national universities in international scientific research projects on energy efficiency in building-related topics.

Once the key indicators to cover this topic were identified, the available sources of information were studied and the standard template for each indicator was developed and generated.

Subsequently, a summary template was defined for each indicator with the main points covered in the complete template.

The result of these methodological steps is a list of indicators grouped into three subgroups:

- The first group refers to the number of buildings with technological innovations that require specific skills on the part of technicians and users when putting them into operation and for their maintenance. Number of buildings equipped with building energy management systems (BEMSs) or similar smart systems per building type (focus on non-residential).
- The second focuses on users involved in the implementation of renewable energies, that is, in energy communities. Citizens participating in energy communities.
- Third in available human capital with technical knowledge and training level. Number of graduated students from university courses with focus on energy efficiency and related smart technologies, number of graduated students from professional/technical training, (EPC Certifiers, HVAC Inspectors, etc.), number of installers skilled in new technologies and working practices and participation of national universities in international scientific research projects on energy efficiency in building-related topics.

Table 2 Variables and indicator developability. Number of buildings equipped with BEMS or similar smart systems per building type (focus on non-residential). *Source* own creation

Indicator: Number of buildings equipped with BEMSs or similar smart systems per building type (focus on non-residential)	
Variables	– Number of buildings equipped with BEMS or similar smart systems per building type (focus on non-residential)
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

3 Indicators

3.1 Number of Buildings Equipped with Building Energy Management Systems (BEMSs) or Similar Smart Systems Per Building Type (Focus on Non-Residential)

The purpose of this indicator is to quantify buildings with smart systems that enable more efficient use of energy. In Table 2 the main variable considered and the developability is indicated, no sources were found that compile this indicator.

3.2 Citizens Participating in Energy Communities

The purpose of this indicator is to quantify the creation of energy communities in municipalities with less than 5000 inhabitants in areas known as 'La España Vaciada' (Emptied Spain). In Table 3 the main variable considered and the developability is indicated, no sources were found that compile this indicator.

Table 3 Variables and indicator developability. Citizens participating in energy communities. *Source* own creation

Indicator: Citizens participating in energy communities. Source: own creation	
Variables	– Citizens participating in energy communities
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

3.3 Number of Graduated Students from University Courses with Focus on Energy Efficiency and Related Smart Technologies

The purpose of this indicator is to estimate the number of university graduates in studies focusing on energy efficiency and related smart technologies. For the development of this indicator there are national and regional data sources available (Table 4).

The published data cannot be filtered by energy efficiency-related degrees, so openly published information needs to be screened. This screening has to be done manually and entails the complexity of having to subjectively estimate which degrees are indeed related to energy efficiency and which are not, without having in-depth knowledge on the full curricula of each one.

Information on the specific university degrees from each of the universities does not include data on doctorates, making it impossible to refine the results for this level of education. Moreover, as a manual selection of energy efficiency-related degrees in each of the Spanish universities has to be made, obtaining national results would require an enormous amount of data analysis.

For these reasons the variable for this indicator is the number of graduates from Bachelor degrees, Master degrees, PhD, University Expert/Specialist Course/ Diploma and similar in different regions of Spain.

Figures 2 and 3 show the graduates from universities of the regions of Aragon and the Basque Country respectively. As can be observed, there is no homogeneity in the selection of studies with data available in the two regions, so comparison cannot be as accurate as it should, and an assessment on a national scale requires the development of a more refined study that is not part of the scope of this chapter.

3.4 Number of Graduated Students from Professional/ Technical Training (EPC Certifiers, HVAC Inspectors, Etc.)

The purpose of this indicator is to know the number of technicians currently trained in energy efficiency, as this is a scarce but highly demanded professional profile that is crucial to achieving carbon neutrality by 2050. For the development of this indicator there are national and regional data sources available (Table 5).

The published data cannot be filtered by energy efficiency-related qualifications, so openly published information needs to be screened. In some cases, it is easy to identify qualifications that have an important energy efficiency component, such as in the professional study area ‘energy and water’. However, in the rest of the professional study areas and sectors, identifying these qualifications is more complex.

Table 4 Sources for indicator. Number of graduated students from university courses with focus on energy efficiency and related smart technologies. *Source* own creation

Indicator: Number of graduated students from university courses with focus on energy efficiency and related smart technologies	
Variables	– Number of graduates from Bachelor degrees, Master degrees, PhD, University Expert/Specialist Course/Diploma and similar in different regions of Spain
Indicator developability	– Data availability: partially available – Processing method from source: indirectly – Data processability: yes, CSV, except in the case of the SIIU infographic, where the formats available for downloading the information are PPT, image and PDF
National source	Ministry of Universities
Source links	https://www.universidades.gob.es/portal/site/universidades/menuitem.78fe777017742d34e0acc310026041a0/?vgnextoid=3b80122d36680710VgnVCM1000001d04140aRCRD https://public.tableau.com/app/profile/equiposiiu/viz/Academica21_EEU/InfografiaEEU
Characteristics of the source	– Availability: open data – Data collection method: the universities send files on their students to the Integrated University Information System (SIIU) platform developed by the General Secretariat for Universities. These files are recorded in a database containing information on all the centers and all the university degrees. From there, the data are cleaned, validated, and tabulated to create the University Student Statistics – Data processability: yes, CSV data – Georeferencing: no – Data update frequency/last update: updated annually, with at least one-year delay
Regional source—Aragon	Government of Aragon
Source links	https://www.aragon.es/-/sistema-universitario-de-aragon#anchor1
Characteristics of the source	– Availability: open data – Data collection method: the information comes mainly from the SIIU – Data processability: yes, CSV data – Georeferencing: no – Data update frequency/last update: updated annually, with at least one-year delay
Regional source—Basque Country	Basque Institute of Statistics (Eustat)

(continued)

Table 4 (continued)

Indicator: Number of graduated students from university courses with focus on energy efficiency and related smart technologies	
Source links	https://www.eustat.eus/elementos/ele0003200/alumnado-que-finalizo-sus-estudios-de-grado-en-las-universidades-de-la-ca-de-euskadi-por-titulacion-segun-territorio-historico-y-sexo-201819/tbl0003210_c.html https://www.eustat.eus/elementos/ele0003200/alumnado-que-finalizo-estudios-en-las-universidades-de-la-ca-de-euskadi-por-titularidad-del-centro-y-rama-de-estudios-segun-el-nivel-de-estudios-y-sexo-201819/tbl0003209_c.html
Characteristics of the source	– Availability: open data – Data collection method: the information comes mainly from the SIIU – Data processability: yes, CSV data – Georeferencing: no – Data update frequency/last update: updated annually, with at least one-year delay

Fig. 2 Graduates from universities of the region of Aragon. *Source* own creation from data in (Government of Aragon 2022)

As with the previous indicator, no data were found for specialization courses, which may be of great interest for specific training modules such as energy assessor or auditor courses.

The reader is referred to the website of the Ministry of Economic Affairs and Digital Transformation of Spain for details regarding the number of graduated students from professional training across Spain, including the regions of Aragon and the Basque Country. Reproduction of this information necessitates specific permission, which we did not acquired. Data on specialization courses and on basic vocational training is non-available either, as no qualifications related to energy efficiency in buildings were identified.

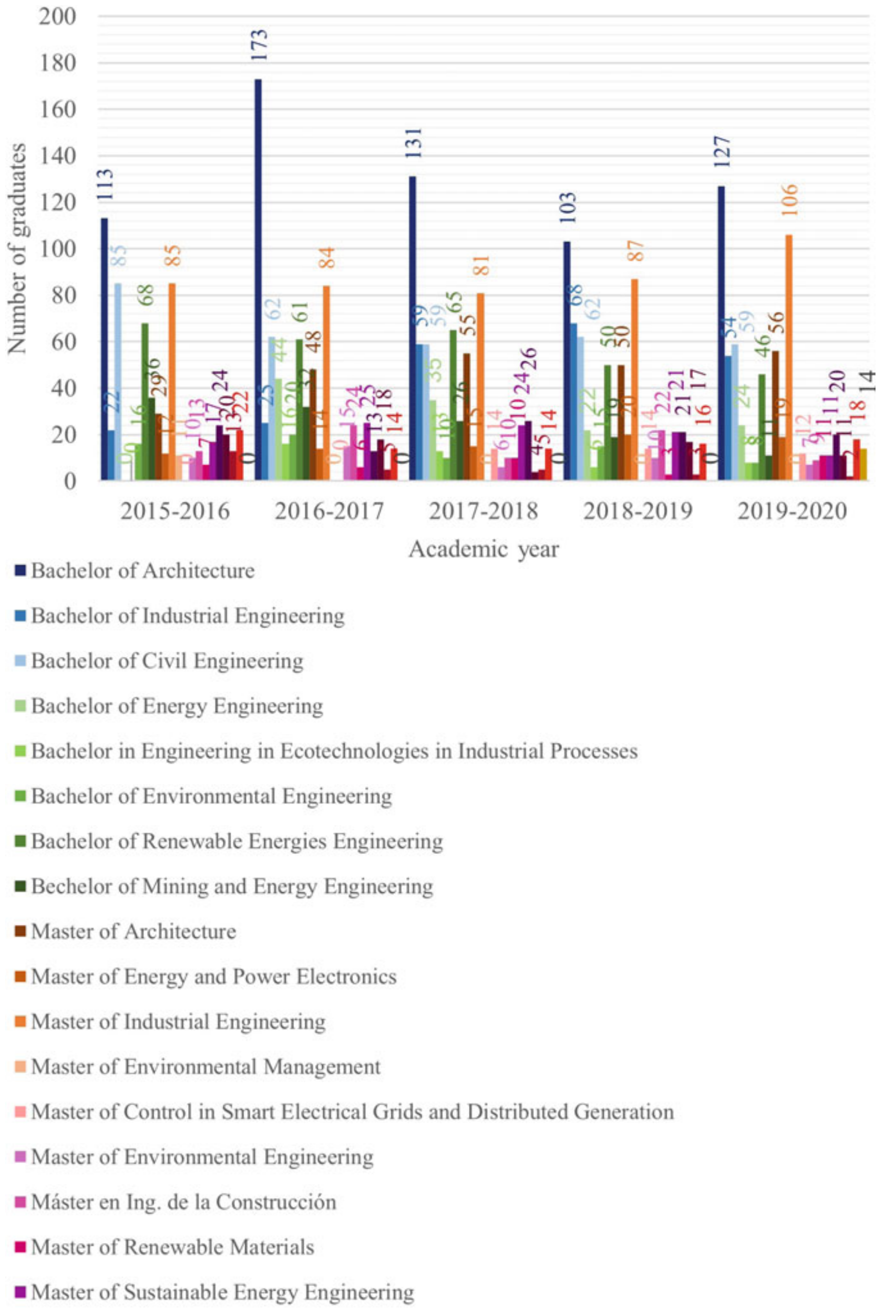


Fig. 3 Graduates from universities in the Basque Country. *Source* own creation from data in (Basque Institute of Statistics 2023)

Table 5 Sources for indicator number of graduated students from professional/technical training (EPC certifiers, HVAC inspectors, etc.). *Source* own creation

Indicator: Number of graduated students from professional/technical training (EPC certifiers, HVAC inspectors, etc.)	
Variables	– Number of graduated students from professional/technical training (EPC certifiers, HVAC inspectors, etc.) in Spain, Aragon, and the— Basque Country – Number of certifies in Spain, Aragon, and the Basque Country
Indicator developability	– Data availability: partially available – Processing method from source: indirect – Data processability: yes (xlsx and CSV). The graphs of the Vocational Training Observatory can be downloaded in PNG, JPEG, PDF and SVG format, which hinders the processability of the data, as is the case with the II Map of Employability of Vocational Training in Aragon. Period 2017–2019, available only in PDF
National source	Ministry of Education and Vocational Training
Source links	http://estadisticas.mecd.gob.es/EducaDynPx/educabase/index.htm?type=pcaxis&path=/no-universitaria/alumnado/fp/2019-2020/resul&file=pcaxis&l=s0 https://todofp.es/inicio.html
Characteristics of the source	– Availability: open data – Data collection method: the information collected by the Autonomous Community Education Administrations (from teaching centers or centralized information systems) is integrated, filtered, analyzed, and disseminated by the General Subdirectorate for Statistics and Studies of the Ministry of Education and Vocational Training, which publishes it in the Non-University Statistics section – Data processability: yes, CSV and XLS formats – Georeferencing: no – Data update frequency/last update: updated annually,
National source	Vocational Training Observatory—Bankia Foundation
Source links	https://www.observatoriofp.com/datos-interactivos
Characteristics of the source	– Availability: open data – Data collection method: data compiled from other unspecified official sources – Data processability: no – Georeferencing: no – Data update frequency/last update: updated annually,
Regional source—Aragon	Government of Aragon
Source links	https://www.aragon.es/-/sistema-universitario-de-aragon#anchor1

(continued)

Table 5 (continued)

Indicator: Number of graduated students from professional/technical training (EPC certifiers, HVAC inspectors, etc.)	
Characteristics of the source	– Availability: open data – Data collection method: data from the Aragon Institute of Statistics – Data processability: no – Georeferencing: no – Data update frequency/last update: every three years
Regional source—Basque Country	Basque Institute of Statistics (Eustat)
Source links	https://www.eustat.eus/elementos/ele0000000/alumnado-matriculado-en-formacion-profesional-en-la-c-a-de-euskadi-por-grado-y-familia-profesional-segun-territorio-historico-y-sexo/tbl0000096_c.html
Characteristics of the source	– Availability: open data – Data collection method: the data come from all the public and private centers that provide regulated education included in the Basque Government's Register of Educational Centers – Data processability: yes, XLS and CSV formats – Georeferencing: no – Data update frequency/last update: annually updated,

3.5 *Number of Installers Skilled in New Technologies and Working Practices*

The purpose of this indicator is to know the number of installers and technicians currently working in the strategic areas explained in the previous section. They have a very important role to play in achieving carbon neutrality by 2050. For the development of this indicator there are national and regional data sources available (Table 6).

In the Register of Installers in the Digitalization and Artificial Intelligence area, the link of each company or installer must be opened to view the services they offer, and it is not possible to filter by discipline.

Furthermore, none of the registers provided information on companies or professionals that specialize in energy efficiency in buildings, in the installation of renewable energy production systems or in other new professional practices related to buildings. It is therefore considered that industrial registers should provide new categories to accommodate these newer but established professions.

In fact, with the available data it was not possible to fully respond to the variables proposed for this indicator, which also come from the Recovery, Transformation, and Resilience Plan.

The reader is referred to the webpage of the Ministry of Economic Affairs and Digital Transformation of Spain to obtain the information on the number of installers skilled in the field of Digitalization and Artificial Intelligence in Spain and the regions

Table 6 Sources for indicator. Number of installers skilled in new technologies and working practices. *Source* own creation

Indicator: Number of installers skilled in new technologies and working practices	
Variables	– Number of companies/Installers in the Digitalization and Artificial Intelligence area in Spain, Aragon, and the Basque Country – Number of companies/Installers of thermal installations in buildings in Spain, Aragon, and the Basque Country – Number of companies/installers of fire protection in Spain, Aragon, and the Basque Country
Indicator developability	– Data availability: partially available – Processing method from source: partially direct. At the national scale the indicator can be compiled directly if the aim is to obtain the number of professionals or companies and indirectly if the aim is to discriminate by area of intervention. In the case of Aragon, the process is direct. In the case of the Basque Country, the indicator needs to be obtained indirectly – Data processability: data from the Integrated Industrial Register can be downloaded in Excel format. Information from the Register of Installers in the Digitalization and Artificial Intelligence area can be downloaded in XLS and CSV format. The Basque register is available in PDF format. The Aragon register can only be viewed on-line, and the data cannot be processed
National source	Ministry of Economic Affairs and Digital Transformation
Source links	https://avancedigital.mineco.gob.es/RegistroInstaladores/Paginas/ResultadosConsultaInstaladores.aspx
Characteristics of the source	– Availability: open data – Data collection method: regional registers transfer the data to the nation-al Integrated Industrial Register – Data processability: yes, XLS and CSV formats – Georeferencing: no – Data update frequency/last update: daily
National source	Ministry of Industry, Trade and Tourism. Integrated Industrial Register
Source links	https://industria.gob.es/registros-industriales/RII/Paginas/consultas-publicas.aspx
Characteristics of the source	– Availability: open data – Data collection method: regional registers transfer the data to the nation-al Integrated Industrial Register – Data processability: yes, XLS format – Georeferencing: no – Data update frequency/last update: unspecified
Regional source—Aragon	Government of Aragon. Department of Industry and Innovation. Register of installation and maintenance companies
Source links	https://www.aragon.es/-/sistema-universitario-de-aragon#anchor1

(continued)

Table 6 (continued)

Indicator: Number of installers skilled in new technologies and working practices	
Characteristics of the source	– Availability: open data – Data collection method: data from the Aragon Institute of Statistics – Data processability: no – Georeferencing: no – Data update frequency/last update: every three years
Regional source—Basque Country	Basque Government. Department of Economic Development, Sustainability and Environment. Register of authorized companies
Source links	https://www.euskadi.eus/empresas-habilitadas/
Characteristics of the source	– Availability: open data – Data collection method: regional registers transfer the data to the nation-al Integrated Industrial Register – Data processability: no – Georeferencing: no – Data update frequency/last update: unspecified. Last update in May 2020

of Aragon and the Basque Country. A specific permission is required to reproduce this information, which we did not obtain. For the same reason, the reader is also referred to the webpage of the Ministry of Industry, Trade and Tourism of Spain to see the data on number of companies or installers of thermal installations in buildings and of fire protection in Spain and the regions of Aragon and the Basque Country.

3.6 Participation of National Universities in International Scientific Research Projects on Energy Efficiency in Buildings-Related Topics

The purpose of this indicator is to understand the implication of universities in international research related to energy saving in the building sector and the development of this research. Therefore, the evolution of research institutions on energy efficiency in building-related topics can therefore be analyzed through several key variables. Through this indicator it may be possible to assess the progress of international projects related to the energy efficiency of buildings, as well as their relevance for national universities. For the development of this indicator there is indirect information from national and regional data sources (Table 7). Due to the fragmentation of the related data across the different university Vice-Rectorates, Departments or Offices, it is not feasible to create the indicator in a direct and effective way. There are no data at the national level.

Table 7 Sources for indicator. Participation of national universities in international scientific research projects on energy efficiency in buildings-related topics. *Source* own creation

Indicator: Participation of national universities in international scientific research projects on energy efficiency in buildings-related topics	
Variables	– Number of universities participating – Number of research projects – Number of researchers
Indicator developability	– Data availability: partially available – Processing method from source: indirect – Data processability: no
Regional source—Aragon	University of Zaragoza. European Projects Office—OPE
Source links	https://ope.unizar.es/2014-2020
Characteristics of the source	– Availability: open data but insufficient to collect the indicator – Data collection method: the data are published by the universities – Data processability: no – Georeferencing: no – Data update frequency/last update: annually. Last update in 2023
Regional source—Basque Country	Vice-Rectorate for Research of the University of the Basque Country. EHUrOPE—International R&D Office
Source links	https://www.ehu.eus/en/web/europeanprojects/antolaketa/upv-ehuren-parte-hartzea/
Characteristics of the source	– Availability: open data but insufficient to collect the indicator – Data collection method: the data are published by the universities – Data processability: no – Georeferencing: no – Data update frequency/last update: annually. Last update unspecified

4 Conclusions

The situation regarding skills and training in the construction, energy efficiency and renewable energy sector in Spain was analyzed using data provided by each indicator, focusing on two case study regions, Aragon and the Basque Country.

The conclusions of this analysis are summarized in the following points:

(1) Regarding the situation of buildings with smart systems that enable more efficient use of energy, and the consequent technical training that allows agents to adequately manage resources linked to building, no sources were found to obtain information related to the proposed indicator, and, therefore, no variables were proposed for this indicator.

(2) A similar situation arises in the evaluation of the implementation of energy communities at national, regional, and local level. It is also not possible to describe and diagnose the link between energy efficiency and renewable energies.

(3) The third subgroup of indicators refers to the state of formal education and training of professionals. These yield some conclusions:

Firstly, it is necessary to consider the heterogeneity in the publication of data at national and regional level (for the specific cases of Aragon and the Basque Country). The information provided by the regional governments, who have competences in education, has a higher level of disaggregation.

Analyzing the data on graduates from university studies in Aragon and the Basque Country, it can be seen that between 2015 and 2020 the percentage of people who were trained in studies related to energy efficiency in buildings and renewable energies ranges from 1.18% to 1.28% of the university population in Aragon (the average is 1.19%) and, in the case of the Basque Country, this range varies between 1.21% and 1.40% (the average is 1.29%). If we extrapolate these data to the Spanish university graduate population (241,157 in 2021), we should have a number of graduates that could join the sector of between 2862 and 3105 professionals with academic studies.

Concerning Professional Training Specialization Course education, the presence of the sector in this type of training is much greater than in the university sector. The data at national level show a figure of 6453 graduates in the year 2021, which means 33.93% of the total number of people studying this type of studies. This dominant trend is similar in Aragon, although with a proportion of 21.87%, and in the Basque Country, somewhat higher than the Spanish average (34.50%).

Regarding the upskilling of professionals by means of training courses, in the three types of training analyzed, at the national level we found values always above 10,000 people who are trained annually in these courses (Digitalization 12,708, Thermal installations 58,717 and Fire protection 32,674). Although we cannot get an idea of the percentage that these figures represent with respect to the volume of students attending these continuous training and professional skills courses, the data seem to indicate that continuous training is an important task for professionals.

No data are available on the research projects involved into this training.

As a conclusion, the question that arises is whether the training efforts made are in line with the renovation needs of the sector. To answer this question, the volume of people trained is related to the expected rate of retrofitting in the country. Thus, if we consider that the annual rate of energy renovation of buildings for the next decade amounts to approximately 120,000 dwellings per year, it can be considered that the number of projects for professionals in complete buildings of 20 dwellings (on average approximately) requires the drafting of 6000 projects per year. If only university graduates with specific training in the sector are counted, it can be considered that about 3000 new professionals who can legally develop projects would have to carry out 3 building energy renovation projects per year, which is a plausible figure for medium-sized consultancy firms and professional studios.[1]

Similarly, considering changes in installations as minor projects to be carried out by installers and graduates of Professional Training Specialization Course, we find 4000 graduates of intermediate degrees and 58,000 professionals who have taken specialization courses. That means that, in order to meet the needs of 300,000 homes, each professional must work on 5 or 6 installations per year.

In conclusion, Spain has a substantial amount of data available to gauge the professional capacity of the sector. The provided estimates are simplified, as they overlook active professionals already in the market capable of approving renovation projects. Additionally, they do not differentiate between building types or the diverse professions that could potentially collaborate. Acknowledging these limitations, it can be asserted that existing professional skills are in line with the requirements. However, it is crucial to ensure that university studies and training programs are continuously answering to the changing real needs of the sector. On the other hand, there is a need for increased emphasis on gathering data regarding the adoption of smart technologies, engagement with energy communities, and assessing administrative capacity.

Acknowledgements This work was funded by the MINISTRY OF SCIENCE AND INNOVATION OF SPAIN, grant number PID2019-104871RB-C21/AEI/10.13039/501100011033 and by GOBIERNO DE ARAGÓN, grant number T37_23R: Built4Life Lab.

References

Basque Institute of Statistics: Students who completed studies at the universities of the C.A. of Euskadi by ownership of the center and branch of study, according to level of education and sex. 2021/22. https://en.eustat.eus/elementos/ele0003200/ti_alumnado-que-finalizo-estudios-en-las-universidades-de-la-ca-de-euskadi-por-titularidad-del-centro-y-rama-de-estudios-segun-nivel-de-estudios-y-sexo-202122/tbl0003209_i.html, last accessed 2023/09/20 (2023).

Building Institute of Valencia (IVE) renUEva: Conoce y mejora tu Vivienda [Know and Improve Your Home], https://renueva.five.es/ last accessed 2023/09/20 (2022)

European Commission: COMMISSION RECOMMENDATION (EU) 2019/786 of 8 May 2019 on building renovation. Official Journal of the European Union (2019: L 127), 34–79 (2019).

European Commission: Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast). COM/2021/802. Brussels (2021).

European Commission. Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast). ST 13280 2022 INIT. Brussels (2022).

[1] According to the National Integrated Energy and Climate Plan (Ministry for the Ecological Transition and the Demographic Challenge 2020, p. 58), the energy renovation objectives between 2021 and 2030 are 1,200,000 homes, which represents a rate of execution of the objectives of 120,000 homes with an improvement in energy efficiency (thermal envelope) throughout the annual decade. Also, it is also established that the needs for intervention in the renovation of thermal heating and DHW installations should reach a rate of 300,000 homes per year.

European Parliament, Council of the European Union: 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. Official Journal of the European Union (2018: L 156), 75–91 (2018).

European Parliament: Energy performance of buildings (recast) Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (COM(2021)0802 – C9–0469/2021 – 2021/0426(COD)). Strasbourg (2023).

Government of Aragon: Estadísticas del sistema universitario de Aragón [Statistics of the university system of Aragon], https://www.aragon.es/-/sistema-universitario-de-aragon#anchor2, last accessed 2023/09/20 (2022).

Ministry for the Ecological Transition and the Demographic Challenge: Plan Nacional Integrado de Energía y Clima (PNIEC) 2021–2030 [National Integrated Energy and Climate Plan (PNIEC) 2021 2030]. Madrid (2020).

Ministry of Education and Vocational Training: Real Decreto 921/2022, de 31 de octubre, por el que se establece el Curso de especialización de Formación Profesional de Grado Superior en Auditoría energética y se fijan los aspectos básicos del currículo [Royal Decree 921/2022, of October 31, establishing the Specialization Course in Higher Vocational Training in Energy Audit and setting the basic aspects of the curriculum]. Official State Gazette (BOE), 275, pp. 155990 a 156015 (2022).

Ministry of Transport, Mobility and Urban Agenda: 2020 Update of the long-term strategy for energy renovation in the building sector in Spain (ERESEE). Madrid (2020).

Ministry of Transport, Mobility and Urban Agenda, 3R City Observatory: Guía de Estrategias Locales de Rehabilitación Urbana [Guide to Local Urban Renovation Strategies]. Madrid (2022).

Ministry of Transport, Mobility and Urban Agenda. renUEva: Know and improve your Home (2022b), https://renueva.five.es/, last accessed 2023/09/20

Ministry of Transport, Mobility and Urban Agenda, Green Building Council Spain: Programa de Impulso a la Rehabilitación de los Edificios Públicos para las Comunidades y Ciudades Autónomas (PIREP autonómico) [Program for the Promotion of Renovation of Public Buildings for Autonomous Communities and Cities (Regional PIREP)] (2021).

Ministry of Transport, Mobility and Urban Agenda: Recomendaciones de los grupos de trabajo para la implementación de las medidas de la ERESEE 2020 [Workgroup recommendations for the implementation of 2020 ERESEE measures]. Madrid (2023).

Ministry of Transport, Mobility and Urban Agenda and Cíclica: URBAN3R https://urban3r.es/, last accessed 2023/09/20. (2023)

Indicators and Data in Spain for an Overview of Actual Energy Savings and Wider Benefits of Renovation of Buildings

Marta Gómez-Gil, Markel Arbulu, Xabat Oregi, Marta Monzón-Chavarrías, Carlos Beltrán-Velamazán, and Francisco J. González-González

Abstract The renovation of buildings brings about energy savings and various other benefits, encompassing not only reductions in energy consumption expenditure but also improvements in living conditions. Those 'other benefits' include quantifiable aspects derived from health savings, the use of materials that extend the life cycle of buildings, avoiding the consequences derived from energy poverty or improving the productivity of workers. This study aims to review the indicators proposed in the European Commission Recommendation (EU) 2019/786 and in the latest version of the ongoing revision of the Energy Performance of Building Directive, in order to propose a set of indicators and analyze their possibilities of being collected at national and regional levels, depending on the available data sources. The results show that while there are some data on benefits from renovation activity at both the national and regional levels that are partially available, a comprehensive and precise understanding of savings and benefits remains unavailable at this time. It is

M. Gómez-Gil · M. Monzón-Chavarrías · C. Beltrán-Velamazán
Built4Life Lab, University of Zaragoza-I3A, 50018 Zaragoza, Spain
e-mail: m.gomez@unizar.es

M. Monzón-Chavarrías
e-mail: monzonch@unizar.es

C. Beltrán-Velamazán
e-mail: cbeltran@unizar.es

M. Arbulu · X. Oregi
Department of Architecture, University of the Basque Country UPV/EHU, 20018 Donostia-San Sebastian, Spain
e-mail: markel.arbulu@ehu.eus

X. Oregi
e-mail: xabat.oregi@ehu.eus

F. J. González-González (✉)
Department of Architecture and Civil Engineering, Universidad Europea, Madrid, Spain
e-mail: franciscojavier.gonzalez@universidadeuropea.es

B. López-Mesa and X. Oregi (eds.), *Assessing Progress in Decarbonizing Spain's Building Stock*, Digital Innovations in Architecture, Engineering and Construction,
https://doi.org/10.1007/978-3-031-51829-4_8

essential to emphasize the advantages of commencing a harmonization process for data collection across the European Union member states in this subject.

1 Introduction

To comprehend the significance given in the European Union (EU) to energy and economic savings resulting from building renovation Member States (MSs), along with other associated benefits, one can examine the strategies and measures proposed in the Commission Recommendation (EU) 2019/786 (European Commission 2019), in the currently in force Energy Performance of Buildings Directive (EPBD) of year 2018, and in the successive versions of the ongoing revision of the EPBD of years 2021, 2022 and 2023 (European Commission 2021; European Commission 2022; European Parliament 2023). These documents are referred to in this book as 2019 EPBD-based Recommendation, 2018 EPBD, and 2021, 2022, and 2023 EPBD Proposal recasts, respectively.

Section 2.3.1.7 of the 2019 EPBD-related Recommendation, which relates to article 2a(1)(g) of the 2018 EPBD, establishes that the implementation of policies must be based on expectations regarding energy cost savings. Additionally, it emphasizes the consideration of other non-financial benefits, which should be managed using quantifiable evidence. The directive provides a non-exhaustive list of non-financial benefits, with a special focus on improvements in the energy performance of buildings leading to a healthier indoor environment and associated health benefits. Specifically, it emphasizes aspects related to:

- Increased resilience to the effects of climate change, especially overheating of homes.
- The benefits derived from lengthening the life cycle of the building, implying the use of materials with less embedded energy, so that the 'whole life carbon approach' would help identifying the overall best combined opportunities for reducing lifetime carbon emissions, and helps avoid "any unintended consequences".
- More indirectly, benefits due to the removal of carcinogenic materials such as asbestos are mentioned.
- The improvement of comfort levels in the interior of buildings as a means of preventing health problems.
- On a broader social impact level, consideration as associated advantages the improvement of labor productivity by improving comfort in the workplace.

According to this approach, the indicators that are proposed to evaluate decision-making, and which are found in Annex II of the 2029 EPBD-based Recommendation, can be divided into those that measure savings over costs, including those derived from solving the problems of energy poverty, and those which measure other benefits (see Table 1 in the methodology section of this chapter).

The 2021 EPBD Proposal recast (European Commission 2021) defends a similar approach in Article 3 on the National Building Renovation Plans (NBRPs). However, the treatment of energy poverty is more developed, with more specific indicators to evaluate the phenomenon in each MS. In this case, the focus shifts from costs derived from energy poverty to quantifying the number of people who cannot alleviate this vulnerable situation (percentage of people affected by energy poverty, proportion of disposable household income spent on energy, and population living in inadequate dwelling conditions or with inadequate thermal comfort conditions). Hence, we consider that the issue of energy poverty is a significant and specific concern, and for this reason, it is excluded from the discussion on savings and additional benefits in this chapter. A more thorough examination of this matter is available in chapter six of this book.

As in the precedent directives, in the 2023 EPBD Proposal recast (European Parliament 2023), Article 3, which is dedicated to the content of the NBRPs, contemplates the need for an evidence-based estimate of expected energy savings, greenhouse gas (GHG) emissions reductions, and wider benefits, including indoor environmental quality, which may be based on an integrated district approach. Additionally, in Annex II(da), on 2050 roadmap for energy poverty reduction, costs and savings are specifically considered again. Thus, a part of the funding for renovation measures must encompass support to local administrations for the "reduction of energy poverty and energy savings achieved among vulnerable households and people living in social housing comprising of nationally established targets and an overview of implemented and planned policies and funding measures supporting the elimination of energy poverty".

Other complementary aspects are discussed in article 7a of the New European Bauhaus initiative, which focuses on maximizing benefits through bottom-up participation processes, showcasing how "individual buildings or whole neighborhoods can be transformed into zero emission buildings and districts in an affordable, sustainable and socially inclusive way" (European Parliament 2023 Art. 7a). Additionally, article 10, relating to the Building Renovation Passport, highlights wider benefits in the fields of "health, comfort, indoor environmental quality, safety such as fire, electrical, and seismic safety, and the improved adaptive capacity of the buildings to climate change" (European Parliament 2023 Art. 10).

In coherence with the points outlined in the main text of the 2023 EPBD Proposal recast, the table 'Template for the national building renovation plans', included in Annex II, highlights the necessity for savings measures and other benefits, as reflected in the indicators applicable to the different proposed roadmaps. These indicators fall under the heading of 'expected wider benefits' and can be found in Table 1 in the methodology section of this chapter. These indicators specifically focus on the creation of new jobs, the impact on energy poverty, and the reduction of indirect costs resulting from improved health conditions inside renovated homes. In essence, we observe that in proposing these indicators, the 2023 EPBD Proposal recast follows the precedent set of indicators in the 2019 EPBD-related Recommendation and the 2021 EPBD Proposal recast. The energy poverty indicators established in previous versions of the frameworks are also reintroduced, albeit in a different set of indicators.

Moving down to the national level, in Spain's 2020 Update of the long-term renovation strategy (LTRS) (Ministry of Transport, Mobility and Urban Agenda 2020), often referred to as 2020 ERESEE by its acronym in Spanish, the savings and other wider benefits are articulated around the possibilities of improving the health of citizens by improving the habitability in homes through enhancing energy conditions. According to the 2020 ERESEE, and based on the study by Ortiz and Salom (2016), it is estimated that with the proposed strategy, families could save between €400–550 per year on their energy bills, which would practically reduce the total energy costs of the home by half. Additionally, public administration would save about €370 per public home, in health and labor costs. In terms of health benefits, the figures are also note-worthy: on the one hand, the energy renovation of 1.2 million homes would prevent around 80,000 people from considering that they have bad or very bad health. On the other hand, around 96,000 people would not be diagnosed with cardiovascular problems. In addition, it would be possible to reduce the number of additional winter deaths due to cold temperatures in housing. Currently, this stands at 650 people under 65 years and around 6700 in people over 65 years.

Although these types of benefits are not directly included within the 10 action axes of the 2020 ERESEE and their corresponding proposed actions and measures, there is a package of measures where energy poverty is taken into consideration in a broad way. This is axis 6, which incorporates measures from the National Strategy against Energy Poverty (2019–2024) related to improving knowledge, with georeferenced maps and databases, or measures for its urgent reduction, contemplating among them express renovation, increasing the public rental housing stock, or monitoring homes with this type of problems, among other actions to be developed. (Ministry of Transport, Mobility and Urban Agenda 2020. Objectives of Axis 6).

The 2020 ERESEE was developed by Spain's Ministry of Transport, Mobility and Urban Agenda, involving a participatory process. This process took place between December 2022 and May 2023 and included experts from different backgrounds (inter-ministerial technicians, technicians with the regional authorities, technicians with local authorities and technicians with sector agents) who were set up in four working groups, whose conclusions were summarized in a report (Ministry of Transport, Mobility and Urban Agenda 2023). In this report, consistent with the 2020 ERESEE text, there is no direct evaluation and recommendations regarding savings and wider benefits. However, there is a description of the actions carried out to develop the strategy regarding the knowledge and reduction of energy poverty, as well as the benefits of this reduction.[1]

[1] Thus, the availability of financing funds for actions in homes with this type of vulnerability is noted in the programs to encourage renovation at the building and neighborhood levels of the Recovery, Transformation and Resilience Plan regulated through the Royal Decree 853/2021, of October 5 (Ministry of Transport, Mobility and Urban Agenda 2021). It establishes the possibility that the aid can cover up to 100% of the cost of the actions in the case of owners who prove that they are in a situation of economic vulnerability. Another measure is the elimination of the tax burden on aid for renovation in the Personal Income Tax, thus overcoming one of the barriers that hampered renovation, especially in these households subject to conditions of poverty energy (Head of State 2022). In addition, two programs have been launched within the framework with the aim of increasing knowledge and evaluating the impact of energy poverty. Additionally, the Habita_

2 Methodology

The methodology outlined in Fig. 1 was employed to formulate indicators enabling a comprehensive assessment of real energy savings and broader benefits resulting from renovations in Spain.

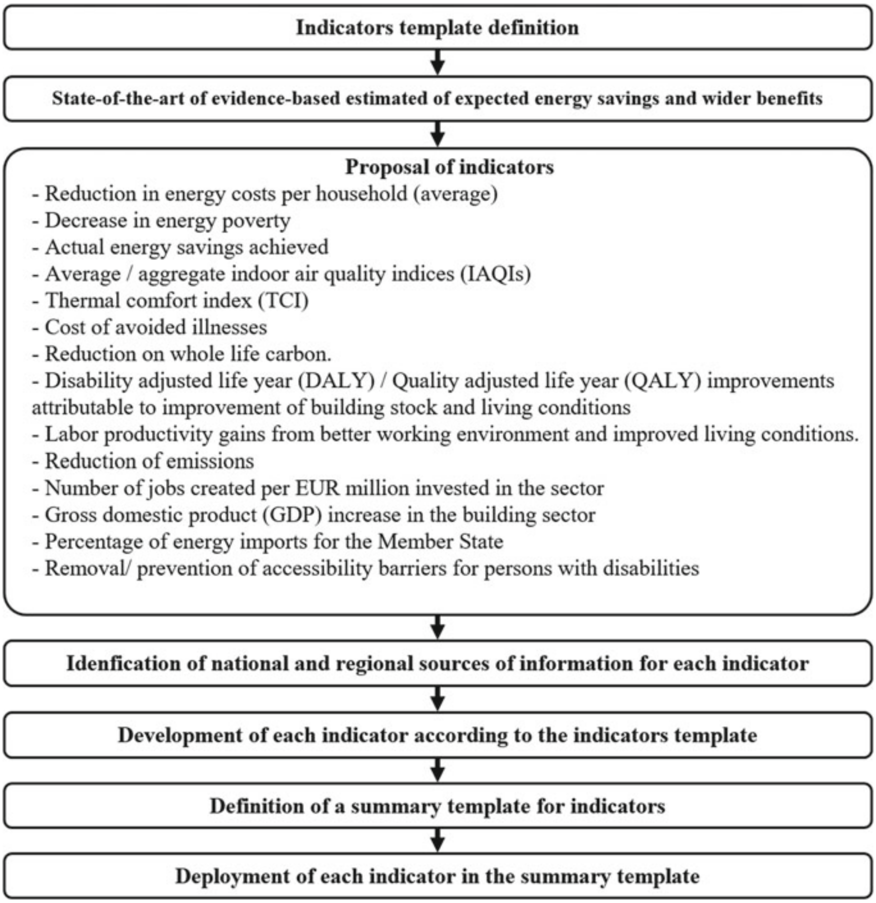


Fig. 1 Methodology implemented to generate indicators on the actual energy savings and wider benefits of building renovation in Spain, and the regions of Aragon and the Basque Country. *Source* own creation

---

RES2 Project, developed by the Eduardo Torroja Institute of Construction Sciences, focuses on monitoring homes immersed in urban regeneration processes at a neighborhood scale in Madrid, whereas the SPAHOUSEC III project, carried out by the Institute for the Energy Diversification and Savings (IDAE), monitored the energy consumption of renovated dwellings in order to create an extensive database.

The first step consisted in the development of a common template for these indicators based on:

- Indicator:
  - Definition of the indicator.
  - Variables to quantify it and their unit of measurement.
  - Purpose and advantages of implementing this indicator.
  - Alignment of the indicator with the directives, agendas, action plans and strategies, covering the European and international, national, and regional scales.
  - Relationship of this indicator with other similar ones.
- Information sources:
  - Availability of information to generate this indicator at different scales.
  - Entity responsible for providing this information.
- Measurement:
  - Measurement method.
  - Methodology.
  - Current possibilities of obtaining it.
  - Information necessary to generate it.
  - Availability and quality of data.

In order to select the indicators to assess the actual energy savings and other wider benefits, we considered those which have been suggested in European directives and related documents. For this study, we mainly considered two documents. On one hand, we studied the indicators included in the 2019 EPBD-related Recommendation (European Commission 2019), which was the first document in which a framework of progress indicators to measure the European building stock decarbonization was proposed. On the other hand, we analyzed the indicators included in the 2023 EPBD Proposal recast (European Parliament 2023), which is the document with the last version of the framework of progress indicators. In Table 1, the indicators in both documents for savings and wider benefits can be compared. As can be seen in Table 1, indicators included in the 2019 EPBD-related Recommendation are more specific than those in the 2023 EPBD Proposal recast and treats a more extended amount of different wider benefits.

For these reasons, it was decided to make a proposal for indicators based on the 2019 EPBD-related Recommendation, including the following ones:

- Reduction in energy costs per household (average).
- Decrease in energy poverty.
- Actual energy savings achieved.
- Average/aggregate indoor air quality indices (IAQIs).
- Thermal comfort index (TCI).
- Cost of avoided illnesses.
- Reduction on whole life carbon.

Table 1 Actual energy savings and wider benefits of renovation of buildings indicators included in selected European directives and related documents. *Source* own creation from data in (European Commission 2019; European Parliament 2023)

Document	Evidence-based estimated of expected energy savings and wider benefits
2019 EPBD-related recommendation	– Reduction in energy costs per household(average)/decrease in energy poverty – Actual energy savings achieved – Average/aggregate indoor air quality indices (IAQIs) and thermal comfort index (TCI) – Cost of avoided illnesses/reduction in health costs attributable to energy efficiency measures – Reduction of whole life carbon – Disability Adjusted Life Year (DALY)/Quality Adjusted Life Year (QALY) improvements attributable to the improvement of building stock and living conditions – Labor productivity gains from better working environment and improved living conditions – Reduction of emissions – Employment in the building sector (No. of jobs created per EUR million invested in the sector) – Gross domestic product (GDP) increase in the building sector – Percentage of energy imports for the Member State (energy security measures) – Removal/prevention of accessibility barriers for persons with disabilities
2023 EPBD proposal recast	– Energy savings (Ktoe): • Per building type • Public buildings – Reduction in energy costs (EUR) per household (average) – Expected wider benefits: • Creation of new jobs • % reduction of people affected by energy poverty • % reduction of people living in inadequate indoor environment and reduction of costs for health systems due to health improvements through improved indoor environmental quality after renovation – Increase of GDP (share and billion Euros)

- Disability adjusted life year (DALY)/Quality adjusted life year (QALY) improvements attributable to improvement of building stock and living conditions.
- Labor productivity gains from better working environment and improved living conditions.
- Reduction of emissions.
- Number of jobs created per EUR million invested in the sector.
- Gross domestic product (GDP) increase in the building sector.
- Percentage of energy imports for the MS.
- Removal/prevention of accessibility barriers for persons with disabilities.

As can be seen, all the indicators proposed in the study belong to the set of the 2019 EPBD-related Recommendation. The indicators of the 2023 EPBD Proposal recast are more limited and serve as qualifiers for those put forth in the Recommendation.

Once the key indicators to cover this topic were identified, the available sources of information were studied. Given that a significant part of building renovation promotion and aid management in Spain is decentralized to regions, we selected the regions of Aragon and the Basque Country as case studies for regional analysis. Then the standard template for each indicator was developed and generated for Spain, Aragon and the Basque Country.

Subsequently, a summary file was defined for each indicator with the main points covered in the complete file.

3 Indicators

3.1 Reduction in Energy Costs Per Household (Average)

The purpose of this indicator is to determine how energy savings and costs derived from energy efficiency interventions in residential building stock evolve. For the development of this indicator there are national and Basque Country data sources available (Table 2).

The published data show the results of one-off studies based on estimated and theoretical values. No studies of a similar nature were found for the region of Aragon. So available data are insufficient to fully compile the indicator.

3.2 Decrease in Energy Poverty

The purpose of this indicator is to raise awareness on the extent of existing risk and the evolution of energy poverty and vulnerability of the population. For the development of this indicator there are national and regional data sources available (Table 3).

According to Spain's National Fuel Poverty Strategy, energy poverty is the situation in which a household energy supply needs cannot be met as a result of an insufficient level of income, and which may be aggravated by having energy inefficient housing.

The variables used in Spain's National Fuel Poverty Strategy to measure the indicator are:

- Reduction in disproportionate expenditure (2 M), defined as the percentage of households whose energy expenditure in relation to their income is more than double the national median.

Table 2 Sources for indicator Reduction in energy costs per household (average). *Source* own creation

Indicator: Reduction in energy costs per household (average)	
Variables	– Euros/year reduced per household
Indicator developability	– Data availability: partially available – Processing method from source: directly – Data processability: no
National source	– Ministry of Transport, Mobility and Urban Agenda. 2020 Update of the long-term strategy for energy renovation in the building sector in Spain (ERESEE)
Source links	https://www.mitma.gob.es/recursos_mfom/paginabasica/recursos/eresee_2020.pdf
Characteristics of the source	– Availability: open data – Data collection method: theoretical calculations of studies and research projects, based on theoretical parameters – Data processability: no – Georeferencing: no – Data update frequency/last update: every three years. Last update in 2020
Regional source—Basque Country	Basque Government's Department of the Environment, Territorial Planning and Housing
Source links	https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.2_Informe_A0.pdf https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.3_Informe_B0.pdf https://www.euskadi.eus/contenidos/informacion/regeneracion_urbana/es_def/adjuntos/2005.4_Informe_G0.pdf
Characteristics of the source	– Availability: open data – Data collection method: theoretical calculations of studies and research projects, based on theoretical parameters – Data processability: no – Georeferencing: no – Data update frequency/last update: Single publication in 2020

- Reduction in Hidden Energy Poverty (HEP), defined as the percentage of households whose absolute energy expenditure is less than half the national median.

We can indirectly take the data from the mentioned source to develop our proposed indicator. Thus, in Fig. 2 we can see the evolution of the reduction in 2 M and HEP in Spain from 2008 to 2021. Additionally, we can also extract regional data from this source, as can be seen in Fig. 3 for the case of the region of Aragon, and in Fig. 4 for the case of the Basque Country. Since the data are provided in PDF format, they must be treated manually.

Table 3 Sources for indicator Decrease in energy poverty. *Source* own creation

Indicator: Decrease in energy poverty	
Variables	– Reduction in disproportionate expenditure (2 m) – Reduction in Hidden Energy Poverty (HEP)
Indicator developability	– Data availability: fully available – Processing method from source: indirect – Data processability: no
National source	Ministry for Ecological Transition and the Demographic Challenge. National Energy Poverty Strategy 2019–2024 report
Source link	https://www.miteco.gob.es/es/prensa/estrategianacionalcontralapobrezaenergetica2019-2024_tcm30-496282.pdf
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: not directly, data provided in PDF format – Georeferencing: no – Data update frequency/last update: the indicator has been published directly twice, in 2019 and 2020

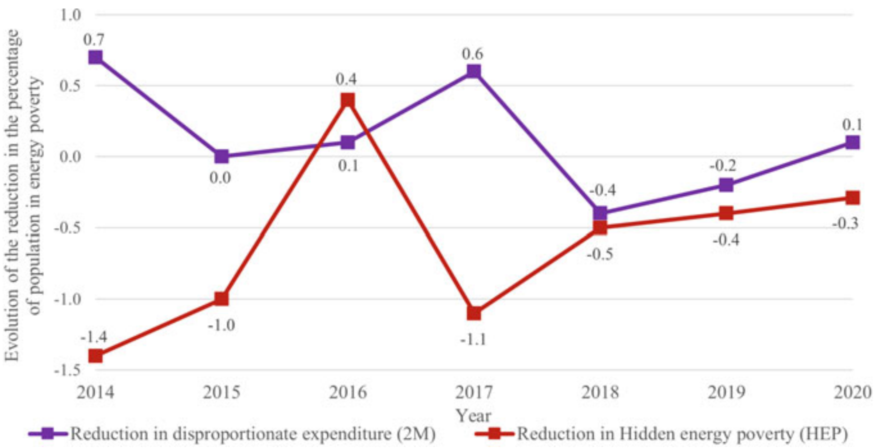


Fig. 2 Evolution of the reduction in the percentage of population affected by energy poverty compared to the previous year in Spain from 2008 to 2021. 2019 *Source*: own creation from data in (Ministry for Ecological Transition and the Demographic Challenge)

3.3 Actual Energy Savings Achieved

The purpose of this indicator is to determine how energy savings and costs derived from energy efficiency interventions in residential building stock evolve. For the development of this indicator there are national and regional data sources available (Table 4).

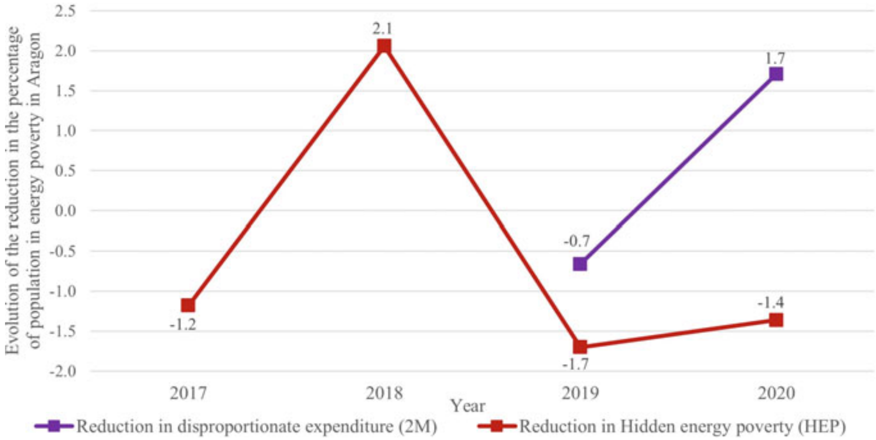


Fig. 3 Evolution of the reduction in the percentage of population affected by energy poverty in the region of Aragon (Spain) from 2016 to 2021. *Source*: own creation from data in (Ministry for Ecological Transition and the Demographic Challenge 2019)

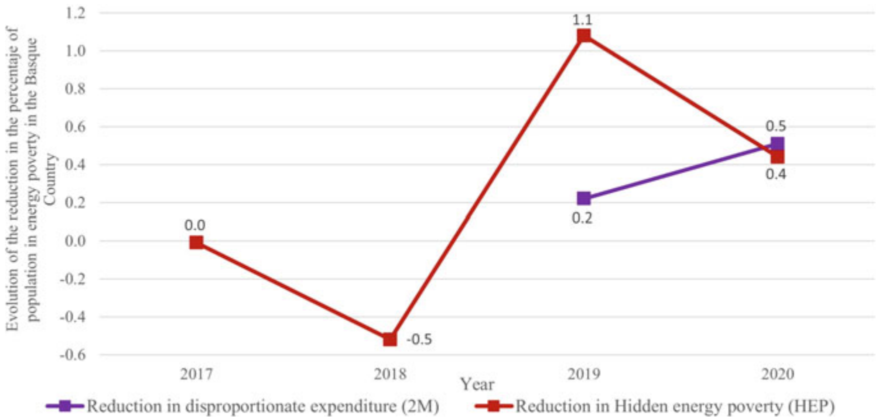


Fig. 4 Evolution of the reduction in the percentage of population affected by energy poverty in the Basque Country (Spain) from 2016 to 2020. *Source*: own creation from data in (Ministry for Ecological Transition and the Demographic Challenge 2019)

The sources responsible for collecting data on renovations do not provide a breakdown of the projects, and environmental data, such as improvements in energy demand/consumption or GHG emissions avoided, are not collected. This means that in order to obtain information of this type, approximations and extrapolations have to be used. This is the case of the report 'Evaluation of public residential renovation policies in Spain 2013–2017' (Rubio del Val et al. 2020a, 2020b), which uses the

Table 4 Sources for indicator Actual energy savings achieved. *Source* own creation

Indicator: Actual energy savings achieved	
Variables	– Estimated energy savings in demand (kWh per year) – Estimated energy savings in consumption (kWh per year)
Indicator developability	– Data availability: partially available. Open data but insufficient to fully collect the indicator – Processing method from source: direct – Data processability: no
National source	3R City Observatory—Evaluation Report on Public Residential Renovation Policies in Spain (2013–2017)
Source link	http://www.observatoriociudad3r.com/wp-content/uploads/2020/01/Informe-Eval-Polit-Pub.pdf
Characteristics of the source	– Availability: open data – Data collection method: surveys of the different regions and cities, data on building and construction permits, and information collected on the – IDAE's funding aid programs and subsidies under the 2013–2017 State Housing Plan – Data processability: no, report in PDF format – Georeferencing: no – Data update frequency/last update: the report, which was published in 2019, is not expected to be updated

average theoretical demand and consumption data from studies, such as the Residential Sector Consumption in Spain report, as a baseline hypothesis to estimate the energy savings obtained.

In addition, data used to prepare the Evaluation Report on Public Residential Renovation Policies in Spain (2013–2017) relate to dwellings renovated within the framework of state or regional funding programs. However, obtaining data from interventions carried out without this type of aid is even more complicated, as only statistics on municipal building permits or construction permits are available. Additionally, these permits do not show disaggregated data, barely collect processable information, and do not cover all the interventions, as many of them do not even pass through these filters.

Finally, the IDAE collects this type of environmental data on the programs it manages. As mentioned in the report that served as the source for this indicator, these data were published openly on the IDAE's website. However, this information is no longer available, leaving only a list regarding the Pareer-Crece program, which hardly contains any relevant data.

Figures 5 and 6 show the estimated energy savings in demand and in consumption respectively in Spain and the Basque Country. As commented before, national data come from different housing plans and programs and are collected through building visas data bases belonging to official architects' professional associations. It can also be noted that there is no data from the Aragon region.

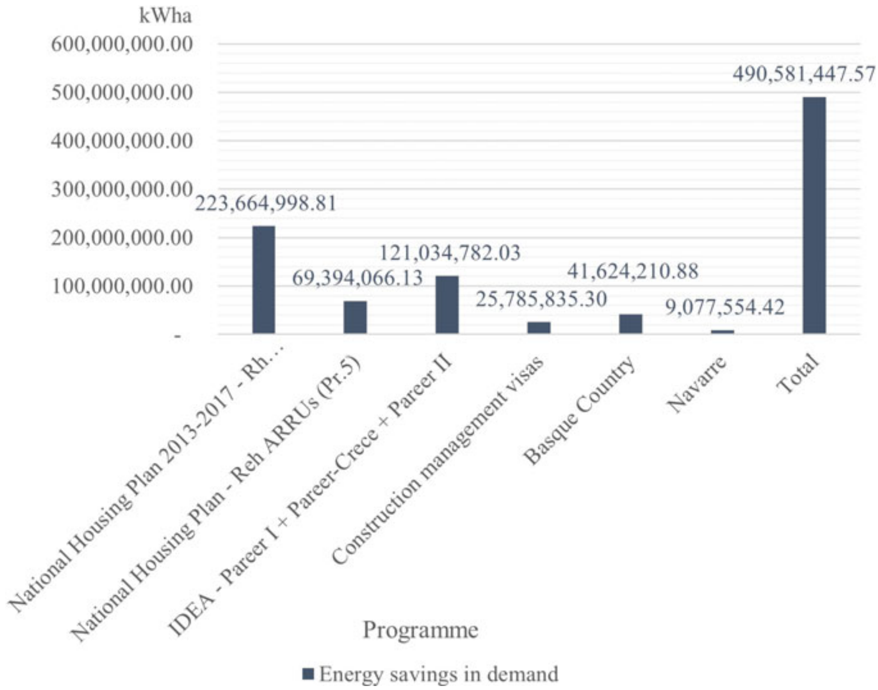


Fig. 5 Estimated energy savings in demand. *Source* own creation from data in (Rubio del Val et al. 2020b)

3.3.1 Average/Aggregate Indoor Air Quality Indices (IAQIs)

The purpose of this indicator is to assess indoor air pollution. The quality of human life is significantly degraded by indoor air pollution, which is exacerbated tenfold compared to outdoor air pollution due to the presence of harmful chemicals and other toxic materials (Dionova et al. 2020). Various sources contribute to indoor air pollution, including fuel-burning combustion appliances, tobacco products, building materials like deteriorated asbestos-containing insulation and certain pressed wood products, household cleaning and maintenance products, central heating and cooling systems, excess moisture, and outdoor sources such as radon, pesticides, and outdoor air pollution. The aggregate indoor air quality index (IAQI) is determined by the cumulative concentration ratio of pollutants as measured through toxicity level tests and calculates the effect of polluted air on the people's health as a whole (Dionova et al. 2020). The average IAQI is the mean concentration ratio of pollutants as measured through toxicity level tests.

No data sources were found to compile this indicator. However, other sources allow related information to be collected, as shown in Table 5. Data collected in the Living Conditions Survey by Spain's National Statistical Institute (INE) are subjective in nature, and it was not possible to compile the indicator with rigorously

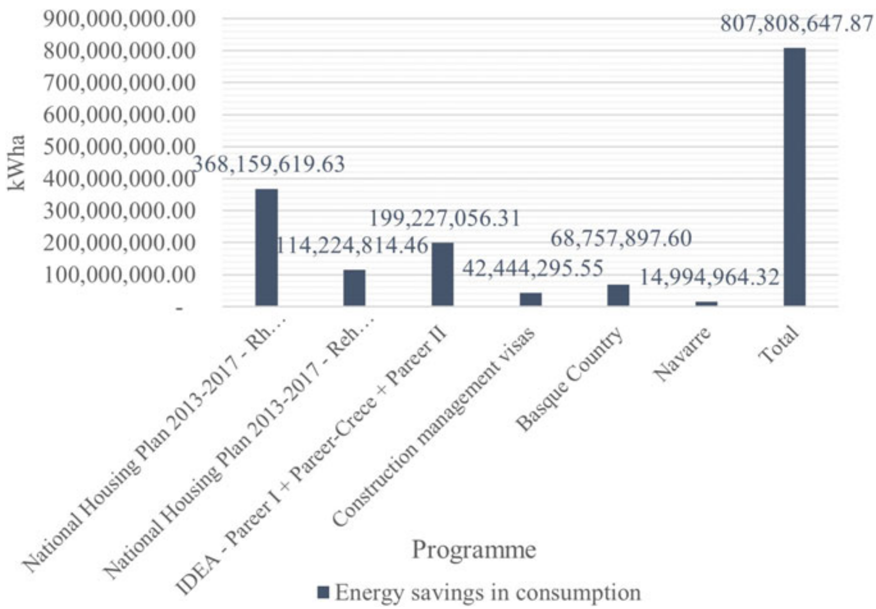


Fig. 6 Estimated energy savings in consumption. *Source* own creation from data in (Rubio del Val et al. 2020b)

measured or simulated values. Therefore, this information should be considered as a guide to the society's perception of pollution in their homes, but never as objective data. Furthermore, it must be noted that the data collected are available at national or regional level (except for outdoor air quality data, which is a different matter).

Figure 7 shows the results for the alternative variables suggested for the indicator, using data coming from the mentioned sources at the national and regional levels.

3.4 Thermal Comfort Index (TCI)

The purpose of this indicator is to serve as a metric for gauging individuals' perceived comfort, in terms of warmth or coolness, considering environmental factors such as temperature, humidity, air movement, and personal elements like clothing. Various indices and models exist to quantify thermal comfort, and they often take into account factors like metabolic rate, clothing insulation, air temperature, radiant temperature, and air velocity. These models aim to provide a standardized way of assessing and predicting the comfort level of occupants in indoor environments, helping to optimize building and heating, ventilating and air conditioning (HVAC) system designs for human well-being and productivity. One commonly used model is the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfied (PPD) developed by Fanger in the 1970s (Streinu-Cercel et al. 2008).

Table 5 Sources for indicator Average/aggregate indoor air quality indices (IAQIs). *Source* own creation

Indicator: Average/aggregate indoor air quality indices (IAQIs)	
Variables	Not applicable to this indicator as stated. Alternative proposed: – Percentage of households with pollution and other environmental problems
Indicator developability	– Data availability: non-available. Alternative indicators are collected openly – Processing method from source: various – Data processability: for alternative indicator CSV, XLS, Json, text, PDF and PPT formats are available. Regional data do not allow for their processability
National source	Spain's National Institute of Statistics—INE. Living Conditions Survey
Source link	https://www.ine.es/jaxiT3/Tabla.htm?t=9998&L=1 https://www.ine.es/jaxiT3/Tabla.htm?t=9999&L=1 https://www.ine.es/jaxiT3/Tabla.htm?t=10000&L=1 https://www.ine.es/jaxiT3/Tabla.htm?t=10002&L=1 https://www.ine.es/ss/Satellite?param1=PYSDetalleFichaIndicador&c=INESeccion_C&param3=1259937499084&p=1254735110672&pagename=ProductosYServicios%2FPYSLayout&cid=1259944616263&L=1 https://www.ine.es/ss/Satellite?param1=PYSDetalleFichaIndicador&c=INESeccion_C&param3=1259937499084&p=1254735110672&pagename=ProductosYServicios%2FPYSLayout&cid=1259944618679&L=1 https://www.ine.es/jaxiT3/Tabla.htm?t=10001&L=1
Characteristics of the source	– Availability: open data – Data collection method: population survey – Data processability: yes, in CSV, XLS, Json, text, PDF, PPT, etc – Georeferencing: not applicable – Data update frequency/last update: annually. Last data belong to 2020
Regional source—Aragon	Government of Aragon. Aragon Institute of Statistics—IAEST
Source link	https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/04/040004A&Action=Navigate&Options=df&NQUser=granpublico&NQPassword=granpublico https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/04/040004TP&Action=Navigate&Options=df&NQUser=granpublico&NQPassword=granpublico https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/04/040004TC&Action=Navigate&Options=df&NQUser=granpublico&NQPassword=granpublico https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/Estadistica%20Local/04/040004TM&Action=Navigate&Options=df&P0=1&P1=eq&P2=%22Localizacion%20territorial%22.%22Provincia%20codigo%22&P3=&NQUser=granpublico&NQPassword=granpublico

(continued)

Table 5 (continued)

Indicator: Average/aggregate indoor air quality indices (IAQIs)	
Characteristics of the source	– Availability: open data – Data collection method: unspecified – Data processability: yes, in CSV, XLS, Json, text, PDF, PPT, etc – Georeferencing: not applicable – Data update frequency/last update: unspecified. Last data belong to 2001
Regional source—Aragon	Government of Aragon
Source link	https://aragonaire.aragon.es/
Characteristics of the source	– Availability: open data – Data collection method: monitoring station networks – Data processability: no – Georeferencing: yes – Data update frequency/last update: continuously
Regional source—Basque Country	Basque Government
Source link	https://www.euskadi.eus/web01-a2ingai2/es/aa17aCalidadAireWar/estacion/mapa?locale=es
Characteristics of the source	– Availability: open data – Data collection method: monitoring station networks – Data processability: no – Georeferencing: yes – Data update frequency/last update: continuously

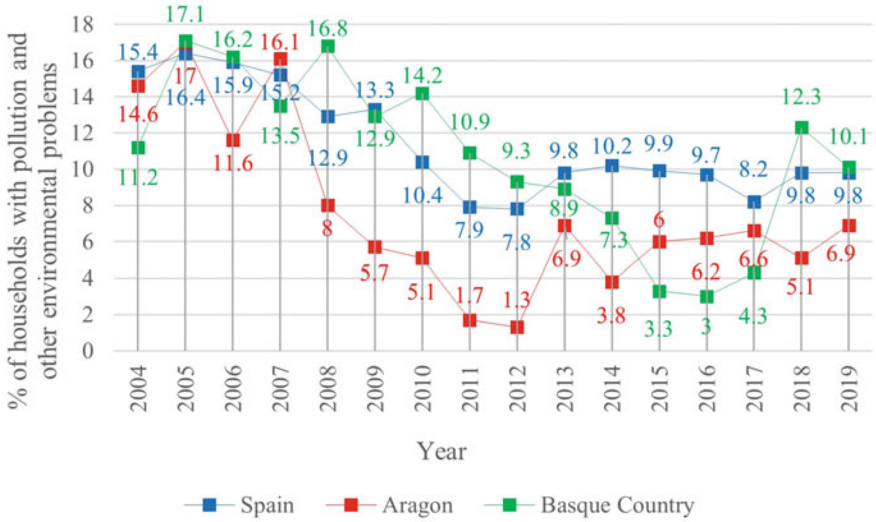


Fig. 7 Percentage of households with pollution and other environmental problems. Source: own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2023a)

No data sources were identified for compiling this indicator. However, other sources provide related information, as indicated in Table 6. Specifically, data on the percentage of people who think that are unable to afford to maintain an adequate temperature in their homes are gathered in the Living Conditions Survey by INE. These data are subjective, and hence it was not feasible to construct the indicator with measured or simulated values. As a result, this information lacks objective value in terms of the actual temperature in homes. It must also be noted that there is no explicit clarification as to whether INE's data on the percentage of people unable to afford to maintain an adequate temperature in their homes pertains to winter or summer months. The Ministry for the Ecological Transition and the Demographic Challenge (MITERD) reports use INE data as its basic source. These reports explain that information is related to winter months so it can be concluded that, although is not clarified in the source itself (INE), these data also refer to the same moment of the year.

Figures 8 and 9 show the results for the alternative variables suggested for the indicator, using data coming from the mentioned sources at the national and regional levels.

3.5 Cost of Avoided Illnesses

The purpose of this indicator is to understand the evolution of the cost of health and hospital care, in order to be able to associate them to the cost of illnesses avoided by applying energy efficiency and renovation measures in residential buildings.

No data were found on the associated costs of illnesses avoided by implementing energy efficiency and renovation measures. Furthermore, the data from the sources found, simply detail either the possible effects of poor housing environmental quality or the overall healthcare costs per inhabitant per year. However, other sources allow related information to be collected, as shown in Table 7.

3.6 Reduction on Whole Life Carbon

The purpose of this indicator is to estimate the reduction in greenhouse gas (GHG) emissions that can be achieved through renovations when the entire life cycle of the buildings is considered.

No data sources were found to compile this indicator (Table 8). One of the main limitations for the compilation of this indicator is the limited consideration of the entire building life cycle in the sources and Spanish building regulation. Usually, when the reduction of certain GHG emissions is analyzed, it is done considering the use stage of the building, disregarding the remaining stages of its life: construction, use, maintenance, renovation, demolition, etc. Furthermore, issues arise also when trying to analyze GHG emission reductions without a life-cycle perspective. In such

Table 6 Sources for indicator Thermal comfort index (TCI). *Source* own creation

Indicator: Thermal comfort index (TCI)	
Variables	Not applicable to this indicator as stated. Alternatives proposed: – Percentage of people that cannot afford to keep their home at an adequate temperature – Percentage of households that cannot afford to keep their home at an adequate temperature
Indicator developability	– Availability: non-available. Information can be obtained directly on the capacity of the population to keep their homes at an adequate temperature – Processing method from source: various – Data processability: data on related indicators can be downloaded in in CSV, SVG, PNG, XLS, Json, and text formats
International source	EU Energy Poverty Observatory
Source link	https://energy-poverty.ec.europa.eu/observing-energy-poverty/national-indicators_en
Characteristics of the source	– Availability: open data – Data collection method: data come from Eurostat, which collects them from the Living Conditions Survey from each country – Data processability: yes, data in CSV, SVG, PNG, XLS, Json, and text formats – Georeferencing: no – Data update frequency/last update: annually. Last data belong to 2022
National source	Spain's National Institute of Statistics (INE). Living Conditions Survey
Source link	https://www.ine.es/jaxiT3/Tabla.htm?t=9967&L=1 https://www.ine.es/jaxiT3/Tabla.htm?t=9968&L=1 https://www.ine.es/jaxiT3/Tabla.htm?t=9969&L=1 https://www.ine.es/jaxiT3/Tabla.htm?t=9970&L=1 https://www.ine.es/jaxiT3/Tabla.htm?t=9971&L=1 https://www.ine.es/jaxiT3/Tabla.htm?t=9973&L=1 https://www.ine.es/jaxiT3/Tabla.htm?t=9974&L=1 https://www.ine.es/jaxiT3/Tabla.htm?t=9972&L=1 https://www.ine.es/jaxiT3/Tabla.htm?t=9975&L=1
Characteristics of the source	– Availability: open data – Data collection method: population surveys – Data processability: yes, data in CSV, SVG, PNG, XLS, Json, and text formats – Georeferencing: no – Data update frequency/last update: annually. Last data belong to 2022
National source	Ministry for the Ecological Transition and Demographic Challenge—MITERD
Source link	https://www.miteco.gob.es/es/prensa/20201106_actualizaciondeindicadores2020_final__tcm30-516466.pdf
Characteristics of the source	– Availability: open data – Data collection method: draws on both of the above sources – Data processability: no – Georeferencing: no – Data update frequency/last update: single publication in 2020

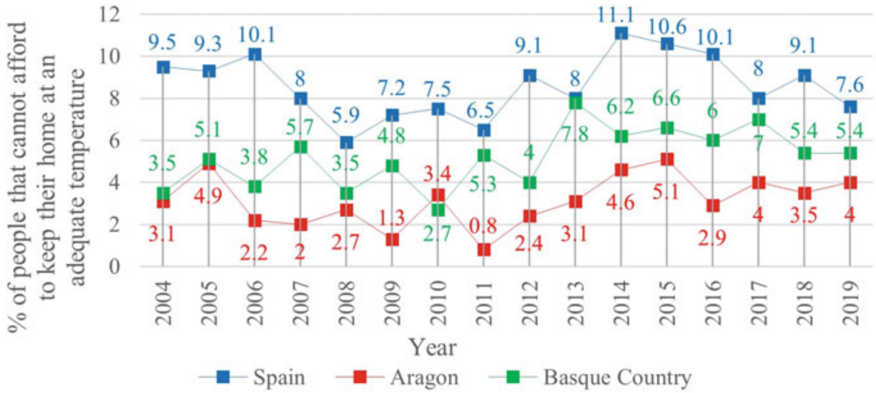


Fig. 8 Percentage of people that cannot afford to keep their home at an adequate temperature. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2023a)

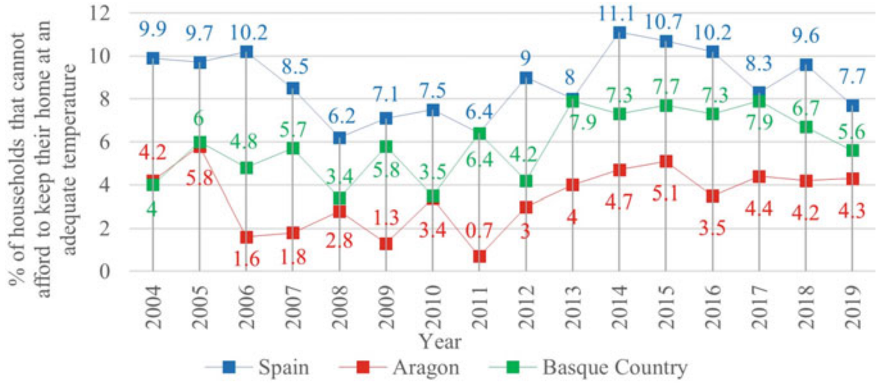


Fig. 9 Percentage of households that cannot afford to keep their home at an adequate temperature. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2023a)

a case, we find that the sources responsible for collecting data on renovations do not provide a breakdown of the environmental data of projects, such as improvements in energy demand/consumption or GHG emissions avoided. This greatly complicates the possibility of understanding environmental matters surrounding the national building stock.

Table 7 Sources for indicator Cost of avoided illnesses. *Source* own creation

Indicator: Cost of avoided illnesses	
Variables	– Cost of avoided illnesses. GDP per capita
Indicator developability	– Availability: Partially available. Open data but insufficient to fully collect the indicator – Processing method from source: it is not possible to obtain the values of the indicator because the sources do not link the costs of illnesses avoided by adopting energy efficiency measures. Expenditure on diseases linked to poor indoor air quality and lack of comfort in housing need to be separated – Data processability: not applicable
International source	International Energy Agency (IEA)
Source link	https://www.iea.org/reports/capturing-the-multiple-benefits-of-energy-efficiency https://iea.blob.core.windows.net/assets/28f84ed8-4101-4e95-ae51-9536b6436f14/Multiple_Benefits_of_Energy_Efficiency-148x199.pdf
Characteristics of the source	– Availability: open data – Data collection method: unspecified – Data processability: no – Georeferencing: not applicable – Data update frequency/last update: single publication from 2014
National source	Spain's National Institute of Statistics (INE). European Health Survey in Spain (EHSS)
Source link	https://www.ine.es/dyngs/INEbase/en/operacion.htm?c=Estadistica_C&cid=1254736176784&menu=resultados&idp=1254735573175 https://www.ine.es/dyngs/INEbase/en/operacion.htm?c=Estadistica_C&cid=1254736176780&menu=ultiDatos&idp=1254735573175
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, CSV format – Georeferencing: not applicable – Data update frequency/last update: updated every five years/annually. Last update in 2020/2022
National source	Ministry of Health. Public Health Expenditure Statistics (EGSP) from 2002 to 2021
Source link	https://www.sanidad.gob.es/en/estadEstudios/estadisticas/inforRecopilaciones/gastoSanitario2005/home.htm
Characteristics of the source	– Availability: open data – Data collection method: data from national accounts – Data processability: yes, CSV format – Georeferencing: not applicable – Data update frequency/last update: annually. Last update in 2021
Regional source— Catalonia	Catalonia Institute for Energy Research (IREC)
Source link	http://www.lacasaqueahorra.org/documentos/estimacionEfectoRehabilitacionSalud.pdf

(continued)

Table 7 (continued)

Indicator: Cost of avoided illnesses	
Characteristics of the source	– Availability: open data – Data collection method: various sources – Data processability: no – Georeferencing: not applicable – Data update frequency/last update: Single publication from 2016
Regional source—Basque Country	Basque Government. Basque Institute of Statistics—EUSTAT
Source link	https://www.eustat.eus/elementos/ele0015700/gasto-en-salud-en-la-ca-de-euskadi-e-indicadores/tbl0015733_c.html https://www.eustat.eus/elementos/ele0000000/principales-variables-e-indicadores-del-sector-hospitalario-de-la-ca-de-euskadi/tbl0000090_c.html https://www.eustat.eus/elementos/ele0000000/recursos-actividad-asistencial-y-economica-del-sector-hospitalario-de-la-ca-de-euskadi-por-territorio-historico-titularidad-y-tipo-de-hospital/tbl0000069_c.html
Characteristics of the source	– Availability: open data – Data collection method: administrative data from the Department of Health and Operations – Data processability: yes, CSV format – Georeferencing: not applicable – Data update frequency/last update: updated every two years. Last up-date in 2020/2021

Table 8 Variables and indicator developability. Indicator reduction on whole life carbon. *Source* own creation

Indicator: Reduction on whole life carbon	
Variables	– Reduction on whole life carbon
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

3.7 Disability Adjusted Life year (DALY)/Quality Adjusted Life year (QALY) Improvements Attributable to Improvement of Building Stock and Living Conditions

The purpose of this indicator is to measure the increase in the number of years lived by people with a good quality of life and without disabilities due to improvements in the conditions of the building stock. According to the World Health Organization (WHO), disability-adjusted life years (DALY) is a time-based measure that combines years of life lost due to premature mortality for a specific cause and years of life lost due to disability from the specific cause. One DALY represents the loss of the equivalent of one year of full health. On the other hand, the quality-adjusted life-year (QALY) is a time-based measure of the value of health outcomes (Prieto and Sacristán 2003). The number of QALYs gained due to building renovation is calculated by multiplying the induced change in utility value by the duration of the treatment effect to provide the number of QALYs gained.

As life expectancy is now very high in developed countries and it is very difficult to increase it further, the focus is now on improving people's quality of life. In this sense, the quality of life, particularly that of the most vulnerable groups, depends to a large extent on the quality of their housing. A high percentage of the housing stock in Spain is very energy inefficient, which means that it consumes a large amount of energy to maintain adequate hydrothermal conditions inside the building that residents cannot always afford. These situations of energy poverty can lead to damp and cold dwellings, resulting in cardiovascular and respiratory diseases among residents.

As indicated by the World Health Organization (WHO), building renovations, such as improving the thermal envelope, reduce illnesses caused by cold and damp and help to reduce the impact of noise. Moreover, improving people's health has a positive impact on national health costs, leading to savings that could equate to 20–30% of annual public investment in renovation works.

Regarding the proposed indicator to measure this phenomenon, no data sources were found. No sources were found to establish what influence improvements to the building stock have on the increase in DALY and QALY, nor the expected future benefits in this regard. However, some sources were found that allow related information to be collected, as shown in Table 9. The data encompass life expectancy, life expectancy in good health, and life expectancy free of disability. However, we observed that the distinction between years of life expectancy in good health and life expectancy free of disability is unclear. Some references treat these concepts as identical, while others define them differently. The variations in terminology create discrepancies in data across sources that, in theory, should be consistent, posing challenges in determining the most relevant source for this indicator. Moreover, many sources rely on subjective data obtained from population surveys to compile these indicators. Consequently, certain sources base their indicators on individuals' perceptions of their health and quality of life rather than objective medical parameters. Additionally, it is worth noting that surveys may not always account for the population residing in retirement homes.

Figure 10 shows the results for the alternative variables suggested for the indicator, using data coming from the mentioned sources at the national and regional levels.

3.8 Labor Productivity Gains from Better Working Environment and Improved Living Conditions

The purpose of the indicator is to evaluate the connection between energy renovation and enhanced indoor conditions, focusing on the productivity benefits derived from

Table 9 Sources for indicator Disability adjusted life year (Daly)/Quality adjusted life year (QALY) improvements attributable to improvement of building stock and living conditions. *Source* own creation

Indicator: Disability adjusted life year (Daly)/quality adjusted life year (QALY) improvements attributable to improvement of building stock and living conditions	
Variables	Not applicable to this indicator as stated. Alternatives proposed: – Life expectancy – Life expectancy in good health – Life expectancy free of disability
Indicator developability	– Availability: partially available – Processing method from source: direct, but with limitations – Data processability: yes, data available in XLSX and CSV formats
International source	European Statistical Office—Eurostat
Source link	https://ec.europa.eu/eurostat/databrowser/view/hlth_hlye/default/table?lang=en
Characteristics of the source	– Availability: open data – Data collection method: Sullivan method, which cross-references mortality and morbidity data to study the current and historical healthy and disability-free life expectancy – Data processability: yes, data available in XLSX format – Georeferencing: no – Data update frequency/last update: annual. Last update in 2019. The Survey on Disability, Personal Autonomy and Situations of Dependency is from 2008. Information for health indicators 4.2 and 4.8 dates from 2019 and 2008 respectively
National source	Spain's National Institute of Statistics
Source link	https://www.ine.es/dynt3/inebase/es/index.htm?type=pcaxis&path=/t15/p418/a2008/hogares/p01/esp_vida&file=pcaxis https://www.ine.es/ss/Satellite?L=es_ES&c=INESeccion_C&cid=1259926378861&p=1254735110672&pagename=ProductosYServicios%2FPYSLayout&param1=PYSDetalle&param3=1259924822888 https://www.ine.es/ss/Satellite?L=es_ES&c=INESeccion_C&cid=1259926668516&p=1254735110672&pagename=ProductosYServicios%2FPYSLayout&param1=PYSDetalle&param3=1259924822888
Characteristics of the source	– Availability: open data – Data collection method: Sullivan method – Data processability: yes, data in XLSX and CSV formats – Georeferencing: no – Data update frequency/last update: Unspecified
National source	Ministry of Health, Social Services and Equality
Source link	https://www.mscbs.gob.es/estadEstudios/estadisticas/inforRecopilaciones/ESPERANZAS_DE_VIDA_2018.pdf https://www.mscbs.gob.es/estadEstudios/estadisticas/inforRecopilaciones/docs/Indicadores2017.pdf

(continued)

Table 9 (continued)

Indicator: Disability adjusted life year (Daly)/quality adjusted life year (QALY) improvements attributable to improvement of building stock and living conditions	
Characteristics of the source	– Availability: open data – Data collection method: Sullivan method – Data processability: no, data in PDF format – Georeferencing: no – Data update frequency/last update: not updated, new reports are pro-duced. Last version from 2018
National source	Ministry of Health, Social Services and Equality
Source link	http://inclasns.msssi.es/?show=true
Characteristics of the source	– Availability: open data – Data collection method: Sullivan method – Data processability: no, data in PDF format – Georeferencing: no – Data update frequency/last update: not updated, new reports are pro-duced. Last version from 2018

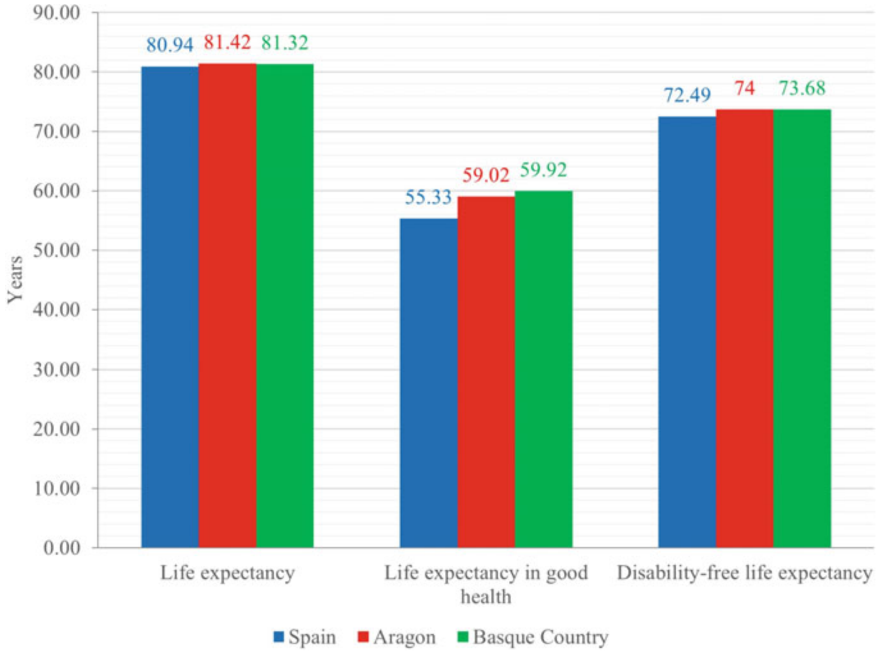


Fig. 10 Comparison between life expectancy, life expectancy in good health and life expectancy free of disability. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2008)

Table 10 Variables and indicator developability. Indicator Labor productivity gains from better working environment and improved living conditions. *Source* own creation

Indicator: Labor productivity gains from better working environment and improved living conditions	
Variables	– Labor productivity gains from better working environment and improved living conditions
Indicator developability	– Availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

increased comfort in indoor workspaces. In essence, it aims to measure the increase in user productivity resulting from building renovations by evaluating improvements in Indoor Environmental Quality (IEQ) and comfort levels in indoor spaces.

There are no sources of data for this indicator (Table 10). In addition, it is difficult to collect data on productivity improvement attributed solely to building renovation, as more factors are involved. Table 10 shows the variables and resume of developability of this indicator.

3.8.1 Reduction of Emissions

The purpose of this indicator is to know the amount of CO_2 that is prevented from being emitted into the atmosphere thanks to energy renovation of the building stock. This is important for planning policies and strategies to decarbonize the housing stock in order to meet the 2050 targets. Thus, the indicator assesses savings in CO_2 emissions achieved by improving the energy efficiency of buildings through renovation works.

The main limitation in developing this indicator lies in the fact that the sources gathering data on renovations do not usually provide a breakdown of the projects. Additionally, environmental data, such as improvements in energy demand/ consumption or GHG emissions avoided, are not collected.

The non-standardized way of collecting data seriously hinders the possibility of knowing the national housing stock, and therefore, of designing adequate public policies and strategies.

The only available document containing environmental data in Spain is the report titled ‘Evaluation of public residential renovation policies in Spain 2013–2017’ (Rubio del Val et al. 2020a, 2020b). The data utilized for this report pertains to dwellings renovated under state or regional funding programs, and therefore, the information is insufficient for the development of the proposed indicator. Collecting information on interventions carried out without any funding programs is even more challenging. Only statistics on municipal building permits or construction management permits are available, but these sources lack detailed breakdowns, collect limited and non-processable data, and do not comprehensively distinguish between different energy-depth of interventions.

Finally, the Institute for Energy Diversification and Savings (IDAE) collects this type of environmental data on the programs it manages. As highlighted by Rubio del Val et al. (2020b), these data were initially openly accessible on the IDEA's website. Unfortunately, this information is currently unavailable, with only a limited list pertaining to the Pareer-Crece program remaining, with minimal relevant data.

As per the calls for financial aid in energy renovation, it is obligatory to demonstrate the achievement of a specified percentage of consumption savings to qualify for the aid. To fulfill this requirement, technicians shall create two Energy Performance Certificates (EPCs): one before the initiation of the renovation project and another after the proposed measures have been outlined. Although this information is integrated into the Renovation Implementation Projects, it is not publicly disclosed. Access to this information would be highly beneficial as it would enable the calculation of energy consumption and CO_2 emission savings, given that both sets of data are present in the EPC. A summary containing the key data and the suggested source is presented in Table 11.

Figure 11 shows the results for the alternative variable suggested for the indicator, using data coming from the mentioned sources at the national level and some data available for two Spanish regions, including the Basque Country.

Table 11 Sources for indicator Reduction of emissions. *Source* own creation

Indicator: Reduction of emissions	
Variables	Not applicable to this indicator as stated. Alternative proposed: – Carbon saving per program and region
Indicator developability	– Availability: partially available – Processing method from source: direct from the source – Data processability: no
National source	3R City Observatory - Evaluation Report on Public Residential Renovation Policies in Spain (2013–2017)
Source link	http://www.observatoriociudad3r.com/wp-content/uploads/2020/01/Informe-Eval-Polit-Pub.pdf
Characteristics of the source	– Availability: open data – Data collection method: surveys of the different Autonomous Communi-ties and cities, data on building permits and construction permits, and in-formation collected on the IDAE's funding aid programs and subsidies under the 2013–2017 State Housing Plan – Data processability: no – Georeferencing: no – Data update frequency/last update: Single publication in November 2019
Characteristics of the source	– Availability: open data – Data collection method: unspecified – Data processability: yes, in CSV, XLS, Json, text, PDF, PPT, etc – Georeferencing: not applicable – Data update frequency/last update: unspecified. Last data belong to 2001

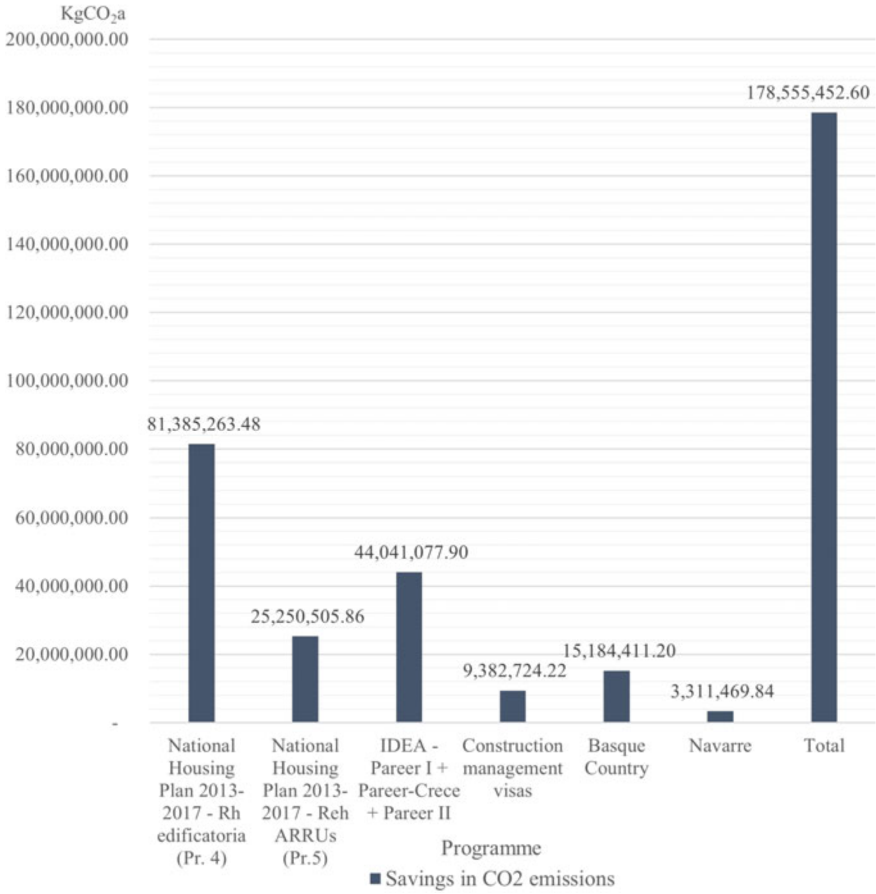


Fig. 11 Carbon saving per program and region. *Source* own creation from data in (Rubio del Val et al. 2020a)

3.8.2 Number of Jobs Created Per EUR Million Invested in the Sector

The purpose of this indicator is to understand the impact on changes in employment resulting from the investments to implement building stock renovation strategies at a large scale.

The ideal variable to develop this indicator is the number of jobs created in the construction sector per EUR million invested. However, no national or regional data were found that establish a relationship between the number of jobs created per million euros invested or according to the funds used. It should also be noted that data coming from the Spain's National Institute of Statistics (INE) and from Aragon's Institute of Statistics (IAEST) do not provide the number of jobs, but the number of people employed in the construction sector.

Other sources provide related information, as shown in Table 12. These sources allow us to obtain information on the number of jobs created per year in the construction sector. Using the available data, Fig. 12 shows the number of people employed (working) in the construction sector per year in Aragon. Figure 13 shows the number of jobs created per year in the provinces of the Basque Country.

3.8.3 GDP Increase in the Building Sector

The purpose of this indicator is to understand the situation and evolution of the construction sector by analyzing associated economic variables. The gross value-added (GVA) is the economic macro-magnitude that measures the value added generated by all producers in an economic area, which ultimately includes the values added to goods and services at the different stages of the production process. A country's gross value added is easily derived from Gross domestic product (GDP), with which it is closely related, as both measure the same thing. GDP is obtained after adding indirect taxes on production operations to the country's value added. Table 13 shows the sources of information of this indicator, which can be classified in international, national, and regional ones.

The variable proposed to define the GDP increase in the building sector is the year-on-year rate of change, measured in percentage. The international source of information provides information about Construction production (volume) index overview to the case of Europe. The production index for construction is a business cycle indicator which measures monthly changes in the price adjusted output of construction. This source shows the annual rate of change for total construction desegregated by the European countries, so there are data for the case of Spain. There are no limitations relating to the data on GDP growth in the construction sector. However, the data are not provided in more detail, so more specific indicators on GDP growth attributed to building renovation construction work cannot be developed. Figure 14 shows the results for the alternative variable suggested for the indicator, using data coming from the mentioned sources at the national and regional levels.

3.8.4 Percentage of Energy Imports for the MS.

The purpose of this indicator is to know the percentage of energy imported in each MS, so that this knowledge would make it possible to assess a territory's capacity to be energy self-sufficient. A high import percentage means that the MS depends on external countries to guarantee access to the resources needed to ensure a diversified energy mix.

Eurostat data are used as a source to develop the indicator at national level, and Eustat data are used for the Basque Country at regional level. Having the data available at both levels allows the indicator to be represented directly. In the case of Aragon, the indicator had to be calculated, as no direct data are available. Table 14

Table 12 Sources for indicator Number of jobs created per EUR million invested in the sector. *Source* own creation

Indicator: Number of jobs created per EUR million invested in the sector	
Variables	– Number of jobs created in the construction per EUR million invested in the sector
Indicator developability	– Data availability: partially available – Processing method from source: direct from the source with limitations – Data processability: Yes (XLS and CSV Pc-Axis, Json, txt)
National source	Labor Force Survey. Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxiT3/Tabla.htm?t=4138&L=0 https://www.ine.es/jaxiT3/Tabla.htm?t=3970&L=0 https://www.ine.es/jaxiT3/Tabla.htm?t=4228&L=0 https://www.ine.es/jaxiT3/Tabla.htm?t=4229&L=0 https://www.ine.es/jaxiT3/Tabla.htm?t=3991&L=0 https://www.ine.es/jaxiT3/Tabla.htm?t=3995&L=0
Characteristics of the source	– Availability: open data but insufficient to collect the indicator – Data collection method: statistical sampling – Data processability: yes, data available in XLS, CSV, Pc-Axis, Json, and txt formats – Georeferencing: no – Data update frequency/last update: quarterly. Last update second quarter of 2023
Regional source—Aragon	Aragon Institute of Statistics (IAEST)
Source link	http://servicios3.aragon.es/iaeaxi/tabla.do?path=/07/01/01/&file=070101B04.px&type=pcaxis&L=0 http://servicios3.aragon.es/iaeaxi/tabla.do?path=/07/01/01/&file=070101A14.px&type=pcaxis&L=0
Characteristics of the source	– Availability: open data but insufficient to collect the indicator – Data collection method: statistical sampling – Data processability: yes, data available in XLS, CSV, Pc-Axis, Json, and txt formats – Georeferencing: no – Data update frequency/last update: decennial. Last update 2019
Regional source—Basque Country	Basque Institute of Statistics (EUSTAT)

(continued)

Table 12 (continued)

Indicator: Number of jobs created per EUR million invested in the sector	
Source link	https://www.eustat.eus/elementos/ele0014300/puestos-de-trabajo-de-la-ca-de-euskadi-por-rama-de-actividad-a-4-y-territorio-historico/tbl0014387_c.html https://www.eustat.eus/elementos/ele0014300/puestos-de-trabajo-de-la-ca-de-euskadi-por-rama-de-actividad-a-4-y-territorio-historico-tasas-de-variacion-interanual/tbl0014388_c.html https://www.eustat.eus/elementos/ele0014300/personas-empleadas-de-la-ca-de-euskadi-por-rama-de-actividad-a-4-y-territorio-historico/tbl0014385_c.html https://www.eustat.eus/elementos/ele0014300/personas-empleadas-de-la-ca-de-euskadi-por-rama-de-actividad-a-4-y-territorio-historico-tasas-de-variacion-interanual/tbl0014386_c.html
Characteristics of the source	– Availability: open data but insufficient to collect the indicator – Data collection method: synthesis operation – Data processability: yes, data available in XLS and CSV formats – Georeferencing: no – Data update frequency/last update: annual. Last update 2022

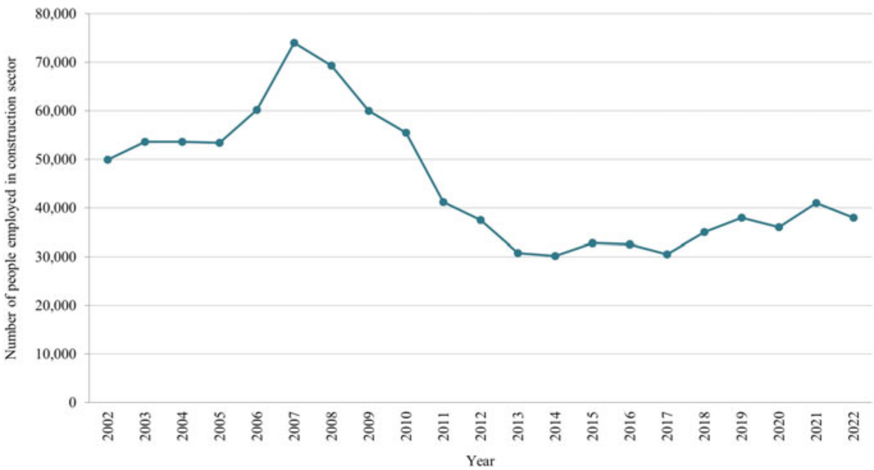


Fig. 12 Number of people employed (working) in the construction sector per year in Aragon. *Source* own creation from data in (Aragon Institute of Statistic 2023)

shows the sources of information, which can be classified in international, national, and regional ones.

Figure 15 shows the results for the indicator, using data coming from the mentioned sources at the national and regional levels.

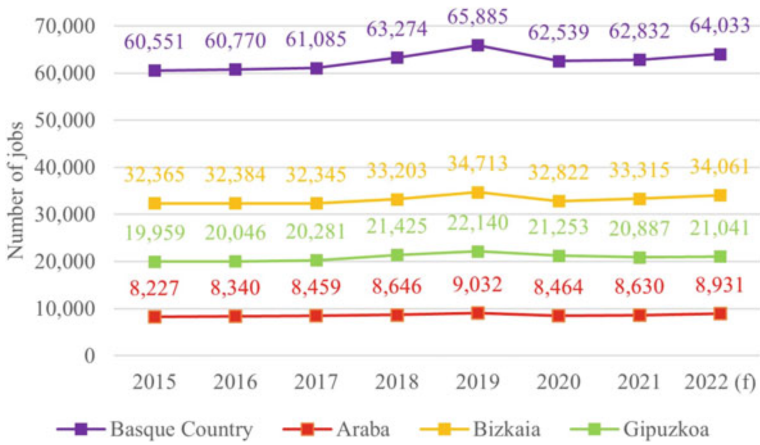


Fig. 13 Number of jobs created per year, since 2015 to 2022, in the Basque Country and its three provinces. *Source* own creation from data in (Basque Institute of Statistics 2023)

3.8.5 Removal/prevention of Accessibility Barriers for Persons with Disabilities

The purpose of this indicator is to quantify the renovation operations that incorporate accessibility improvements, including the installation of lifts and platforms and the adaptation of accesses. The simultaneous focus on energy renovation of buildings and the removal of accessibility barriers is advantageous for various reasons. On one hand, combining energy renovation and accessibility improvements aligns with a holistic approach to sustainability. It allows for the integration of environmental considerations, such as energy efficiency, with social considerations, such as making spaces more inclusive and accessible to people with disabilities. On the other hand, presenting energy renovation initiatives alongside accessibility improvements can facilitate greater acceptance among users and building occupants. Accessibility enhancements often provide tangible and immediate benefits that are easier for people to grasp and appreciate, fostering a positive perception of the overall renovation project. For these reasons, governments and organizations in Spain often offer funding that incentivize comprehensive improvements. Studying this indicator allows to track the evolution of the removal or prevention of accessibility barriers for persons with disabilities as well as the exploitation of the synergies between accessibility barriers removal and energy renovation of buildings.

No data sources were found to compile this indicator as stated. However, other sources allow related information to be collected, as shown in Table 15. The main limitation in developing this indicator is that disaggregated data on renovation interventions are not collected by most of the responsible entities. Furthermore, the data that is collected is not published openly for public consultation. As previously noted, the main source of information for this indicator, the Evaluation Report on Public Residential Renovation Policies in Spain (2013–2017) report (Rubio del Val et al.

Table 13 Sources for indicator GDP increase in the building sector. *Source* own creation

Indicator: GDP increase in the building sector	
Variables	GDP annual rate of change in construction sector, measured in percentage
Indicator developability	– Data availability: fully available – Processing method from source: direct with limitations – Data processability: yes, data available in XLS, CSV, Pc-Axis, Json, and txt formats
International source	European Statistical Office—Eurostat
Source link	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Construction_production_(volume_index_overview#Construction_output_in_Europe(
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, data available in XLSX format – Georeferencing: no – Data update frequency/last update: not specified
National source	Annual national accounts for Spain. Spain´s National Institute of Statistics (INE)
Source link	https://www.ine.es/dyngs/INEbase/es/operacion.htm?c=Estadistica_C&cid=1254736177057&menu=resultados&idp=1254735576581 https://www.ine.es/dyngs/INEbase/es/operacion.htm?c=Estadistica_C&cid=1254736167628&menu=resultados&idp=1254735576581#
Characteristics of the source	– Availability: open data but insufficient to collect the indicator – Data collection method: statistical sampling – Data processability: yes, data available in XLS, CSV, Pc-Axis, Json, and txt format – Georeferencing: no – Data update frequency/last update: quarterly. Last update second quarter of 2023
Regional source—Aragon	Aragon Institute of Statistics (IAEST)
Source link	https://opendata.aragon.es/datos/catalogo/dataset/producto-interior-bruto-a-precios-de-mercado-y-valor-anyadido-bruto-a-precios-basicos-aragon-y-espanya

(continued)

Table 13 (continued)

Indicator: GDP increase in the building sector	
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, data available in CSV and Pc-Axis formats – Georeferencing: no – Data update frequency/last update: annual. Last update in 2017
Regional source—Basque Country	Basque Institute of Statistics (EUSTAT)
Source link	https://www.eustat.eus/elementos/ele0014300/producto-interior-bruto-de-la-ca-de-euskadi-por-territorio-historico-y-componente-oferta-volumen-encadenado-tasas-de-variacion-interanual/tbl0014379_c.html
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, data available in XLS and CSV formats – Georeferencing: no – Data update frequency/last update: annual. Last update in 2022

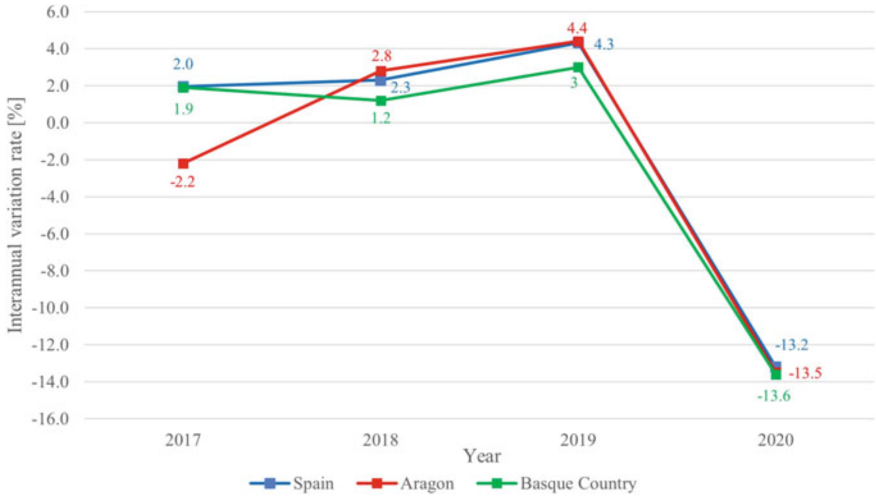


Fig. 14 Interannual rate of change for GDP in Spain, Aragon, and the Basque Country. Source: own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2023b)

2020a, Rubio del Val et al. 2020b), provides data related to dwellings renovated with the financial participation of national or regional programs. Collecting data on interventions carried out without without funding program is even more challenging, as only statistics on municipal building permits or construction management permits are available, which do not distinguish between different energy-depth interventions and whose data are non-processable. It is highly recommended that construction management permits include the identification and description of the type of work carried out and that the data collected can be processed for statistical purposes. In summary, the data available are not considered sufficient to correctly develop the indicator.

Figures 16, 17 and 18. show the results for the alternative variables suggested for the indicator, using data coming from the mentioned sources at the national and regional levels, even provinces data in the last of these graphs.

4 Conclusions

The analysis of the indicators proposed by the different frameworks on current energy savings and other benefits of renovation allows us to formulate some conclusions. Some of them are related to methodological issues on the indicators, whereas others discuss the current situation in this matter, at the state and regional levels.

Table 14 Sources for indicator Percentage of energy imports for the member state. *Source* own creation

Indicator: Percentage of energy imports for the member state	
Variables	– Percentage of energy dependency (energy imports)
Indicator developability	– Availability: fully available – Processing method from source: direct in all cases, except for Aragon, where direct data are non-available, but the required calculation data can be obtained – Data processability: yes, partially. Data from some sources are available in XLS and CSV formats
International source	European Statistical Office—Eurostat
Source link	https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Construction_production_(volume_index_overview#Construction_output_in_Europe
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, data available in XLS and CSV format – Georeferencing: no – Data update frequency/last update: not specified
National source	Ministry of Ecological Transition and Demographic Challenge—MITERD
Source link	https://energia.gob.es/balances/Balances/Paginas/Balances.aspx
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, data available in ODS format – Georeferencing: no – Data update frequency/last update: annually. Last update in 2022
National source	National Institute of Statistics—INE
Source link	https://www.ine.es/ss/Satellite?L=es_ES&c=INEPublicacion_C&cid=1259924856416&p=1254735110672&pagename=ProductosYServicios%2FPYSLayout&param1=PYSDetalleGratuitas
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: no – Georeferencing: no – Data update frequency/last update: annually. Latest data are from 2022
Regional source—Aragon	Aragon Institute of Statistics—IAEST
Source link	https://www.aragon.es/-/balances-energeticos-de-aragon-1998-actualidad-
Characteristics of the source	– Availability: open data – Data collection method: not indicated – Data processability: no – Georeferencing: no – Data update frequency/last update: annually. Last update in 2020

(continued)

Table 14 (continued)

Indicator: Percentage of energy imports for the member state	
Regional source—Basque Country	Basque Institute of Statistics—EUSTAT
Source link	https://www.eustat.eus/elementos/ele0018500/dependencia-energetica--de-la-c-a-de-euskadi-y-de-los-paises-de-la-union-europea-/tbl0018533_c.html
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, data available in XLS and CSV formats – Georeferencing: no – Data update frequency/last update: annually. Last update in 2021

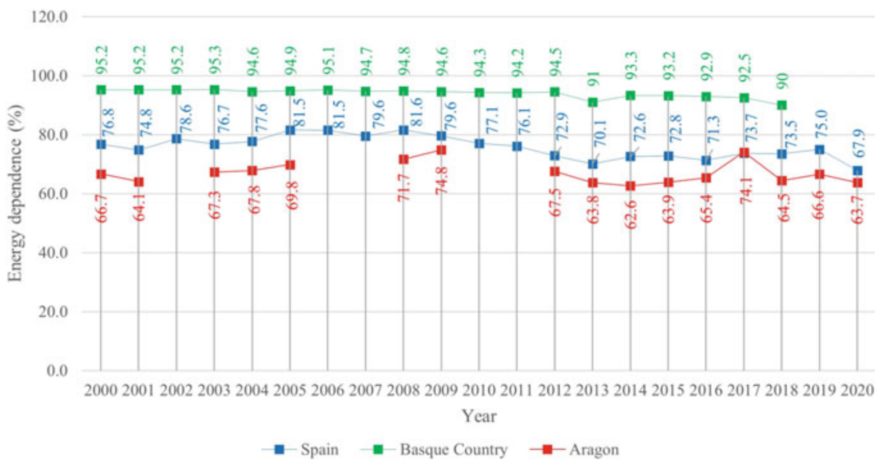


Fig. 15 Percentage of energy dependency of Spain and the regions of Aragon and the Basque Country. *Source* own creation from data in (Ministry of Ecological Transition and Demographic Challenge (2022)) for Spain, from data in (Aragon Institute of Statistics—IAEST (2020)) for Aragon and from data in (Basque Institute of Statistics—EUSTAT (2021)) for the Basque Country

Thus, the first thing to remark is the impossibility, in many cases, to find sources of data to collect the indicators proposed in the European directives. For some indicators, there is no data available (e.g., in Average/aggregate indoor air quality indices and in Reduction on whole life carbon), but, for most of the proposed indicators, the Spanish institutions have developed equivalent data that were used as alternative variables to construct a similar indicator. Those similar indicators align closely with the objectives outlined in European directives. Nevertheless, it is essential to emphasize the advantages of commencing a harmonization process for data collection across the EU MSs. In other cases, sources are available but with non-homogeneous data, so knowing the state of the country and the regions with respect to some indicators

Table 15 Sources for indicator Removal/prevention of accessibility barriers for persons with disabilities. *Source* own creation

Indicator: Removal/prevention of accessibility barriers for persons with disabilities	
Variables	Not applicable to this indicator as stated. Alternative proposed: – Number of renovated dwellings with improved accessibility per program – Number of accessible buildings per regions and provinces
Indicator developability	– Availability: non-available. Alternative variables proposed are partially available – Processing method from source: direct, partially, in the case of the main source. Alternative or related data sources do not allow the indicator to be developed – Data processability: no.
National source	3R City Observatory. Evaluation Report on Public Residential Reno-vation Policies in Spain (2013–2017)
Source link	http://www.observatoriociudad3r.com/wp-content/uploads/2020/01/Informe-Eval-Polit-Pub.pdf
Characteristics of the source	– Availability: open data – Data collection method: population survey – Data processability: yes, in CSV, XLS, Json, text, PDF, PPT, etc – Georeferencing: not applicable – Data update frequency/last update: single publication
National source	Spain’s National Institute of Statistics (INE)
Source link	https://www.ine.es/jaxi/Tabla.htm?path=/t20/e244/edificios/p03/l0/&file=01008.px&L=0 https://www.ine.es/dynt3/inebase/index.htm?type=pcaxis&path=/t20/e244/edificios/p04/&file=pcaxis&L=0
Characteristics of the source	– Availability: open data – Data collection method: statistical sampling – Data processability: yes, data available in XLS, CSV – Georeferencing: no – Data update frequency/last update: decennial. Last update in 2011
Regional source—Aragon	Aragon Institute of Statistics (IAEST)

(continued)

Table 15 (continued)

Indicator: Removal/prevention of accessibility barriers for persons with disabilities	
Source link	https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/ED3_C&Action=Navigate&NQUser=granpublico&NQPassword=granpublico&Options=df https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/ED3_M10&Action=Navigate&NQUser=granpublico&NQPassword=granpublico&Options=df https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/ED3_M2&Action=Navigate&NQUser=granpublico&NQPassword=granpublico&Options=df https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/ED3_M0&Action=Navigate&NQUser=granpublico&NQPassword=granpublico&Options=df
Characteristics of the source	– Availability: open data but insufficient to collect the indicator – Data collection method: statistical sampling – Data processability: yes, data available in XLS, CSV – Georeferencing: no – Data update frequency/last update: decennial. Last update in 2011
Regional source – Basque Country	Basque Institute of Statistics (EUSTAT)
Source link	https://www.eustat.eus/elementos/ele0018900/edificios-residenciales-de-la-ca-de-euskadi-por-ambitos-territoriales-segun-ascensor-garaje-y-trastero-p/tbl0018928_c.html
Characteristics of the source	– Availability: open data but insufficient to collect the indicator – Data collection method: statistical sampling – Data processability: yes, data available in XLS, CSV – Georeferencing: no – Data update frequency/last update: decennial. Last update in 2020
Regional source—Basque Country	Basque Housing Observatory. Evaluation Report on the Renovation Policy of the Basque Country
Source link	https://www.etxebide.euskadi.eus/contenidos/informacion/ovv_rhb_2019/es_ovv_admi/adjuntos/RehabilItacion-2019.pdf
Characteristics of the source	– Availability: open data but insufficient to collect the indicator – Data collection method: predictions – Data processability: no – Georeferencing: no – Data update frequency/last update: single publication in 2020

requires prior processing and unification of criteria within the Spanish scope to make the use of this information operational and direct.

With these methodological limitations and with the data available at the national and regional levels (for Aragon and the Basque Country), the following conclusions

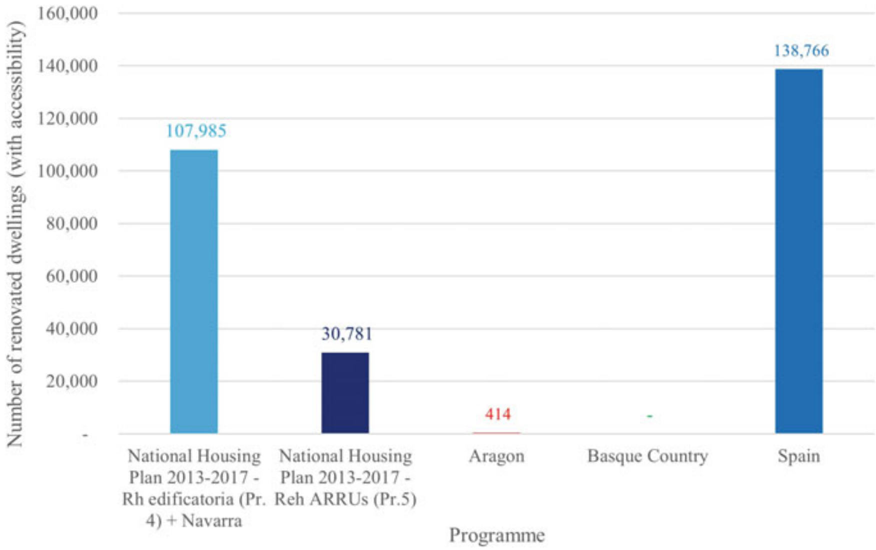


Fig. 16 Number of renovated dwellings with improved accessibility per program. Source: own creation from data in (Rubio del Val et al. 2020b)

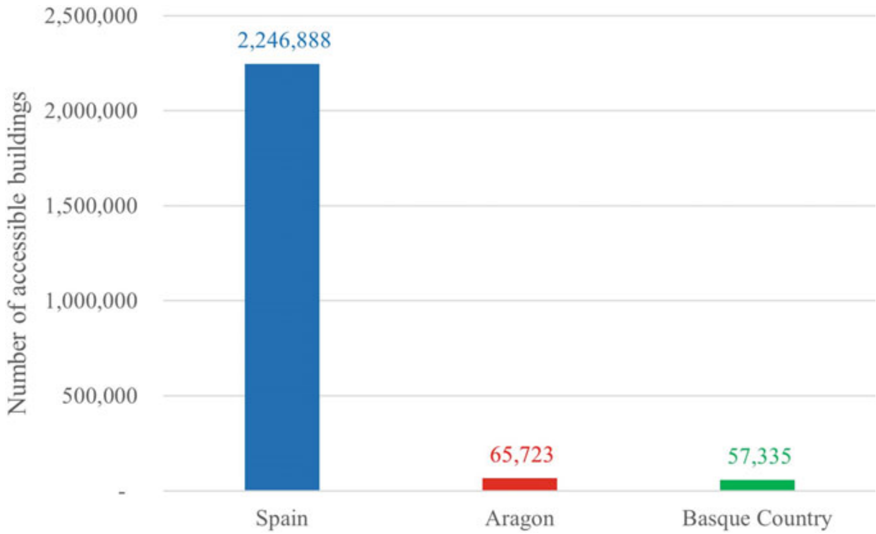


Fig. 17 Number of accessible buildings in Spain, Aragon, and the Basque Country in 2011. *Source* own creation using data extracted from the INE website: www.ine.es (Spain's National Institute of Statistics 2011), and from (Aragon Institute of Statistics 2011) and (Basque Housing Observatory 2020)

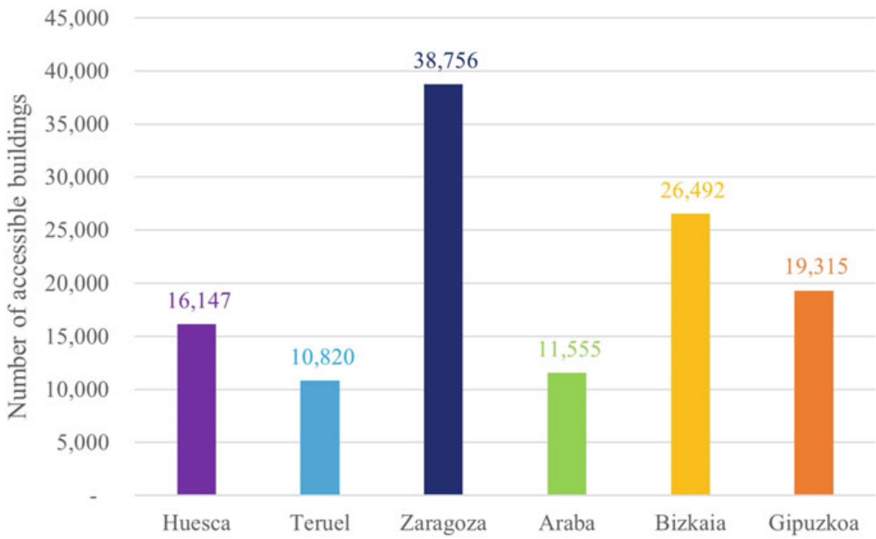


Fig. 18 Number of accessible buildings per provinces. Source: own creation from data in (Aragon Institute of Statistics 2011) and in (Basque Housing Observatory 2020)

were drawn on the Spanish situation regarding energy savings and other benefits of renovation:

- Regarding actual energy savings achieved, the data available from different sources are not homogeneous and there is no source that provides overall savings for the country. However, the figures recorded by the National Housing Plan are significant, showing savings up to 223 thousand kWh per year. This data is not available in all regions, as is the case of Aragon. However, the data is available in the Basque Country, where the savings are up to 41 thousand kWh per year.
- Although data on indoor air quality is not available in terms of indoor air quality index in Spain, there are some data on homes affected by pollution and other environmental problems. The development of this alternative indicator shows that between 2004 and 2016 the number of homes affected by pollution and other environmental problems decreased from 17% (2005) of the housing stock to 8% in 2012 in Spain. Between 2012 and 2019, the percentage of households affected increased until around 9% of the stock. A similar behavior is observed in Aragon and the Basque Country regions. In the case of Aragon, the percentages fluctuated between 17 and 1.73% and for the Basque Country between 17 and 15.3%. The three data series found indicate that, by 2019, between 7 and 10% of the housing stock was affected by low air quality.
- Even if there is not available data in Spain in terms of disability adjusted life year (DALY) and quality adjusted life year (QALY) due to improvements in the conditions of the building stock, there is available data on the number of years lived by people with a good quality of life and without disabilities. The available

life expectancy data, which include the improvement in building stock as one of the implicit causes although not the only one, indicates a high life expectancy in Spain and in the regions of Aragon and the Basque Country. People have an average life expectancy of between 80 and 85 years, with good health until the age of 60, and without disabilities until an age slightly above 70 years.
- Some data regarding emissions reduction are available from the statistics of different carbon savings programs, from the public administration of some regions, and in a publication (Rubio del Val et al. 2020a, Rubio del Val et al. 2020b). According to the National Housing Plan (2013–2017) savings reach up to 89 thousand $KgCO_2$ per year.
- Regarding the growth of GDP in the construction sector, there are moderate positive fluctuations, ranging from 5 to 1% at both the national and regional levels. However, the data for 2019–2020 indicates a significant and sharp decline of over 10 points. This decline coincided with the reduced activity in the sector during the global pandemic crisis, which has since been overcome in Europe.
- Data on the dependence of Spain and the regions of Aragon and the Basque Country on imported energy are fully available. On the one hand, data from the Basque Country show that, for the whole period analyzed, over the 90% energy is imported. On the other hand, Aragon is only dependent on imported energy between 60 and 70%, depending on the year. For the whole country, dependency ranges move from the current 67 to 81% in 2006, coinciding with the peak of the construction of new buildings.
- The available data on renovated homes including accessibility improvements show that most of the actions have contemplated this type of improvement. In the case of the national housing plan, data show that the percentage is around 75% of the homes computed.

In summary, energy savings and other benefits of buildings renovation are not yet parameterized according to sources with easily exploitable and usable data. Although renovation activity at the national and regional levels provides benefits that can partially be noticed in some indicators, a complete and precise picture of savings and benefits is not yet available.

Acknowledgements This work was funded by the MINISTRY OF SCIENCE AND INNOVATION OF SPAIN, grant number PID2019-104871RB-C21/AEI/10.13039/501100011033 and by GOBIERNO DE ARAGÓN, grant number T37_23R: Built4Life Lab.

References

Aragon Institute of Statistics (IAEST): Censos de población y viviendas. Año 2011 [Census of Population and Housing. Year 2011]. (2011). https://obiee.aragon.es/analytics/saw.dll?Go&path=/shared/IAEST-PUBLICA/MENUWEB/Demografia/0201030104/ED3_C&Action=Navigate&NQUser=granpublico&NQPassword=granpublico&Options=df, last accessed 2023/09/20.

Aragon Institute of Statistics (IAEST): Balances Energéticos de Aragón (1998- actualidad) [Energy Balances of Aragon (1998-present)]. (2020). https://www.aragon.es/-/balances-energeticos-de-aragon-1998-actualidad-, last accessed 2023/09/20.

Aragon Institute of Statistics (IAEST): Encuesta de población activa (EPA) [Active Population Survey (APS)]. (2023). https://www.aragon.es/-/encuesta-de-poblacion-activa, last accessed 2023/09/20.

Basque Housing Observatory (EUSTAT): Residential buildings of the Basque Country by territorial areas, according to the lift, garage and storage room (p). 06/30/2020. (2020). https://en.eustat.eus/elementos/ele0018900/ti_edificios-residenciales-de-la-ca-de-euskadi-por-ambitos-territoriales-segun-ascensor-garaje-y-trastero-p-30062020/tbl0018928_i.html, last accessed 2023/09/20.

Basque Institute of Statistics (EUSTAT): Energy dependence(*) of the Basque Country and the countries of the European Union (%). 2010–2021. (2021). https://en.eustat.eus/elementos/ele0018500/ti_dependencia-energetica--de-la-c-a-de-euskadi-y-de-los-paises-de-la-union-europea--2010-2021/tbl0018533_i.html, last accessed 2023/09/20.

Basque Institute of Statistics (EUSTAT): Jobs in the Basque Country by A-4 activity branch and province. 2015–2022. (2023). https://en.eustat.eus/elementos/ele0014300/ti_puestos-de-trabajo-de-la-ca-de-euskadi-por-rama-de-actividad-a-4-y-territorio-historico-2015-2022/tbl0014387_i.html, last accessed 2023/09/20.

Dionova, B. W., Mohammed, M.N., Al-Zubaidi, S., Yusuf, E.: Environment indoor air quality assessment using fuzzy inference system. ICT Express 6(3), 185–194(2020).

European Commission: COMMISSION RECOMMENDATION (EU) 2019/786 of 8 May 2019 on building renovation. Official Journal of the European Union (2019: L 127), 34–79 (2019).

European Commission: Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast). COM/2021/802. Brussels (2021).

European Commission: Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast). ST 13280 2022 INIT. Brussels (2022).

European Parliament: Energy performance of buildings (recast) Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (COM(2021)0802 – C9–0469/2021 – 2021/0426(COD)). Strasbourg (2023).

Head of State: Ley 10/2022, de 14 de junio, de medidas urgentes para impulsar la actividad de rehabilitación edificatoria en el contexto del Plan de Recuperación, Transformación y Resiliencia [Law 10/2022, of June 14, on urgent measures to boost building renovation activity in the context of the Recovery, Transformation, and Resilience Plan]. Official State Gazette (BOE) 142, sec. I, pp. 81569–81587 (2022).

Ministry for Ecological Transition and the Demographic Challenge: ESTRATEGIA NACIONAL CONTRA LA POBREZA ENERGÉTICA 2019–2024 [NATIONAL STRATEGY AGAINST ENERGY POVERTY 2019–2024]. Madrid (2019). https://www.miteco.gob.es/content/dam/miteco/es/prensa/estrategianacionalcontralapobrezaenergetica2019-2024_tcm30-496282.pdf, last accessed 2023/09/20.

Ministry of Ecological Transition and Demographic Challenge: Estadísticas y Balances Energéticos [Energy Statistics and Balances]. (2022). https://energia.gob.es/balances/Balances/Paginas/Balances.aspx, last accessed 2023/09/20.

Ministry of Transport, Mobility and Urban Agenda: 2020 Update of the long-term strategy for energy renovation in the building sector in Spain (ERESEE). Madrid (2020).

Ministry of Transport, Mobility and Urban Agenda: Real Decreto 853/2021, de 5 de octubre, por el que se regulan los programas de ayuda en materia de rehabilitación residencial y vivienda social del Plan de Recuperación, Transformación y Resiliencia [Royal Decree 853/2021, of October 5, regulating assistance programs for residential renovation and social housing under the Recovery, Transformation, and Resilience Plan]. Official State Gazette (BOE) 239, sec. I, pp. 122127–122197. (2021).

Ministry of Transport, Mobility and Urban Agenda: Recomendaciones de los grupos de trabajo para la implementación de las medidas de la ERESEE 2020 [Workgroup recommendations for the implementation of 2020 ERESEE measures]. Madrid (2023).
Ortiz, J., Salom, J.: Estimación del efecto de la rehabilitación energética en la salud de las personas. Enfoque económico [Estimation of the Effect of Energy Renovation on People's Health. Economic Approach]. Catalonia Institute for Energy Research. Barcelona (2016).
Prieto, L., Sacristán J.A.: Problems and solutions in calculating quality-adjusted life years (QALYs). Health and Quality of Life Outcomes 1(80), (2003).
Rubio del Val, J. (coord.), López-Mesa, B., Monzón-Chavarrías, M., Espinosa, A., García-Pérez, S.: Informe de Evaluación de las Políticas Públicas de Rehabilitación Residencial en España (2013–2017) [Report on the Evaluation of Public Policies for Residential Renovation in Spain (2013–2017)]. (2020a). ISBN 978–84–09–19847–4.
Rubio del Val, J., Espinosa-Fernández, A., Monzón, M., López-Mesa, B.: Evaluation of public residential renovation policies in Spain 2013–2017. Anales de Edificación. 6 (3), 6–12. (2020b). https://doi.org/10.20868/ade.2020.4609.
Spain's National Institute of Statistics (INE): Disability, Independence and Dependency Situations Survey 2008. (2008). https://www.ine.es/dynt3/inebase/en/index.htm?type=pcaxis&path=/t15/p418/a2008/hogares/p01/esp_vida&file=pcaxis, last accessed 2023/09/20.
Spain's National Institute of Statistics (INE): Population and Housing Census 2011. Buildings (2011). https://www.ine.es/jaxiPx/Tabla.htm?path=/t20/e244/edificios/p03/l0/&file=01008.px&L=1, last accessed 2023/09/20.
Spain's National Institute of Statistics (INE): Life Conditions Survey (2023a). https://www.ine.es/dyngs/INEbase/en/operacion.htm?c=Estadistica_C&cid=1254736176807&menu=resultados&idp=1254735976608, last accessed 2023/09/20.
Spain's National Institute of Statistics (INE): Spanish Regional Accounts. Results (2023b). https://www.ine.es/dyngs/INEbase/en/operacion.htm?c=Estadistica_C&cid=1254736167628&menu=resultados&idp=1254735576581, last accessed 2023/09/20.
Streinu-Cercel, A., Costoiu, S., Mârza, M., Streinu-Cercel, A., Mârza, M.: Models for the indices of thermal comfort. Journal of Medicine and Life 1(2):148–56(2008).

Indicators and Data in Spain Regarding Evidence-Based Estimate of Expected Energy Savings and of Reduction of Costs for Health Systems from Buildings Renovation

Marta Gómez-Gil, Matxalen Etxebarria-Mallea, Markel Arbulu, Olatz Grijalba-Aseguinolaza, Almudena Espinosa-Fernández, and Marta Monzón-Chavarrías

Abstract Europe is setting ambitious targets for decarbonization by the year 2050. These goals are essential for mitigating the impact of climate change and transitioning towards a more sustainable future. Setting realistic and binding targets is a key component of this strategy, so the evidence-based approach ensures that these goals are rooted in a solid foundation of expected energy savings. Moreover, the energy renovation of buildings entails a series of benefits that go beyond energy savings, such as improvement in people's health and, consequently, economic expenditure in health systems reduction. In this chapter, we propose indicators regarding evidence-based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation. We also studied the sources of information available in Spain for the development of these indicators, at national and regional scales, and developed them when there were data for the case of the whole country and two

M. Gómez-Gil · A. Espinosa-Fernández · M. Monzón-Chavarrías (✉)
Built4Life Lab, University of Zaragoza-I3A, 50018 Zaragoza, Spain
e-mail: monzonch@unizar.es

M. Gómez-Gil
e-mail: m.gomez@unizar.es

A. Espinosa-Fernández
e-mail: almudenaef@unizar.es

M. Etxebarria-Mallea · M. Arbulu · O. Grijalba-Aseguinolaza
Department of Architecture, University of the Basque Country UPV/EHU, 20018 Donostia - San Sebastian, Spain
e-mail: matxalen.etxebarria@ehu.eus

M. Arbulu
e-mail: markel.arbulu@ehu.eus

O. Grijalba-Aseguinolaza
e-mail: olatz.grijalba@ehu.eus

B. López-Mesa and X. Oregi (eds.), *Assessing Progress in Decarbonizing Spain's Building Stock*, Digital Innovations in Architecture, Engineering and Construction,
https://doi.org/10.1007/978-3-031-51829-4_9

regions, Aragon and the Basque Country. Based on our study, it can be inferred that in Spain, although the current data sources provide trustworthy information regarding expected energy savings, they fall short in providing sufficient details to set targets concerning the reduction in health costs attributed to energy efficiency measures and improved air quality. At the regional level, there is room for improvement in both aspects.

1 Introduction

Europe is setting ambitious targets for the decarbonization of the building stock by the year 2050. These goals are essential for mitigating the impact of climate change and transitioning towards a more sustainable future. To achieve these objectives successfully, Europe has introduced a comprehensive framework that includes the establishment of indicators to provide an overview of actual energy-saving efforts and the definition of clear, evidence-based targets for expected energy savings.

One of the crucial aspects of this initiative is the use of indicators to assess the current state of energy conservation within Europe. These indicators serve as a snapshot of the region's energy-saving performance. By carefully monitoring and evaluating these indicators, policymakers and stakeholders gain valuable insights into the progress that has been made, as well as areas where more attention and effort are required. This overview ensures that Europe remains on track in its journey towards decarbonization.

Setting realistic and binding targets is a key component of this strategy. While ambitious goals are essential, they must also be attainable. The evidence-based approach ensures that these goals are rooted in a solid foundation of expected energy savings. These targets serve as a roadmap for countries and regions to follow, driving them to reduce carbon emissions and minimize energy consumption effectively. These decarbonization goals are not only important for environmental reasons but also for the development of effective renovation and energy policies. By having clear and measurable targets, policymakers can design policies that align with the overarching goal of decarbonization. They can implement strategies for energy efficiency, renewable energy adoption, and infrastructure improvements with a clear understanding of the intended outcome. These objectives provide a framework for innovation and investment in green technologies, creating opportunities for economic growth and job creation, and improve the health of users.

The Energy Performance of Buildings Directive (EPBD) (European Parliament, Council of the European Union 2003) as well as its updates and recasts establish the obligation for Member States (MS) to set requirements for the calculation of expected energy savings in the context of building retrofitting. In this sense, Directive 2002/27/UE on energy efficiency (European Parliament and the Council of the European Union 2003) and its recast 2018/844 (European Parliament and the Council of the European Union 2018) (which in this book are referred to as 2002 EPBD and

2018 EPBD, respectively) stablish that each MS shall establish a long-term renovation strategy (LTRS) to support the renovation of the national stock of residential and non-residential buildings, both public and private, into a highly energy efficient and decarbonized building stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly zero-energy buildings. In this strategy, MSs must identify expected objectives to be met in the coming years. The EPBD is now being revised. The latest draft version of the ongoing EPBD revision (European Parliament 2023), which in this book it is referred to as 2023 EPBD Proposal recast, states that MSs shall establish a National Building Renovation Plan (NBRP) to ensure the renovation of their national stock of residential and non-residential buildings, transforming them into energy-efficient and decarbonized building stock by 2050, with the aim of transforming existing buildings into zero-emission buildings. Building renovation plans will be based on the principle of 'energy efficiency first' and will include, among other things, a roadmap with nationally set targets, measurable progress indicators and specific deadlines for all existing buildings to achieve higher energy efficiency classes by 2030, 2040 and 2050, with a view to the goal of climate neutrality by 2050, in order to ensure a decarbonized and highly energy-efficient national building stock and the transformation of existing buildings into zero-emission buildings by 2050. These roadmaps should include an evidence-based estimate of energy savings and greenhouse gas (GHG) emission reductions. The NRBPs will also serve to determine the joint compliance with the goals and establish actions to correct possible deviations.

Moreover, the energy renovation of buildings entails a series of benefits that go beyond energy savings. Thermal comfort and the healthiness of the interior enclosures are enhanced due to, for example, the improvement of condensations and internal humidity. This leads to an improvement in people's health and, consequently, economic expenditure in health systems is reduced. These benefits, which transcend the energetic aspect, have also been included as targets in some documents.

The 2020 update of Spain's LTRS (Ministry of Transport, Mobility and Urban Agenda 2020), often known as 2020 ERESEE for its acronym in Spanish, has set energy saving and decarbonization targets as part of its energy and climate policy for the building sector in Spain. These objectives are designed to address climate change, improve energy efficiency, and promote the use of cleaner and more sustainable energy sources. Within these objectives, specific targets have been set for the renovation of the existing building stock, as they are major contributors to energy consumption and GHG emissions. In addition to including expected energy savings, it includes a section on long-term impact and benefits of energy renovation in housing on air quality, condensation, and human health.

The Spanish National Integrated Energy and Climate Plan (Ministry of Ecological Transition and Demographic Challenge 2020a) (PNIEC for its acronym in Spanish) was planned for the period between 2021 and 2030. The PNIEC is divided into two main blocks: the first one details the process, objectives, existing policies, and measures necessary to achieve the Plan's objectives. The second block, consisting of the Appendices to the main document, is the analytical part and contains a description of the different models that have made the prospective analysis possible and that provide robustness to the results. In addition to the plan, a report on the Economic, Employment, Social and Public Health Impact of the Integrated National Energy and Climate Plan 2021–2030 (Ministry of Ecological Transition and Demographic Challenge 2020c) is published, which includes the main results of the assessment of the economic, social, and public health impact of the Plan.

The 2023 EPBD Proposal recast also makes it mandatory for buildings to have a building renovation passport (BRP), which is a document that provides a tailored roadmap for the in-depth renovation of a specific building in a maximum number of stages, which will transform the building into a zero-emission building by 2050 at the latest. This passport will include the expected benefits in terms of energy savings, savings on energy bills and GHG emissions reduction over the entire life cycle when a building renovation is carried out. However, this passport should also include more general benefits related to health, comfort, indoor environmental quality, fire, electrical and seismic safety, and improved building resilience to climate change. In the context of benefits beyond energy, the 2023 EPBD proposal includes further developments. The Commission establishes a comparative methodological framework for calculating cost-optimal levels of cost-optimal minimum energy performance requirements for existing buildings undergoing major renovation. This methodological framework will consider, among other things, the environmental, economic and health externalities of energy consumption. These will include, among other issues, the reduction of the costs of health and social security systems.

Scientific literature has addressed the issue of predicting energy savings at the city and country scale. Urban Building Energy Modeling (UBEM) has become an effective way to understand the energy use of urban buildings and explore the potential for energy conservation and emission reductions (Zhang et al. 2022). Some of these studies are carried out for the residential buildings of a city (Zhang et al. 2022), others focus on a typology of buildings obtaining more precise results as in the case of historic buildings (Lin et al., 2023) or non-residential buildings (Ahmed et al. 2023). The automation of processes becomes a useful tool for the constant updating of data (Deng 2023). In Spain, Ortiz and Salom, published a report on how an economic approach to the effect of energy retrofitting on people's health can be used to improve energy efficiency (Ortiz and Salom 2016).

The objective of this chapter is to propose a set of indicators regarding evidence-based estimate of expected energy savings and wider benefits of buildings renovation, analyze the availability of data in Spain, and develop them when they are available. Furthermore, the intention is to make these indicators adaptable for development at a regional level. To achieve this, the study employs two specific regions, namely Aragon and the Basque Country, as case studies.

2 Methodology

To develop the indicators regarding evidence-based estimate of expected energy savings and wider benefits of buildings renovation in Aragon, the Basque Country and Spain, the process indicated in Fig. 1 was followed.

The first step consisted in the development of a common template for these indicators based on:

- Indicator:
  - Definition of the indicator.
  - Variables to quantify it and their unit of measurement.
  - Purpose and advantages of implementing this indicator.
  - Alignment of the indicator with the directives, agendas, action plans and strategies, covering the European and international, national, and regional scales.
  - Relationship of this indicator with other similar ones.
- Information sources:
  - Availability of information to generate this indicator at different scales.
  - Entity responsible for providing this information.

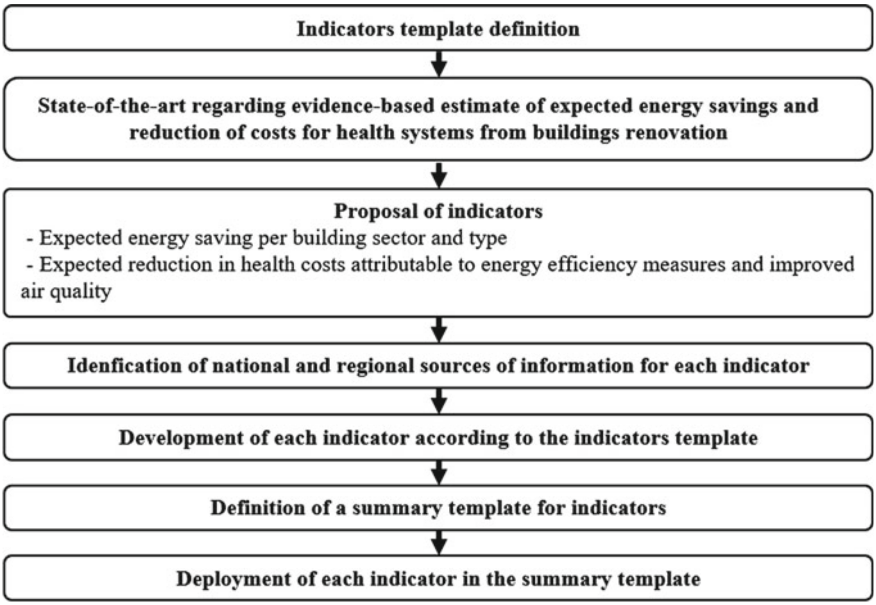


Fig. 1 Methodology implemented to generate indicators regarding evidence-based estimate of expected energy savings and reduction of costs for health systems from buildings renovation in Spain and two of its regions, Aragon and the Basque Country. *Source* own creation

- Measurement:
  - Measurement method.
  - Methodology.
  - Current possibilities of obtaining it.
  - Information necessary to generate it.
  - Availability and quality of data.

With the aim to select the indicators that best represents the evidence-based estimate of expected energy savings and wider benefits of buildings renovation, we considered the indicators which have been suggested in European directives and related documents. First, we studied the indicative milestone included in the Commission Recommendation (EU) 2019/786 (European Commission 2019), which is referred to as 2019 EPBD-related Recommendation in this book and was the first document in which a framework of progress indicators to measure the European building stock decarbonization was proposed. Then, we analyzed the targets, identified as roadmap 2030, 2040 and 2050, included in the 2023 EPBD Proposal recast, which is the document with the last version of the framework of progress indicators. Table 1 shows the indicators recommended by these sources.

In the pursuit of selecting indicators that most accurately reflect the evidence-based estimation of expected energy savings and wider benefits resulting from building renovations, we considered indicators recommended in European directives and associated documents. Our initial examination focused on the indicative milestones outlined in the Commission Recommendation (EU) 2019/786 (referred to as the 2019 EPBD-related Recommendation in this book). This document, recognized as the first to propose a framework of progress indicators for measuring the decarbonization of the European building stock, set the foundation. Subsequently, we scrutinized the targets outlined in the 2023 EPBD Proposal recast, denoted as roadmap 2030, 2040, and 2050. This proposal represents the latest version of the indicator framework to measure the effectiveness of building renovation policies and

Table 1 Indicators regarding evidence-based estimate of expected energy savings and wider benefits of buildings renovation included in selected European directives and related documents. *Source* own creation from data in (European Commission 2019; European Parliament 2023)

Document	Evidence-based estimate of expected energy savings	Estimate wider benefits of buildings renovation
2019 EPBD-related recommendation	– Total energy saving potential per building sector	– Cost of avoided illnesses/ reduction in health costs attributable to energy efficiency measures
2023 EPBD proposal recast	– Expected energy savings per buildings type	– Reduction of costs for health systems due to health improvements through improved indoor environmental quality after renovation

the building decarbonization progress in Europe. Table 1 illustrates the indicators recommended by these sources.

After consulting the indicators proposed in European legislation, we searched for available sources of information to develop them. The proposed indicators to develop are the following, which coincide with those proposed by Europe:

- Expected energy saving per building sector and type.
- Expected reduction in health costs attributable to energy efficiency measures and improved air quality.

Once the key indicators to cover this topic were identified, the available sources of information were studied and the standard template for each indicator was developed and generated.

Subsequently, a summary file was defined for each indicator with the main points covered in the complete file Fig. 1.

3 Indicators

3.1 Expected Energy Saving Per Building Sector and Type

The purpose of this indicator is to know the potential energy savings that could be achieved in the different building sectors and types by implementing energy efficiency actions and measures.

The variables of the indicator are defined by its title, as Commission Recommendation (EU) 2019/786 (European Commission 2019) specifies that 'building sector' refers to both residential and non-residential sectors. Additionally, this classification was broken down into a second level for the non-residential sector, which is used in the data sources identified to collect the indicator.

The sources of information to develop this indicator in Spain are national and regional (Table 2). At the national scale, as required by the EU to each MS, Spain drew up a PNIEC (Ministry of Ecological Transition and Demographic Challenge 2020a), which identifies the challenges and opportunities in the 5 dimensions of the Energy Union: decarbonization, energy efficiency, energy security, internal energy market, and research, innovation, and competitiveness. In particular, and among other things, it identifies the cumulative savings potential of the residential sector in the period 2021–2030. In addition, the Long Term Decarbonization Strategy 2050 (ELP2050, in Spanish) (Ministry of Ecological Transition and Demographic Challenge 2020b), prepared according to Regulation (EU) 2018/1999, establishes energy and emissions savings targets for all economic activities in Spain, including the building sector. For the period 2021–2030 these targets are in line with those of the PNIEC. Furthermore, the ERESEE 2020 (Ministry of Transport, Mobility and Urban Agenda 2020) compiles the objectives proposed in the PNIEC and the ELP2050. It also includes a series of complementary reports on specific issues related to the Strategy. Specifically, document 9 ‘Report on typologies, consumption, improvement actions and potential energy savings in the building stock of the tertiary sector’ (A3e. Association of Energy Efficiency Companies 2019), prepared by A3e: Association of Energy Efficiency Companies, sets out the potential energy savings that could be achieved by implementing the proposed measures. This study applies to the buildings in the tertiary sector indicated in the variables section.

At the regional scale, on the one hand, the Department of Industry and Innovation of the Government of Aragon is in charge of preparing the Energy Plans of this region, where energy saving targets are set. On the other hand, the Department of Economic Development and Competitiveness of the Basque Government prepared the Basque Country Energy Strategy 2030, which sets out a vision of the current energy panorama in the region and establishes a series of objectives for 2030, which should be achieved by applying the 8 proposed lines of action. Specifically, line of action L3 ‘Reduce consumption and increase the use of renewables in buildings and households’ establishes energy savings indicators and targets for 2025 and 2030.

To collect the data of this indicator, it was assumed that the expected energy savings of the building sector coincide with the energy savings targets set for them in Spain’s Long Term Decarbonization Strategy (ELP) 2050, in the ERESEE 2020 and in the supporting studies on improvement potential and costs from which said objectives were established, such as the ‘Report on typologies, consumption, improvement actions and potential energy savings in the building stock of the tertiary sector’ (A3e. Association of Energy Efficiency Companies 2019).

A limitation in the collection of the indicator was the different time horizons in which the data are expressed: some of them refer to the savings produced by specific measures at a specific point in time, while others refer to a complete period, which prevents a direct comparison. In addition, the data are expressed in different units in each document, which implies the need to convert the units to establish comparisons.

With these considerations, the indicator was developed at the national scale based on two approaches. Firstly, the energy savings targets established up to 2050 for both residential and non-residential sectors were visually depicted in Fig. 2 using the 2050 ELP data, which are aligned with the 2020 ERESEE data. This chart is produced by transposing the data directly from the cited sources, where the information is readily available.

The second approach (Fig. 3) shows the potential energy savings that can be achieved by implementing specific energy efficiency improvement measures for the tertiary sector. Each of the proposed measures estimates a range of energy savings that such a measure could produce. Based on this hypothesis, two energy savings scenarios were created: a low energy savings scenario and a high energy savings scenario. In this case, the information is also readily available, and all the necessary data can be found in the ‘Report on typologies, consumption, improvement actions and potential energy savings in the building stock of the tertiary sector’ (A3e. Association of Energy Efficiency Companies 2019). However, no equivalent information applied to the residential sector was found.

Table 2 Sources for indicator Expected energy saving potential per building sector and type. *Source* own creation

Indicator: Expected energy saving potential per building sector and type	
Variables	– Residential sector – Non-residential sector: – Office buildings Small and medium-sized offices (250–3500 m^2) Large office buildings (4500–25,000 m^2) – Healthcare buildings Large hospital (49,000 to 181,000 m^2) Hospital (4500 to 48,000 m^2) Primary Healthcare Centre (500 to 9000 m^2) – Hotels Urban hotel (500–30,000 m^2) Holiday hotel (4000–70,000 m^2) Aparthotel (500–30,000 m^2) – Training centers Schools (500–9000 m^2) Training centers for continuous use (3500–37,000 m^2) – Shopping centers Large commercial premises (2500 to 10,000 m^2) Small businesses (100–2500 m^2)
Indicator developability	– Data availability: fully available for Spain, but partially available at a regional scale – Processing method from source: direct, except for Aragon, where no updated data are available – Data processability: no
National source	Ministry of Ecological Transition and Demographic Challenge. National Integrated Energy and Climate Plan (PNIEC) 2021 2030
Link	https://www.miteco.gob.es/es/prensa/pniec.html
Characteristics of the source	– Availability: open data – Data collection method: simulations and modelling – Data processability: no – Georeferencing: not applicable to this indicator – Data update frequency / last update: unique publication in January 2020
National source	Ministry of Ecological Transition and Demographic Challenge. Long Term Decarbonization Strategy (ELP) 2050
Link	https://ec.europa.eu/clima/sites/lts/lts_es_es.pdf https://www.miteco.gob.es/es/prensa/anexoelp2050_tcm30-516147.pdf
Characteristics of the source	– Availability: open data – Data collection method: simulations and modelling. Specifically, TIMES—SINERGIA method – Data processability: no – Georeferencing: not applicable to this indicator – Data update frequency/last update: unique publication in November 2020

(continued)

Table 2 (continued)

Indicator: Expected energy saving potential per building sector and type	
National source	A3e. Association of Energy Efficiency Companies. Report on typologies, consumption, improvement actions and potential energy savings in the building stock of the tertiary sector. In: ERESEE 2020
Link	https://cdn.mitma.gob.es/portal-web-drupal/planes_estartegicos/9_2020_informe_tipologias_y_actuaciones_terciario.pdf
Characteristics of the source	– Availability: open data – Data collection method: energy audits – Data processability: no – Georeferencing: not applicable to this indicator – Data update frequency/last update: unique publication in December 2019
Regional source—Aragon	Government of Aragon. Department of Industry and Innovation
Link	https://transparencia.aragon.es/sites/default/files/documents/plan_energetico_de_aragon_2013-2020.pdf
Characteristics of the source	– Availability: open data – Data collection method: simulations and modelling – Data processability: no – Georeferencing: not applicable to this indicator – Data update frequency/last update: unique publication in July 2020
Regional source—the Basque Country	Basque Government. Department of Economic Development and Competitiveness. Basque Country Energy Strategy 2030
Link	https://www.euskadi.eus/contenidos/informacion/estrategia_energetica_euskadi/es_def/adjuntos/3E2030_Estrategia_Energetica_Euskadi_v3.0.pdf
Characteristics of the source	– Availability: open data – Data collection method: simulations and modelling – Data processability: no – Georeferencing: not applicable to this indicator – Data update frequency/last update: unique publication in July 2016

At the regional scale, data is only available for the Basque Country. Based on the Basque Country Energy Strategy 2030, and the potential energy savings are presented in Table 3.

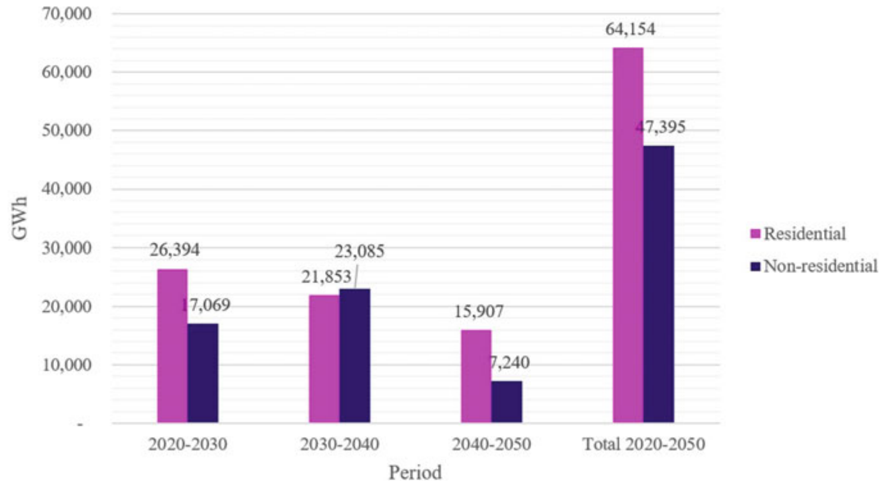


Fig. 2 Expected energy savings for the residential and non-residential buildings in Spain. A3e. Association of energy efficiency companies. *Source* own creation from data in (2019)

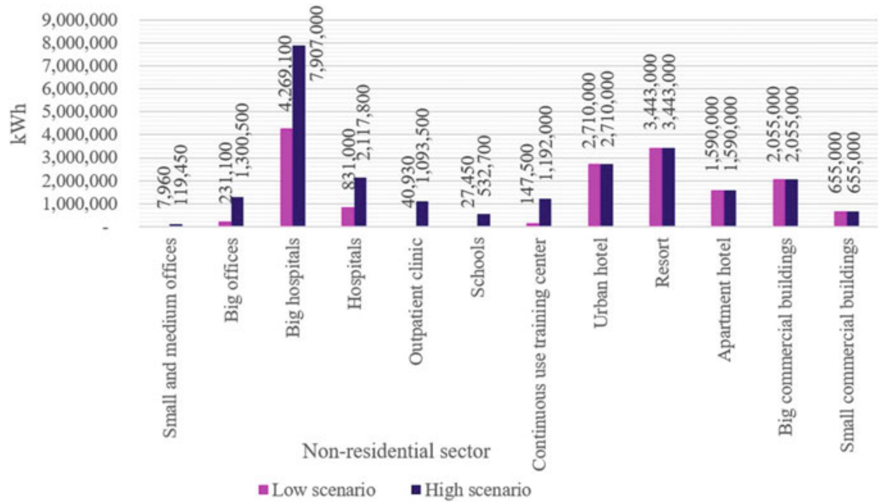


Fig. 3 Energy savings targets for 2050 in Spain for non-residential sector. *Source* own creation from data in (Ministry of Ecological Transition and Demographic Challenge 2020b)

Table 3 Potential energy savings in the Basque Country. *Source* own creation from data in (Basque Government. Department of Economic Development and Competitiveness 2016)

	Year 2025	Year 2030
Reduction of energy consumption in buildings (toe/year)	135,000	199,000
Percentage energy savings in buildings (%)	12.1	17.2
Reduction in building consumption compared to 2015 (%)	–3	–5

3.2 Expected Reduction in Health Costs Attributable to Energy Efficiency Measures and Improved Air Quality

The purpose of this indicator is to understand the evolution of healthcare costs attributed to implementing energy efficiency measures in residential buildings and to establish a target of reduction.

The indicator is related to the strategies defined by the International Energy Agency (IEA) as stated in its publication 'Capturing the Multiple Benefits of Energy Efficiency' (International Energy Agency 2014). The aim of the publication is twofold. On the one hand, it aims to raise awareness of the multiple benefits associated with energy efficiency. On the other, it aims to demonstrate how policy makers and other stakeholders can use existing tools to measure and maximize the benefits they seek. It focuses on five key benefit areas: macroeconomic development, public budgets, health and welfare, industrial productivity, and energy supply.

There are several sources of information internationally, nationally for Spain, and regionally that collect information related to this indicator. However, most of them do not provide the data necessary to collect it. On an international scale, the IEA produced the aforementioned report 'Capturing the Multiple Benefits of Energy Efficiency' (International Energy Agency 2014). Although the report proposes some indicators to measure these benefits, these indicators are not developed nor is information provided for this purpose.

At the national level for Spain, through the Spain's National Institute of Statistics (INE), access to the Hospital Morbidity Survey (EMH) is available, which provides information on hospitalizations at the national, regional, and provincial levels. Despite offering detailed information on the pathologies of hospitalized individuals, allowing the identification of those that may be associated with poor housing conditions that can be addressed through renovation and improvement of energy efficiency, the data is not sufficient to develop this indicator. Similarly, the Aragon Institute of Statistics (IAEST) and the Basque Institute of Statistics (EUSTAT) also provide this information on hospitalizations, but specific to the regions of Aragon and the Basque Country.

The only source (Table 4) that actually compiles the indicator is the Catalonia Institute for Energy Research (IREC) through its report on the estimation of the effect of energy renovation on people's health from an economic approach (Ortiz and Salom, 2016), in which the energy, economic and health benefits of the energy renovation of the built stock are analyzed on a national scale, as well as the relationship between all of them.

In the aforementioned source, the public and private economic balances of energy renovation for an average household are presented. These balances include healthcare, labor, and energy costs. Additionally, the balances are divided into four housing scenarios: a base scenario, which is the unrenovated household, a medium scenario, a high scenario, and a low scenario. In turn, each of these scenarios are broken down into different types of energy renovation interventions, although this does not affect the health costs per household.

Table 4 Reduction in health costs attributable to energy efficiency measures and improved air quality. *Source* own creation

Indicator: Reduction in health costs attributable to energy efficiency measures and improved air quality	
Variables	Not applicable to this indicator
Indicator developability	– Data availability: partially available – Processing method from source: indirect – Data processability: no
Regional source (national scope)	Catalonia Institute for Energy Research (IREC)
Link	http://www.lacasaqueahorra.org/documentos/estimacionEfectoRehabilitacionSalud.pdf
Characteristics of the source	– Availability: open data – Data collection method: report based on various sources – Data processability: no – Georeferencing: not applicable to this indicator Data update frequency/last update: unique publication in July 2016

Subtracting from the healthcare costs of the base scenario those of each of the energy renovation scenarios allows for the calculation of the healthcare cost savings specified in this indicator. In this way, it is determined that for a low renovation scenario, the savings in associated healthcare costs amount to 20 euros per year per household. For a medium scenario, the savings would be 152 euros per year per household, and for a high scenario, they would be 257 euros per year per household.

The data available for calculating this indicator have some limitations that prevent it from being fully developed. One of these limitations is that the calculation has been done for a generic household without specifying its characteristics or location, which, as indicated in the report, has a significant impact on both energy and healthcare costs. Additionally, since the location of the generic household is not detailed, it is also not possible to develop the indicator at a regional level. Finally, to obtain conclusive results at the national level, it would be necessary to have the number of renovated households corresponding to the renovation scenarios outlined in this report, which seems unfeasible. Therefore, despite being able to obtain rough estimates of healthcare cost savings per household, it has not been possible to create a graph with aggregated results at the national or regional scale.

4 Conclusions

European governance encourages the development of indicators to assess the efficacy of building renovation policies and monitor the progress of decarbonization of the building stock. Some of these indicators are meant provide an overview of the current status of the building stock, and others are aimed to measure potential and expected objectives and milestones. In this chapter, indicators were proposed regarding evidence-based estimate of expected energy savings and wider benefits of buildings renovation. The indicators proposed were:

- Expected energy saving potential per building sector and type.
- Expected reduction in health costs attributable to energy efficiency measures and improved air quality.

We studied the sources of information available for the development of these indicators and developed them when there were data available.

The first of them, which establishes the potential for energy savings in the building sector, can be fully developed at the national scale, and only partially at the regional scale. The available sources are focused on energy savings targets.

As for the second indicator, it is a topic of interest to European countries, and for them there are different international, national, and regional sources that deal with related topics. However, they do not provide the information necessary to develop the proposed indicator. Generic data on healthcare cost savings was obtained, however there is not enough information to develop indicators on a national or regional scale.

In conclusion, the available data sources provide quite good data on expected energy savings but do not provide sufficient information to determine targets regarding reduction in health costs attributable to energy efficiency measures and air quality improvement.

Acknowledgements This work was funded by the MINISTRY OF SCIENCE AND INNOVATION OF SPAIN, grant number PID2019-104871RB-C21/AEI/10.13039/501100011033 and by GOBIERNO DE ARAGÓN, grant number T37_23R: Built4Life Lab.

References

Ahmed, W., Alazazmeh, A., Asif, M.: Energy and Water Saving Potential in Commercial Buildings: A Retrofit Case Study. Sustainability 15 (1) 518 (2023). Doi: https://doi.org/10.3390/su15010518.

A3e. Association of Energy Efficiency Companies: (09) Informe sobre tipologías, actuaciones de mejora y potenciales ahorros en el parque edificatorio del sector terciario [(09) Report on typologies, improvement actions, and potential savings in the building stock of the tertiary sector]. In: ERESEE 2020 "Estrategia a largo plazo para la Rehabilitación Energética en el Sector de la Edificación en España" [2020 ERESEE "Long-term Strategy for Energy Renovation in the Building Sector in Spain"] (2019).

Basque Government. Department of Economic Development and Competitiveness: Basque Energy Strategy 2030 (2016).

Deng, Z., Chen, YX., Yang, JJ., Causone, F.: AutoBPS: A tool for urban building energy modeling to support energy efficiency improvement at city-scale. Energy and Buildings. 282–112794 (2023). Doi: https://doi.org/10.1016/j.enbuild.2023.112794.

European Commission: COMMISSION RECOMMENDATION (EU) 2019/786 of 8 May 2019 on building renovation. Official Journal of the European Union (2019: L 127), 34–79 (2019).

European Parliament, Council of the European Union: 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. Official Journal of the European Union (2018:L 156), 75–91 (2018).

European Parliament, Council of the European Union: DIRECTIVE 2002/91/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 December 2002 on energy performance of buildings. Official Journal of the European Union (2003: L 1), 65–71 (2003).

European Parliament: Energy performance of buildings (recast) Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (COM(2021)0802 – C9–0469/2021 – 2021/0426(COD)). Strasbourg (2023).

International Energy Agency: Capturing the Multiple Benefits of Energy Efficiency (2014).

Lin, ZQ., Hong, TZ., Xu, XD., Chen, JY., Wang, W.: Evaluating energy retrofits of historic buildings in a university campus using an urban building energy model that considers uncertainties. Sustainable Cities and Society. 95–104602 (2023). Doi: https://doi.org/10.1016/j.scs.2023.104602.

Ministry of Ecological Transition and Demographic Challenge: Plan Nacional Integrado de Energía y Clima (PNIEC) 2021–2030 [National Integrated Energy and Climate Plan (PNIEC) 2021–2030]. Madrid. (2020a).

Ministry of Ecological Transition and Demographic Challenge: Estrategia de Descarbonización a Largo Plazo [Long-Term Decarbonization Strategy]. Madrid. (2020b).

Ministry of Ecological Transition and Demographic Challenge: Impacto económico, de empleo, social y sobre la salud pública del Plan Nacional Integrado de Energía y Clima PNIEC 2021–2030 [Economic, Employment, Social, and Public Health Impact of the National Integrated Energy and Climate Plan (PNIEC) 2021–2030]. (2020c). https://www.miteco.gob.es/content/dam/miteco/images/es/informesocioeconomicopnieccompleto_tcm30-508411.pdf, last acceded 2023/09/20.

Ministry of Transport, Mobility and Urban Agenda: 2020 Update of the long-term strategy for energy renovation in the building sector in Spain (ERESEE). Madrid (2020).

Ortiz, J., Salom, J.: Estimación del efecto de la rehabilitación energética en la salud de las personas. Enfoque económico [Estimation of the Effect of Energy Renovation on People's Health. Economic Approach]. Catalonia Institute for Energy Research. Barcelona (2016).

Zhang, D., Yixing, C., Jingjing, Y., Zhihua. C.: Archetype identification and urban building energy modeling for city-scale buildings based on GIS datasets. Building Simulation, 15 (9) 1547–1559 (2022). Doi: https://doi.org/10.1007/s12273-021-0878-4.

Indicators and Data in Spain Regarding Policies and Measures for the Mobilization of Investments into the Renovation of Buildings

Markel Arbulu, Marta Gómez-Gil, Markel Rueda-Esteban, Marta Monzón-Chavarrías, and Almudena Espinosa-Fernández

Abstract Indicators are necessary in the building sector to measure whether the long-term renovation strategies of the European Union Member States deliver the necessary progress towards the transformation of the building stock into a decarbonized one. Policies and measures for the mobilization of investments into the renovation of buildings have been identified as key issues to be addressed in the decarbonization of the building sector. In this chapter, we propose indicators to measure the evolution in Spain of the policies and measures for the mobilization of investments into the renovation of buildings following the European Commission recommendations and directives. We also studied the sources of information available in Spain for the development of these indicators and developed them when there were data. This study allowed us to conclude that in this country, there are not enough data sources to develop relevant indicators that measure progress in policies and measures for the mobilization of investments into buildings renovation. The need to resort to different sources depending on the information required implies a loss of data and lack of accuracy.

M. Arbulu · M. Rueda-Esteban
Department of Architecture, University of the Basque Country UPV/EHU, 20018 Donostia-San Sebastian, Spain
e-mail: markel.arbulu@ehu.eus

M. Rueda-Esteban
e-mail: markel.rueda@ehu.eus

M. Gómez-Gil · M. Monzón-Chavarrías · A. Espinosa-Fernández (✉)
Built4Life Lab, University of Zaragoza-I3A, 50018 Zaragoza, Spain
e-mail: almudenaef@unizar.es

M. Gómez-Gil
e-mail: m.gomez@unizar.es

M. Monzón-Chavarrías
e-mail: monzonch@unizar.es

B. López-Mesa and X. Oregi (eds.), *Assessing Progress in Decarbonizing Spain's Building Stock*, Digital Innovations in Architecture, Engineering and Construction,
https://doi.org/10.1007/978-3-031-51829-4_10

1 Introduction

The construction sector, mainly driven by the residential building segment, became the driving force of productive activity in Spain, with an average annual growth of close to 6% from 1998 to 2007. This increase in housing was motivated by the increase in employment, migratory flows and changes in family structures that allow families to afford home ownership (Spain's Economic and Social Council 2016).

The expansion of the construction sector in Spain stopped in 2007 with the burst of the real estate bubble, after years of unsustainable growth. Since that moment, the sector started a free fall, accumulating a 50% collapse due to lower residential buildings construction and the decline in civil works (Llamas 2017).

The beginning of 2021 marked a period characterized by optimism, strength, and resilience in the construction sector, bolstered by the inflow of European funds through the recovery and resilience mechanism. Despite this positive trend, the 2021 construction sector Situation Survey in Spain (Ministry of Industry, Commerce, and Tourism 2023) indicates a decline in building construction by 15.5%. However, there is a contrasting rise in specialized construction (renovation activity), showing an increase of 15.7% according to the construction climate indicator.

Hence, directing investments towards the renovation of energy-efficient buildings can serve as an opportunity for their revitalization and the creation of sustainable employment, given the myriad benefits associated with such initiatives. It is crucial to implement various measures that promote this activity through all available mechanisms, including regulations, information and communication, financing, public aid, and effective policies.

A report from the Spanish Confederation of Business Organizations (CEOE, for its acronym in Spanish), published in September 2014, explored the feasibility of the activity of buildings energy renovation until 2020. This model proposed two scenarios for investment in energy building renovation: the residential sector and the tertiary sector. In addition, it took into account factors such as economic support from the Administration, the heterogeneity in energy consumption associated with buildings, the jobs generated, or the economic return obtained due to the improvement in energy efficiency, compared to the investment made in the execution of the most efficient measures (Spanish Confederation of Business Organizations 2014). According to the CEOE report, investment should initially be made in residential buildings where it is easier to improve energy efficiency, that is, where the investment would be lower and greater returns could be obtained due to savings in energy consumption. In later years, the energy renovation of residential buildings should be undertaken where it is more expensive to improve energy efficiency and the energy savings obtained are lower. Furthermore, over time costs should be reduced since the technical resources to improve energy efficiency would have been internalized and learned.

Regarding aid and subsidies from the Administration, the CEOE report argued that these measures are not permanent but instead function as a crucial initial catalyst. They play a vital role until the operations related to the renovation of energy-efficient buildings are well-established, and the requisite mechanisms are thoroughly understood and internalized. It was estimated that the need for financing through aid would be progressively reduced and would end up disappearing within a 10-year timeframe. In contrast, subsidization of loans would grow up each year, as more and more homes would be renovated, and these are accumulated for amortization.

Finally, the CEOE report reflected the amortization periods of private investment in the energy residential building renovation. The greater the public support, as an input for the activation of the energy residential buildings renovation, the shorter the amortization time of the private investment, that is, the investment made by the owners who decide to invest in renovating their home.

However, the CEOE's predictions have not come true for several reasons. Renovation activity has not kept pace with what was expected, evidencing the need to overcome important economic barriers, among others. This need has been reflected in the successive evolutions of the Energy Performance of Buildings Directive (EPBD).

The first version of the EPBD was published in 2002 (Directive 2002/91/EC). The EPBD was recast in 2010 (Directive 2010/31/EU). These directives are referred to as 2002 EPBD and 2010 EPBD in this book, respectively. The 2010 EPBD established that Member States (MSs) should take appropriate measures to consider financial instruments to promote the energy efficiency of buildings and the transition to almost zero energy buildings. A revised version of the EPBD was published in 2018 (Directive 2018/844/EU), which is referred to as 2018 EPBD in this book and is the EPBD currently in force. According to the 2018 EPBD, financial mechanisms, incentives and the mobilization of financial institutions for energy efficiency renovations in buildings should have a central role in national long-term renovation strategies (LTRSs) and be actively promoted by MSs. Such measures should include encouraging energy efficient mortgages for certified energy efficient building renovations, promoting investments for public authorities in an energy efficient building stock, for example by public–private partnerships or optional energy performance contracts, reducing the perceived risk of the investments, providing accessible and transparent advisory tools and assistance instruments such as one-stop-shops that provide integrated energy renovation services, as well as implementing other measures and initiatives such as those referred to in the Commission's Smart Finance for Smart Buildings Initiative.

In 2019, the European Commission published Commission Recommendation (EU) 2019/786 of 8 May 2019 on building renovation (European Commission 2019), including guidelines for EU countries related to the application of the requirements of the 2018 EPBD. This recommendation is referred to as 2019 EPBD-related Recommendation in this book. It established a set of optional indicators to track the evolution of mechanisms set by MSs to support the mobilization of investments in renovation. Among these indicators we can find:

– Aggregation of projects, for example, investment platforms or groups that allow access for investors, as well as solution packages for potential clients.
– Reduction of the risk perceived by investors and the private sector in renovation actions that improve energy efficiency.

– Use of public financing to leverage greater investments in the private sector. The EU has increased public funding for energy efficiency through the ESI (European Structural and Investment) Funds.
– Direct investments towards public buildings with efficient use of energy.
– Development of accessible and transparent advice tools.

Currently, the EPBD is being revised. The latest draft version of the ongoing EPBD revision (European Parliament 2023), which in this book is referred to as 2023 EPBD Proposal recast, argues that financing plays a key role in achieving the Union's energy and climate goals for 2030. There is a need for more cost-effective use of existing financing options, as well as the development and introduction of innovative financing mechanisms to support investments in building renovation and help homeowners as part of national initiatives.

Spain's Ministry of Transport, Mobility and Urban Agenda (MITMA) has published a guide of recommendations to accelerate the renovation of the building stock and, thus, achieve an energy-efficient and decarbonized building sector by 2050 (Ministry of Transport, Mobility and Urban Agenda 2023). The document seeks to promote the implementation of measures identified in Spain's LTRS (commonly referred to as 2020 ERESEE for its acronym in Spanish) as necessary for the transformation of residential and non-residential, public, and private buildings. These measures are organized into twelve structuring lines, which include initiatives such as public funding and the promotion and mobilization of private financing. Hereafter, a concise presentation is provided for the conclusions derived from this document regarding a state-of-the art of financing measures.

Regarding public funding measures, the main conclusions are:

- A Renovation Plan has not been designed to coordinate existing and future lines of aid.
- Law 38/2003, of November 17, General Subsidies, has been modified in 2020, 2021 and 2022, but the modifications introduced are not linked to the energy renovation of buildings.
- In the study of a new tax system favorable to renovation, Royal Decree-Law 19/2021, of October 5, has introduced new deductions in the Personal Income Tax for the cost of energy efficiency improvement works in residential buildings and homes and Law 10/2022, of June 14, has established the non-integration into the tax base of said tax of aid for the energy refurbishment of buildings.
- There are several regions that have developed initiatives for the implementation of a network of renovation offices.
- The National Subsidies Database (BDNS) is the system that in aggregate provides adequate transparency to subsidies and other aid granted by public administrations in Spain. In this last period there have been updates to the base, but they have not followed the line proposed by the 2020 ERESEE.

Regarding the promotion and mobilization of private financing, the main conclusions are:

- A line of guarantees has been approved for partial coverage on behalf of the State of the financing of renovation works that contribute to the improvement of energy efficiency.
- As a measure to eliminate existing barriers to private financing, the capacity of action of communities of owners to access credit for renovation and improvement works on buildings has been strengthened.
- Mechanisms have been activated from the public sector to complement the financing of urban renovation, regeneration, and renewal actions.
- Local entities have carried out initiatives to create public–private-citizen collaboration formulas to promote the urban regeneration of neighborhoods.
- On June 14, 2022, Law 10/2022 was enacted as an urgent measure to promote building renovation activity within the context of the Recovery, Transformation, and Resilience Plan. This law establishes a partnership between the Ministry of Transport, Mobility and Urban Agenda and the Institute of Official Credit, creating a line of guarantees to partially cover the financing of renovation projects aimed at improving the energy efficiency of residential buildings. This initiative provides credit institutions with the means to offer financing in the form of a loan with a repayment term of up to fifteen years.

This chapter aims to propose and develop indicators to track the evolution of policies and measures for the mobilization of investments into the renovation of buildings. The indicators will be developed for the case study of Spain. This will also allow us to draw the main conclusions on their evolution.

2 Methodology

To develop the indicators that allow an overview of policies and measures for the mobilization of investments into the renovation of buildings we followed the methodology shown in Fig. 1.

The first step consisted in the development of a common template for these indicators based on the following scheme:

- Indicator:
  - Definition of the indicator.
  - Variables to quantify it and their unit of measurement.
  - Purpose and advantages of implementing this indicator.
  - Alignment of the indicator with the directives, agendas, action plans and strategies, covering the European and international, national, and regional scales.
  - Relationship of this indicator with other similar ones.
- Information sources:
  - Availability of information to generate this indicator at different scales.

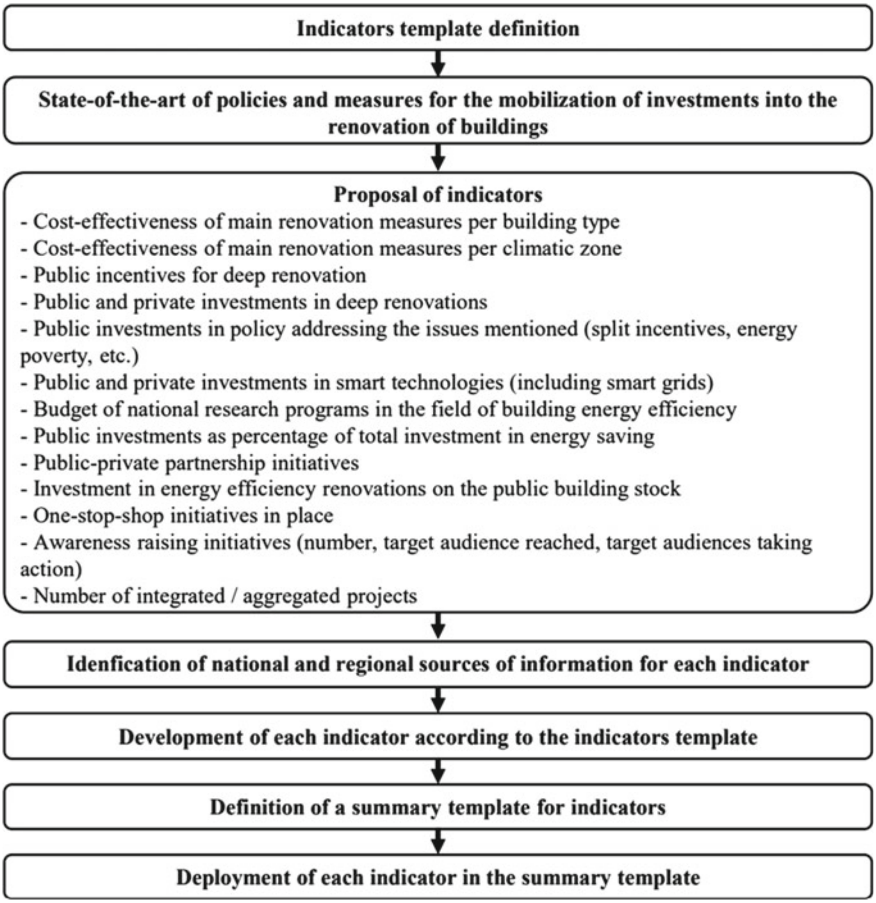


Fig. 1 Methodology implemented to generate indicators on policies and measures for the mobilization of investments into the renovation of buildings for the cases of Spain and two of its regions. *Source* own creation

  - Entity responsible for providing this information.

- Measurement:
  - Measurement method.
  - Methodology.
  - Current possibilities of obtaining it.
  - Information necessary to generate it.
  - Availability and quality of data.

To identify indicators for the evaluation of policies and measures aimed at mobilizing investments in building renovations, we examined suggestions from European directives and related documents. Two key documents were considered for this study. Firstly, we scrutinized the indicators outlined in the 2019 EPBD-related Recommendation (European Commission 2019), which introduced a framework of progress indicators for measuring the decarbonization of the European building stock. Additionally, we analyzed the indicators presented in the 2023 EPBD Proposal recast, representing the latest version of the progress indicator framework. Table 1 displays the indicators from both documents pertaining to policies and measures for mobilizing investments in building renovations.

The proposed indicators are grouped into two blocks in the 2019 EPBD-related Recommendation: comprehensive strategy to achieve a highly decarbonized building stock by 2050 and mechanisms to support the mobilization of investments (Table 1). The 2023 EPBD Proposal recast groups all the indicators in one section, named 'Policies and measures'.

Given the extensive variety of indicators in the 2023 EPBD Proposal recast, we decided to develop a simplified version by leveraging the framework established in the 2019 EPBD-related Recommendation. In summary, the following indicators were suggested:

- Cost-effectiveness of main renovation measures per building type.
- Cost-effectiveness of main renovation measures per climatic zone.
- Public incentives for deep renovation.
- Public and private investments in deep renovations.
- Public investments in policy addressing the issues mentioned (split incentives, energy poverty, etc.).
- Public and private investments in smart technologies (including smart grids).
- Budget of national research programs in the field of building energy efficiency.
- Public investments as percentage of total investment in energy saving.
- Public–private partnership initiatives.
- Investment in energy efficiency renovations on the public building stock.
- One-stop-shop initiatives in place.
- Awareness raising initiatives (number, target audience reached, target audiences taking action).
- Number of integrated/aggregated projects.

Once the key indicators to cover this topic were identified, the available sources of information were studied. Since in Spain a good deal of the promotion and aid management of building renovation is delegated to regions, we used as regional case studies the regions of Aragon and the Basque Country. The previously defined indicator template was used to develop each indicator.

For the sake of transmitting all the information of each indicator in a user-friendly way, we also developed a summary template, which was used to deploy in a summarized way the information we got for each indicator.

Table 1 Indicators on policies and measures for the mobilization of investments into the renovation of buildings included in selected European directives and related documents. *Source* own creation from data in (European Commission 2019), (European Parliament 2023)

Document	Comprehensive strategy	Mobilization of investments
2019 EPBD-related Recommendation	– Cost-effectiveness of main renovation measures per building type – Cost-effectiveness of main renovation measures per climatic zone – Public incentives for deep renovation – Public and private investments in deep renovations – Public and private investments in smart technologies (including smart grids) – Budget of national research programs in the field of building energy efficiency – Public investments as percentage of total investment in energy saving	– Public investments in policy addressing the issues mentioned (split incentives, energy poverty, etc.) – Public–private partnership initiatives – Investment in energy efficiency renovations on the public building stock – One-stop-shop initiatives in place – Awareness raising initiatives (number, target audience reached, target audiences taking action) – Number of integrated / aggregated projects

(continued)

Table 1 (continued)

Document	Comprehensive strategy	Mobilization of investments
2023 EPBD Proposal recast	Overview of implemented and planned policies and measures	Detailed roadmap of the investment needs, the budgetary sources and the administrative resources
	– Name of policy or measure, short description (precise scope, objective and modalities of operation), quantified objective, type of policy or measure (such as legislative; economic; fiscal; training, awareness), planned budget and funding sources, entities responsible for implementing the policy, expected impact, status of implementation for the following areas: • Identification of cost-optimal approaches to renovation for different building types and climatic zones, considering potential relevant trigger points in the lifecycle of the building; • National minimum energy performance standards to target the worst-performing segments of the national building stock; • Promotion of deep renovation of buildings, including staged deep renovation; • High indoor environmental quality both in new and renovated buildings; • Empowering and protecting vulnerable customers and the alleviation of energy poverty; • Creation of one-stop shops or similar mechanisms for the provision of technical, administrative and financial advice and assistance; • Decarbonization of heating and cooling, including through efficient district heating and cooling networks and the phase out of fossil fuels in heating and cooling in buildings; • Promotion of renewable energy sources in buildings; • Deployment of solar energy installations on buildings; • Reduction of whole life-cycle greenhouse gas emissions for the construction, renovation, operation and end of life of buildings, and the uptake of carbon removals; • Reduction of the overall environmental footprint of all parts and components of buildings; • Prevention and high-quality treatment of construction and demolition waste; • Increase in the coverage of the building stock with energy performance certificates including low income households; • District and neighborhood approaches, including the role of renewable energy communities and citizen energy communities; • Improvement of buildings owned by public bodies; • Promotion of smart technologies and sustainable mobility in buildings; • Addressing market barriers and market failures; • Addressing skills gaps and mismatches in human capacities, and promoting education, training, upskilling and reskilling in the construction, sector and energy efficiency and renewable energy sectors including with a gender dimension; • Key performance indicators for upskilling and/or reskilling actions, as well as jobs created • Awareness raising campaigns and other advisory tools • Promotion of smart technologies for monitoring, analysis and simulation of buildings' energy performance across the whole-life cycle, including 3D modelling technologies; • New inspection schemes including digital tools and checklists, to verify compliance with Building Automation and Control capabilities; • Promotion of energy management solutions, such as Energy Performance Contracts (EnPCs); • Measures to increase the coverage of the building stock with energy performance certificates or alternative real time measurement systems; • New development and support of citizen-led energy efficiency and renovation initiatives, in particular the role of renewable energy communities and citizen energy communities	– Total investment needs for 2030, 2040, 2050 (million EUR) – Public investments (million EUR) – Private investments (million EUR), including energy efficiency loans, mortgages for building renovation, bond issuance or other financing mechanisms – Budgetary resources – Secured budget

Table 2 Sources for indicator Cost-effectiveness of main renovation measures per building type. *Source* own creation

Indicator: Cost-effectiveness of main renovation measures per building type	
Variables	Annual savings achieved by the measures envisaged and the investment made (kWh /€·year) per building type: – Residential buildings: single-family building, multi-family building – Non-residential buildings
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

3 Indicators

3.1 *Cost-Effectiveness of Main Renovation Measures Per Building Type*

The purpose of this indicator is to quantify and assess the evolution of the cost-effectiveness of building renovations towards the decarbonization of the building stock. The indicator specifically seeks to assess the cost-effectiveness of energy renovation interventions in buildings by considering the annual savings resulting from the envisaged measures and the corresponding investment. The inclusion of the variable building type is proposed as it allows for the identification and differentiation of specific requirements and scales for residential and non-residential buildings. However, no sources were found that compile this indicator (Table 2).

3.2 *Cost-Effectiveness of Main Renovation Measures Per Climatic Zone*

The purpose of this indicator is to quantify and assess the evolution of the cost-effectiveness of building renovations towards the decarbonization of the building stock depending on the climate zone. Specifically, the cost-effectiveness of energy renovation interventions in buildings is based on the annual savings achieved by the measures envisaged and the investment made. The potential profitability of renovations and the differences between climate zones can be identified using the climate zone variables. It is worth noting that climate zones within the same province change according to altitude, and a wide range of climate zones can be found in some territories. However, no sources were found in Spain that compile this indicator (Table 3).

Table 3 Sources for indicator Cost-effectiveness of main renovation measures per climatic zone. *Source* own creation

Indicator: Cost-effectiveness of main renovation measures per climatic zone	
Variables	Annual savings achieved by the measures envisaged and the investment made (kWh /€·year) per climatic zone: – Winter Climate Severity (SCI): A, B, C, D, E, α – Summer Climate Severity (SCV): 1, 2, 3, 4
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

3.3 Public Incentives for Deep Renovation

The purpose of this indicator is to know the existing public incentives for deep building renovations. Economic incentives are financial motivations for people to take certain actions. Deductions are intended to subtract a certain amount from the amount to be paid to the State in respect of taxes in order to encourage certain conduct. In this way, the deduction for deep renovation is considered a public incentive.

The entity responsible for Tax-deductible expenses at the state level is Spain´s Tax Agency, of the Ministry of Finance and Public Administration, which regulates personal income tax deductions relating to housing renovations. Each region has its own deductions, but they are regulated by the State through the Tax Agency, except in the case of the Basque Country, where each Provincial Council has its own tax authority. The sources of information to develop this indicator in Spain are national and regional (Table 4).

As this indicator cannot be developed with available data, an alternative variable was suggested: tax deduction for renovation or extension of primary households (€/year).

The national and regional (for the case of Aragon) data are directedly collected from the entity that manages national tax collection, i.e., Spain´s Tax Agency. Regional data on the Basque Country are collected directly from regional reports.

National data collected does not differentiate types of renovations and only considers renovations or extension of primary households, thus, it is possible to create an indicator partially related to public incentives for major renovations. Data from the Basque Country does not differentiate types of renovations either, being in the same situation. In Fig. 2, we can see the evolution of tax deduction to renovate and enlarge primary households per year [€/year] from 2013 to 2020 in Spain. Additionally, we can also obtain regional data from this source, as can be seen in Fig. 3 for the case of the region of Aragon. Figure 4 shows the data for the Basque Country.

Table 4 Information sources for indicator 'Public incentives for deep renovation'. *Source* own creation

Indicator: Public incentives for deep renovation	
Variables	Public incentives to financially support major building renovations: – Tax deduction for deep renovation (€/year)
Indicator developability	– Data availability: partially available – Processing method from source: direct from the source – Data processability: no
National source	**Spain's Tax Agency of the Ministry of Finance and Public Administration**
Link	https://sede.agenciatributaria.gob.es/AEAT/Contenidos_Comunes/La_Agencia_Tributaria/Estadisticas/Publicaciones/sites/irpf/2020/mapaf4de67f6b0eae312df79444e4b30cb2b5eb179d57.html
Characteristics of the source	– Availability: open data (non-available for the Basque Country) – Data collection method: collection by the Tax Agency – Data processability: no – Georeferencing: no – Data update frequency/last update: annual. Last update in 2019
Regional source—the Basque Country	**Basque Housing Observatory (Department of Territorial Planning, Housing and Transport, Basque Government)**
Link	https://www.etxebide.euskadi.eus/contenidos/informacion/ovv_adm_fiscal_20/es_ovv_admi/adjuntos/Fiscal-2020.pdf
Characteristics of the source	– Availability: open data – Data collection method: not specified – Data processability: no – Georeferencing: no – Data update frequency/last update: annual. Last update in 2020, data from 2018

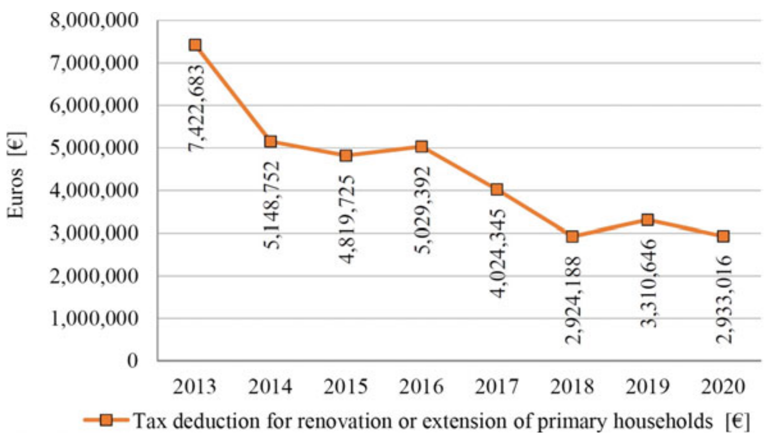


Fig. 2 Public incentives: tax deduction for renovation or enlarge of primary households in Spain, between 2013 and 2020. *Source* own creation from data in (Spain's Tax Agency of the Ministry of Finance and Public Administration 2020)

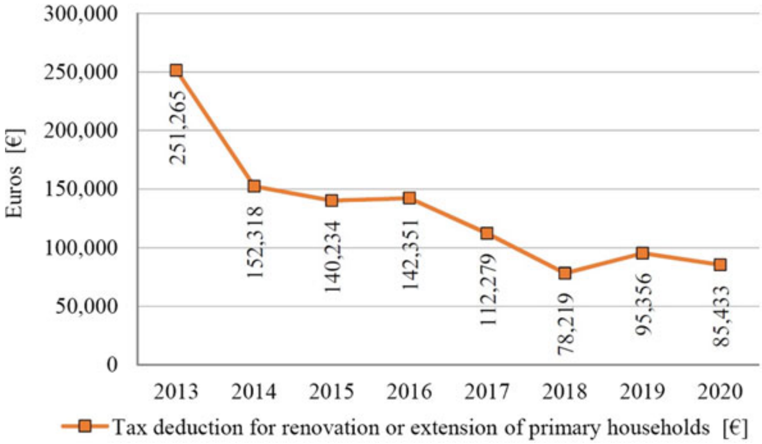


Fig. 3 Public incentives: tax deduction for renovation or enlarge of primary households in the region of Aragon (Spain), between 2013 and 2020. *Source* own creation from data in (Spain's Tax Agency of the Ministry of Finance and Public Administration 2020)

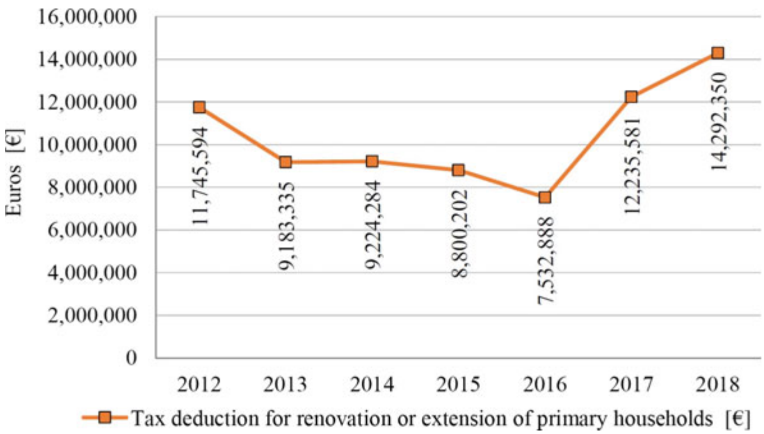


Fig. 4 Public incentives: tax deduction for renovation or enlarge of primary households in the Basque Country, between 2012 and 2018. *Source* own creation from data in (Basque Housing Observatory 2020)

3.4 Public and Private Investments in Deep Renovations

The purpose of this indicator is to quantify and track funding provided by public entities for major building renovations and private investments. Understanding the source, whether public or private, of the economic inputs for deep building renovation offers valuable insights in various ways. On one hand, differentiating between public and private funding sources provides a clearer picture of the dynamics in the renovation market. It helps in understanding the level of private sector engagement and the market's ability to attract private investments in building deep renovations. On the other hand, knowledge of the funding origin contributes to assessing the financial sustainability of renovation initiatives. It helps in determining whether there is a healthy balance between public and private investments, which is crucial for the long-term viability and scalability of renovation efforts. Finally, it is also helpful in decision-making. Stakeholders involved in building renovation, such as investors, developers, and policymakers, can make more informed decisions based on the understanding of where the funding is coming from. This information guides resource allocation and strategic planning for achieving decarbonization goals. The sources of information to develop this indicator include national and regional for the case of the Basque Country. Data for Aragon are unavailable (Table 5).

Data on public and private investments in deep renovations are incomplete for both the national and Basque Country levels. While updated information on the number of renovations is available, the energy-depth of these renovations remains unknown. Consequently, it is not feasible to establish an indicator specifically for public and private investments in deep renovations. Instead, an indicator can only be created for investments related to comprehensive renovations. This is assessed by considering the grants awarded, with data processed for each application cycle using CSV files provided by the information source. These datasets are openly published. For the case of the region of Aragon it is not possible to develop the indicator due to lack of data.

The public investment in buildings renovation indicator was developed at the national scale based on the following variables: amount in euros of public investment in building renovations (annual amount in euros of subsidies awarded and granted) and number of public investments in building renovations (number of subsidies awarded and loans granted), as shown in Figs. 5 and 6, respectively.

The public investment in renovations indicator was developed at regional scale for the Basque Country based on the same two variables, as shown in Figs. 7 and 8, respectively.

3.5 Public Investments in Policy Addressing the Issues Mentioned (Split Incentives, Energy Poverty, Etc.)

The purpose of this indicator is to quantify and track public investments granted from public entities for building renovations with a focus in different areas, such as split incentives dilemma, energy poverty, etc. This information provides insights into where resources are being allocated and whether they align with the overarching goals, and it also enables policymakers to assess the effectiveness of public investment strategies in addressing specific challenges. There are no available sources of information to develop this indicator in Spain or, at the regional level, in Aragon and the Basque Country (Table 6).

Table 5 Sources for indicator Public and private investments in deep renovations. *Source* own creation

Indicator: Public and private investments in deep renovations	
Variables	Investments such as financial support for major renovations to improve buildings: – Public investments: €/year – Subsides: Number of subsides/year, amount subsided / year – Loans: Number of loans/year, amount borrowed – Private investments
Indicator developability	– Data availability: partially available – Processing method from source: direct from the source – Data processability: yes, data available in CSV format
National source	**Spain's National Publicity System for Public Subsidies and Aid**
Link	https://www.pap.hacienda.gob.es/bdnstrans/GE/es/convocatorias https://www.pap.hacienda.gob.es/bdnstrans/GE/es/concesiones/convocatoria/367917 https://www.pap.hacienda.gob.es/bdnstrans/GE/es/concesiones/convocatoria/377556
Characteristics of the source	– Availability: published openly in part – Data collection method: journal from the entities convening the programs – Data processability: yes, data available in CSV and XLS formats – Georeferencing: no – Data update frequency/last update: daily
Regional source—the Basque Country	**Basque Housing Observatory (Department of Territorial Planning, Housing and Transport, Basque Government)**
Link	https://www.etxebide.euskadi.eus/contenidos/informacion/ovv_adm_fiscal_20/es_ovv_admi/adjuntos/Fiscal-2020.pdf
Characteristics of the source	– Availability: open data – Data collection method: not specified – Data processability: no – Georeferencing: no – Data update frequency/last update: annual. Last update in 2020, data from 2018

There is no data on public investment in policies addressing the issues mentioned in the variables. The only data available on public investment was already developed in Sect. 3.4 of this chapter.

3.6 Public and Private Investments in Smart Technologies (Including Smart Grids)

The purpose of this indicator is to track the public and private investments made to improve the smart readiness of the existing building stock. The term 'smart readiness

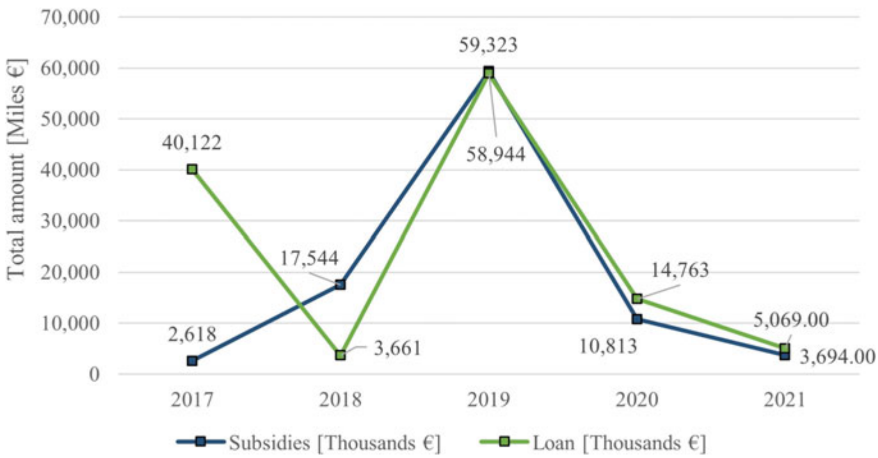


Fig. 5 Total amount of public investments in building renovations through national programs (subsidies and loans) from 2017 to 2021 in Spain. *Source* own creation from data in *Intervención General de la Administración del Estado* (Spain's National Publicity System for Public Subsidies and Aid 2023)

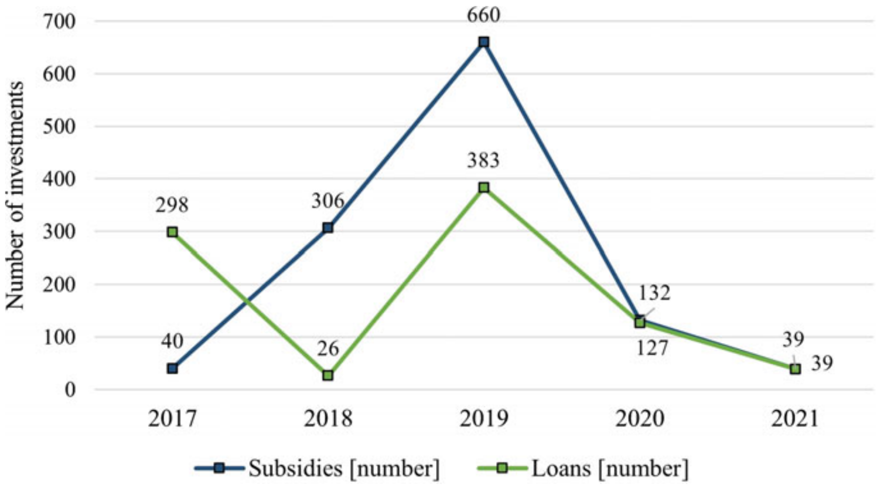


Fig. 6 Number of public investments in building renovation through national programs (subsidies and loans) from 2017 to 2021 in Spain. *Source* own creation from data in *Intervención General de la Administración del Estado* (Spain's National Publicity System for Public Subsidies and Aid 2023)

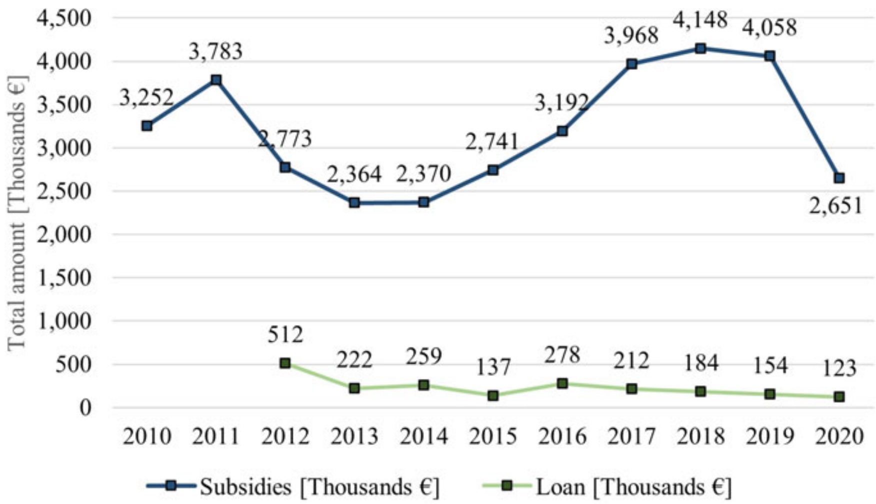


Fig. 7 Total amount of public investments in building renovations (subsidies and loans) in the Basque Country (Spain) from 2010 to 2020. *Source* own creation from data in (Basque Housing Observatory 2020)

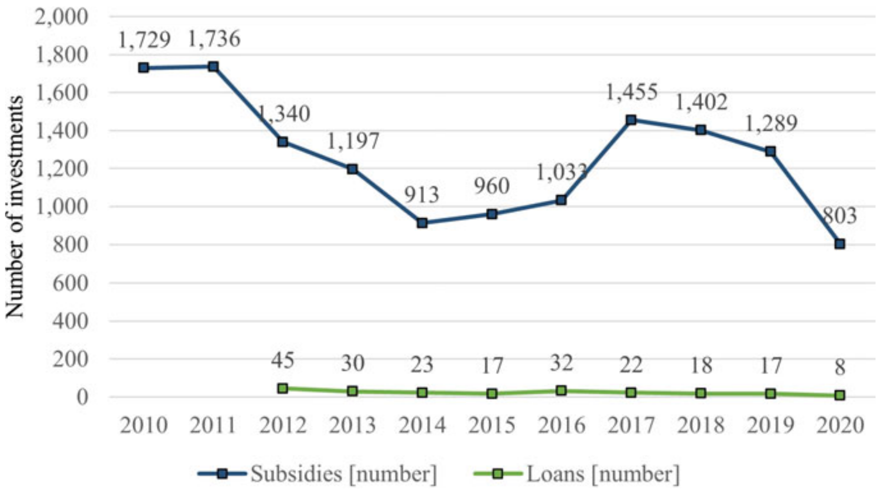


Fig. 8 Number of public investments in building renovation (subsidies and loans) in the Basque Country (Spain) from 2010 to 2020. *Source* own creation from data in (Basque Housing Observatory 2020)

Table 6 Information sources for indicator 'Public investments in policy addressing the issues mentioned (split incentives, energy poverty, etc.)'. *Source* own creation

Indicator: Public investments in policy addressing the issues mentioned (split incentives, energy poverty, etc.)	
Variables	– Annual investments in the area of: – Split incentives – Energy poverty – Wider benefits – Staged deep renovation – Accessibility – Quality of air – Decarbonization of heating and cooling – Renewable energy – Reduction of whole life-cycle greenhouse gas emissions
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

of buildings' refers to the capacity of a building to effectively integrate and utilize smart technologies and solutions to enhance its overall performance, efficiency, and functionality. It encompasses the building's ability to adapt and respond intelligently to various factors, including occupant needs, energy efficiency, environmental conditions, and connectivity. The concept of smart readiness involves the integration of advanced technologies such as the Internet of Things (IoT), sensors, automation systems, and data analytics within a building's infrastructure. These technologies enable buildings to optimize energy consumption, enhance security, provide better comfort for occupants, and contribute to sustainable practices.

No sources were found that compile this indicator (Table 7). However, it was found out that the Provincial Council of Gipuzkoa is working on implementing monitoring systems and energy information systems aimed at more efficient and sustainable use of energy in public buildings. In the city of Zaragoza, the Housing Municipal Company is also implementing monitoring campaigns supported by smart sensors before and after the renovation of public rental housing to know the thermal performance, quality of air, and consumptions, in cooperation with researchers from the University of Zaragoza involved in the project of which this book is a result.

Table 7 Information sources for indicator 'Public and private investments in smart technologies (including smart grids)'. *Source* own creation

Indicator: Public and private investments in smart technologies (including smart grids)	
Variables	Investments (€) related to smart technologies applied in buildings: – Public buildings – Private buildings
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

3.7 Budget of National Research Programs in the Field of Building Energy Efficiency

The purpose of this indicator is to understand the importance and development of national public investment in research on energy efficiency in the building sector. This way it is possible to analyze the progress of public investment in this area and to compare different policies and territories. The sources of information to develop this indicator in Spain are national and regional (Table 8).

The available national and regional data for this indicator in Spain are openly accessible, but the intricate nature of budget allocations across different authorities makes it challenging to directly identify and quantify the total investment in research on energy-saving in buildings. Investments are fragmented into different programs of different ministries, entities or public bodies.

3.8 Public Investments as Percentage of Total Investment in Energy Saving

The purpose of this indicator is to track the percentage of public investment in energy saving in buildings. This percentage reveals the level of public and private sector participation. A balanced contribution from both public and private sectors is ideal for sustained and widespread adoption of energy-saving measures. A significant public investment percentage, especially in the early stages of an activity that is not yet widely established, such as building renovation, can instill confidence in the market and encourage private investors to engage in energy-saving projects, contributing to the overall growth of the sector.

National and regional data for indicator 'Public investments as percentage of total investment in energy saving' are partially available, and they have to be obtained by combination of different data. It is possible to identify a specific investment, but identifying the total public amount invested in 'energy saving projects' in a direct way is not considered feasible. The budgets are spread over several chapters and items of the public budgets from various public authorities, and it is not possible to break down the items in detail in order to identify the energy saving items. In addition, the data for total investment, including both public and private investment in energy saving, were not been found. Consequently, it is not possible to obtain the percentage of public participation. Thus, no figure could be developed for this indicator (Table 9).

Table 8 Information sources for indicator 'Budget of national research programs in the field of building energy efficiency'. *Source* own creation

Indicator: Budget of national research programs in the field of building energy efficiency	
Variables	National public investment (€) in research programs in areas related to the energy efficiency of buildings
Indicator developability	– Data availability: non-available – Processing method from source: indirect – Data processability: no
National source	**Spain's Ministry of Finance and Public Administration. General State Budget**
Link	https://www.sepg.pap.hacienda.gob.es/sitios/sepg/es-ES/Presupuestos/DocumentacionEstadisticas/Estadisticas/Paginas/Estadisticas.aspx
Characteristics of the source	– Availability: open data but insufficient to collect the indicator – Data collection method: data are published by the responsible governments – Data processability: no – Georeferencing: no – Data update frequency/last update: annual. The last data update was the budget data for financial year 2023
Regional source—Aragon	**Government of Aragon. Budget for the Autonomous Community of Aragon**
Link	https://www.aragon.es/-/presupuestos
Characteristics of the source	– Availability: open data but insufficient to collect the indicator – Data collection method: data are published by the responsible governments – Data processability: no – Georeferencing: no – Data update frequency/last update: annual. The last data update was the budget data for financial year 2023
Regional source—The Basque Country	**Basque Government. General Budgets for the Autonomous Community of the Basque Country**
Link	https://www.euskadi.eus/presupuestoscae/web01-a3ogappt/es/
Characteristics of the source	– Availability: open data but insufficient to collect the indicator – Data collection method: data are published by the responsible governments – Data processability: no – Georeferencing: no – Data update frequency/last update: annual. The last data update was the budget data for financial year 2023

3.9 Public–private Partnership Initiatives

The purpose of this indicator is to know the number of public–private partnership initiatives aimed at leveraging building energy renovations. No entities were identified that create an inventory of public–private partnership initiatives (Table 10).

Table 9 Information sources for indicator 'Public investments as percentage of total investment in energy saving'. *Source* own creation

Indicator: Public investments as percentage of total investment in energy saving	
Variables	Percentage of public investment allocated to stimulating energy savings
Indicator developability	– Data availability: partially available. No data on total investments was found, which prevents the indicator from being developed – Processing method from source: not applicable to this indicator – Data processability: yes, partially
National source	**Spain's Ministry of Finance and Public Administration. General State Budget**
Link	https://www.sepg.pap.hacienda.gob.es/sitios/sepg/es-ES/Presupuestos/DocumentacionEstadisticas/Estadisticas/Paginas/Estadisticas.aspx
Characteristics of the source	– Availability: open data – Data collection method: data are published directly by the responsible governments – Data processability: yes, data available in XLS – Georeferencing: no – Data update frequency/last update: annual. Last update in 2023
Regional source—Aragon	**Government of Aragon. Budget for the Autonomous Community of Aragon**
Link	https://www.aragon.es/-/presupuestos
Characteristics of the source	– Availability: open data – Data collection method: data are published directly by the responsible governments – Data processability: no – Georeferencing: no – Data update frequency/last update: annual. Last update in 2023
Regional source—The Basque Country	**Basque Government. General Budgets for the Autonomous Community of the Basque Country**
Link	https://www.euskadi.eus/k28aVisWar/k28aPrin.jsp
Characteristics of the source	– Availability: open data – Data collection method: data are published directly by the responsible governments – Data processability: no – Georeferencing: no – Data update frequency/last update: annual. Last update in 2022

Table 10 Information sources for indicator 'Public–private partnership initiatives'. *Source* own creation

Indicator: Public–private partnership initiatives	
Variables	Number of public–private partnership initiatives to leverage investments in building energy renovations
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

Table 11 Information sources for indicator 'Investment in energy efficiency renovations on the public building stock'. *Source* own creation

Indicator: Investment in energy efficiency renovations on the public building stock	
Variables	Investments related to improving energy efficiency for the public housing stock. Euros per year invested in the energy improvement of the public residential building stock
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

3.10 Investment in Energy Efficiency Renovations on the Public Building Stock

The purpose of this indicator is to measure and track the investment made in the public housing stock to improve its energy efficiency. No entities were found that collect data on investment in energy efficiency-related renovations in public housing stock (Table 11).

3.11 One-Stop-Shop Initiatives in Place

The purpose of this indicator is to determine the number of one-stop-shops and/or local offices that currently exist to assess whether they are achieving their objective of promoting building renovation by raising awareness and accompanying residents to manage the processes.

In Spain, the Recovery, Transformation, and Resilience Plan, crafted by the Spanish Government and unveiled in April 2021, seeks to enhance information and communication in renovation processes. This goal is pursued through the promotion of one-stop-shops under the Renovation Offices Support Program. These offices are designed to coordinate, inform, and facilitate aid applications, offering services that support the comprehensive management of energy renovation projects in the residential sector. Their mission is to serve citizens, owners' associations, companies, and renovation agents, fostering a centralized hub for streamlined assistance and guidance.

In Aragon, following the launch of the mentioned Recovery, Transformation, and Resilience Plan, the Renovation Support Offices initiative '*Rehabilita Aragón*' was created. It was initiated by the Official Association of Architects of Aragon (COAA) and the Aragon Renovation Office, in collaboration with the Official Associations of Quantity Surveyors and Technical Architects in Huesca, Teruel, and Zaragoza. On the contrary, in the Basque Country, there is a rich tradition in the management of renovation through local offices. Typically, each renovation area has been served by a dedicated renovation office, functioning as a comprehensive one-stop-shop. The roots of this system can be traced back to 1983 with the approval of Decree 278/

Table 12 Information sources for indicator 'One-stop-shop initiatives in place'. *Source* own creation

Indicator: One-stop-shop initiatives in place	
Variables	Number of one-stop shops initiatives: (Number of one-stop shops/ Number of renovations addressed) × 100
Indicator developability	– Data availability: non-available. Only data from a European research project conducted in the Basque Country was found – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator
National source	**Superior Council of Professional Colleges of Architects of Spain (CSCAE, for its acronym in Spanish)**
Link	https://www.cscae.com/index.php/modulo-arquitectos/301-red-de-oficinas-de-apoyo-a-la-rehabilitacion
Characteristics of the source	– Availability: open data – Data collection method: new projects are added in the web page – Data processability: no – Georeferencing: no – Data update frequency/last update: not specified
Regional source—the Basque Country	**The Basque Government—OpenGela project**
Link	https://opengela.eus/casos
Characteristics of the source	– Availability: open data – Data collection method: new projects are added in the web page – Data processability: no – Georeferencing: no – Data update frequency/last update: not specified

1983 on the renovation of the built and urbanized heritage, laying the foundation for this enduring practice.

At the national scale, the Council of Architects of Spain collects the renovation offices (Table 12). At the regional level, the OpenGela research project provides information for the Basque country (Table 12). However, since regions and municipalities are responsible for approving the renovation areas, typically associated with the one-stop-shops, their management services should be capable of collecting and publicly disclosing this data, and therefore the mentioned existing sources of information are considered insufficient for the development of this indicator.

3.12 Awareness Raising Initiatives (Number, Target Audience Reached, Target Audiences Taking Action)

The purpose of this indicator is to know the initiatives that are being developed to promote energy renovation in all sectors of the population, as misinformation was identified as one of the barriers that hinder and impede the generalized implementation of energy renovation of buildings. No centralized databases on awareness-raising initiatives were found. However, significant initiatives in this field are listed in Table 13.

3.13 Number of Integrated/Aggregated Projects

The purpose of this indicator is to quantify renovation projects that have been grouped with others of a similar nature to be able to access certain resources (such as financial, technological, human, etc.) that would not be available to them individually. No sources were found that compile this indicator (Table 14).

4 Conclusions

In this chapter, we proposed indicators regarding policies and measures for the mobilization of investments into the renovation of buildings. We studied the sources of information available for the development of these indicators in Spain, and two of its regions, Aragon and the Basque Country, and we developed them when there were enough available data.

For cost-effectiveness of main renovation measures per building type and climatic zone indicators, no open data were found to specifically develop these indicators, making it difficult or impossible to evaluate them.

With regard to public incentives for deep renovation, national and regional data collected include all types of renovations (without distinguishing between different energy depths) and only take into account renovations on primary households. This indicator cannot, therefore, be developed with available data. An alternative variable was suggested: tax deduction for renovation or extension of primary households (€/year). In Spain, from 2013 to 2020, tax deduction for renovation or extension of households decreased 39%, and in the region of Aragon by 34%. In the Basque Country, from 2012 to 2016, a decrease of 64% was observed and from 2016 to 2018 and increase of 55%.

Regarding public and private investments in deep renovations, national data are limited as only data from specific programs are available. On the other hand, the available data do not provide the energy depth of renovation and it is, therefore, not possible to distinguish between light, medium and deep renovations. For regional data, in the Basque Country, there are fewer limitations as both the number and number of subsidies and loans are provided, calculated annually.

Regarding the budget of national research programs in the field of building energy efficiency and public investments as a percentage of the total investment in energy savings, the data are dispersed across various ministries, entities, and public bodies. This fragmentation and lack of detailed information in the published data make it

Table 13 Information sources for indicator 'Awareness raising initiatives (number, target audience reached, target audiences taking action)'. *Source* own creation

Indicator: Awareness raising initiatives (number, target audience reached, target audiences taking action)	
Variables	Number of initiatives to raise awareness on the importance of energy renovation and operational aspects: – Campaigns to raise awareness among local residents – Public consultations to gather public opinion – Portals and information and outreach campaigns
Indicator developability	– Data availability: non-available (there is some open data but it is insufficient to collect the indicator) – Processing method from source: indirect – Data processability: no
National source	**Spain's Ministry of Public Works—Spanish Urban Agenda**
Link	https://www.aue.gob.es/plan-de-accion-de-la-age/intercambio-y-difusion-del-conocimiento https://www.aue.gob.es/plan-de-accion-de-la-age/gobernanza-age
Characteristics of the source	– Availability: open data – Data collection method: not applicable – Data processability: not applicable – Georeferencing: not applicable – Data update frequency/last update: not applicable
National source	**Spain's Institute for Energy Diversification and Saving - IDAE**
Link	https://www.idae.es/publicaciones?field_title_value=&field_tax_ref_cat_pub_target_id=All&field_taxref_collection_target_id=All&field_file1_lang_multi_target_id=All
Characteristics of the source	– Availability: open data – Data collection method: not applicable – Data processability: not applicable – Georeferencing: not applicable – Data update frequency/last update: not applicable
National source	**Spanish Federation of Municipalities and Provinces – "Look after your house for you, and for them, renovate it" initiative**
Link	http://femp.femp.es/Microsites/Front/PaginasLayout3/Layout3_Personalizables/MS_Maestra_3/_MznynrPoTrWQkdSM25kR-rKuNTn2bYU4pzX7H3Mwgdcf3eDyLx6eFmLyZ-LXJjq1
Characteristics of the source	– Availability: open data – Data collection method: not applicable – Data processability: not applicable – Georeferencing: not applicable – Data update frequency/last update: not applicable
National source	**3R City Observatory**
Link	http://www.observatoriociudad3r.com/que-esta-pasando/

(continued)

Table 13 (continued)

Characteristics of the source	– Availability: open data – Data collection method: not applicable – Data processability: not applicable – Georeferencing: not applicable – Data update frequency/last update: not applicable
National source	**Green Building Council Spain**
Link	https://gbce.es/eresee-2020/
Characteristics of the source	– Availability: open data – Data collection method: not applicable – Data processability: not applicable – Georeferencing: not applicable – Data update frequency/last update: not applicable
Regional source—Aragon	**Government of Aragon—The Aragon Climate Change Strategy**
Link	https://www.aragon.es/-/estrategia-aragonesa-de-cambio-climatico-eacc-.-horizonte-2030 https://www.eseficiencia.es/2019/10/24/gobierno-aragon-inicia-campana-sensibilizacion-autoconsumo-fotovoltaico-rehabilitacion-energetica
Characteristics of the source	– Availability: open data – Data collection method: not applicable – Data processability: not applicable – Georeferencing: not applicable – Data update frequency/last update: not applicable
Regional source—Aragon	**Other strategies in Aragon**
Link	https://marquitectos.files.wordpress.com/2013/02/nuevas-propuestas-de-rehabilitacion-urbana-en-zaragoza.pdf
Characteristics of the source	Not applicable
Regional source—the Basque Country	**Basque Energy Agency. Basque Government—Basque Country Energy Strategy 2030**
Link	https://www.eve.eus/Conoce-la-Energia/La-energia-en-Euskadi/Publicaciones/Planes-Energeticos/Basque-Energy-Strategy-2030
Characteristics of the source	– Availability: open data – Data collection method: not applicable – Data processability: not applicable – Georeferencing: not applicable – Data update frequency/last update: not applicable
Regional source—the Basque Country	**Etxebizitza. Basque Housing Observatory**
Link	https://etxebizitza.blog.euskadi.eus/es/

(continued)

Table 13 (continued)

Characteristics of the source	– Availability: open data – Data collection method: not applicable – Data processability: not applicable – Georeferencing: not applicable – Data update frequency/last update: not applicable
Regional source—the Basque Country	**Other strategies in the Basque Country**
Link	https://www.vitoria-gasteiz.org/wb021; https://contenidosEstaticos/adjuntos/es/96/92/49692.pdf https://www.alokabide.euskadi.eus/acompanamiento-energetico-a-familias-e-lagun/ https://www.alokabide.euskadi.eus/contenidos/recurso_tecnico/aa10_comun/es_def/adjuntos/2021/Cuaderno_eLagun_cast.pdf https://www.etxebide.euskadi.eus/evaluacion-del-servicio-2020-sobre-el-proceso-de-ayudas-a-la-rehabilitacion/x39-ovcntgen/es/
Characteristics of the source	Not applicable

Table 14 Information sources for indicator 'Number of integrated / aggregated projects'. *Source* own creation

Indicator: Number of integrated/aggregated projects	
Variables	Number of aggregate demand projects that have been grouped or integrated with other similar projects to favor access to certain resources
Indicator developability	– Data availability: non-available – Processing method from source: not applicable to this indicator – Data processability: not applicable to this indicator

impractical to create the indicator directly and effectively, hindering the identification of specific energy-saving items.

With regard to public investments in policy addressing the issues mentioned (split incentives, energy poverty, etc.), data are limited as only data from specific programs are available. It should be noted that there are no direct data on the indicator, they have to be processed and this implies a loss of data and lack of accuracy of the indicator. For regional data, in the Basque Country, there are fewer limitations as both the number of subsidies and loans are provided, calculated annually. The only limitation is the lack of data on square meters renovated.

Two webpages, one national and one in the Basque country, were found that collect information on one-stop-shops initiatives. However, as the approval of renovation areas (to which one-stop shops are commonly associated with) typically falls under the jurisdiction of regions and municipalities, these web pages are deemed insufficient for the development of the indicator 'Number of One-stop-shop initiatives in place'.

The first of the limitations encountered when analyzing the awareness raising initiatives lies in the difficulty of narrowing down which initiatives are included in the group of awareness-raising initiatives and which are not, as this is a broad concept.

Moreover, as this type of action is often carried out by organizations, municipalities, etc., it is very complex to identify all the actions that are being developed, as there is no centralized database to collect this information. Therefore, the data collected here show only a small part of all the initiatives that are likely to be taking place.

Regarding number of integrated / aggregated projects, no source was found that collects data related to this indicator. The regions would be in charge of compiling this information, which is obtained in the renovation area approval reports and other requests to promote renovation at the expense of public funds that are identified as aggregated projects.

With regard to public–private partnership initiatives, investment in energy efficiency renovations on the public building stock and public and private investments in smart technologies (including smart grids), no source were found that collects data related to these indicators.

In conclusion, the insufficient availability of information sources in Spain hinders the development of the majority of the indicators aimed at gauging the mobilization of investments in building renovations. The necessity to rely on too many diverse sources results in data loss and a lack of precision, leading to the difficulty of development of some indicators. The lack of distinction in the data collected regarding energy depth of renovations makes it difficult to reach the desired conclusions on the effectiveness of policies and measures for the mobilization of investments into the renovation of buildings.

Acknowledgements This work was founded by the MINISTRY OF SCIENCE AND INNOVATION OF SPAIN, grant number PID2019-104871RB-C21/AEI/10.13039/501100011033 and by GOBIERNO DE ARAGÓN, grant number T37_23R: Built4Life Lab.

References

Basque Housing Observatory (Department of Territorial Planning, Housing and Transport, Basque Government: La Política Fiscal vinculada a la vivienda en Euskadi: alcance e impacto del gasto fiscal [Fiscal Policy Linked to Housing in the Basque Country: Scope and Impact of Fiscal Expenditure] (2020).

European Commission: COMMISSION RECOMMENDATION (EU) 2019/786 of 8 May 2019 on building renovation. Official Journal of the European Union (2019: L 127), 34–79 (2019).

European Parliament: Energy performance of buildings (recast) Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (Proposal recast) (COM(2021)0802 – C9–0469/2021 – 2021/0426(COD)). Strasbourg (2023).

Llamas, M: La construcción avanza su primer crecimiento desde 2007 [Construction sees its first growth since 2007]. Libre Mercado. (2017). https://www.libremercado.com/2014-12-17/la-construccion-avanza-su-primer-crecimiento-desde-2007-1276536218/, last accessed 2023.

Ministry of Industry, Commerce and Tourism: Survey of Juncture in the construction Sector (2023). https://www.mincotur.gob.es/en-us/indicadoresyestadisticas/industria/encuestacoyuntura/paginas/encuesta-coyuntura.aspx, last accessed 2023.

Ministry of Transport, Mobility and Urban Agenda (MITMA): Recomendaciones de los grupos de trabajo para la implementación de las medidas de la ERESEE 2020 [Workgroup recommendations for the implementation of 2020 ERESEE measures]. Madrid (2023).
Spanish Confederation of Business Organizations (CEOE): La rehabilitación de edificios como motor de crecimiento y empleo. Comisión de Infraestructuras y Urbanismo [The renovation of buildings as an engine for growth and employment. Infrastructure and Urbanism Commission] (2014).
Spain's Economic and Social Council: EL PAPEL DEL SECTOR DE LA CONSTRUCCIÓN EN EL CRECIMIENTO ECONÓMICO: COMPETITIVIDAD, COHESIÓN Y CALIDAD DE VIDA [THE ROLE OF THE CONSTRUCTION SECTOR IN ECONOMIC GROWTH: COMPETITIVENESS, COHESION, AND QUALITY OF LIFE]. Madrid (2016). https://www.ces.es/documents/10180/3557409/Inf0216.pdf, last accessed 2023/09/20.
Spain's National Publicity System for Public Subsidies and Aid: Latest calls published. (2023). https://www.pap.hacienda.gob.es/bdnstrans/GE/en/index, last accessed 2023/09/20.
Spain's Tax Agency of the Ministry of Finance and Public Administration: Deducción por rehabilitación o ampliación de la vivienda habitual (parte estatal). Tipo de Declaración: Conjunta. Aragón [Deduction for the renovation or expansion of the main residence (national part). Type of Declaration: Joint. Aragon]. (2020). https://sede.agenciatributaria.gob.es/AEAT/Contenidos_Comunes/La_Agencia_Tributaria/Estadisticas/Publicaciones/sites/irpf/2020/jrubikf7c3feaf16d8973153d227d0d86c739b4014c2fc0.html, last accessed 2023/09/20.
Spain's Tax Agency of the Ministry of Finance and Public Administration: Estadística de los declarantes del Impuesto sobre la Renta de las Personas Físicas: Total 2020 [Statistics of declarants for the Personal Income Tax: Total 2020]. (2020). https://sede.agenciatributaria.gob.es/AEAT/Contenidos_Comunes/La_Agencia_Tributaria/Estadisticas/Publicaciones/sites/irpf/2020/mapa3611577d7713901bc32df86e9e21bb822ee7d12c.html, last accessed 2023/09/20.

On the Availability and Quality of Data in Spain for the Development of Indicators to Measure Building Renovation Policies Effectiveness and the Decarbonization of the Building Stock

Marta Gómez-Gil, Markel Arbulu, Rufino J. Hernández-Minguillón, and Belinda López-Mesa

Abstract It is crucial to achieve long-term decarbonization goals in the building sector by relying building renovation policies on well-founded evidence based on indicators regarding the current state of the building stock, decarbonization requirements and potential, feasibility of solutions, possible failures, risks, and other relevant factors. To develop such indicators, it is necessary to have data of good quality. This chapter analyzes the availability of data in Spain and its quality to develop indicators to assess the effectiveness of building renovation policies and the progress of decarbonization. With this objective, the developability of a set of indicators was analyzed regarding their availability, processing method and data processability, and the data source quality was assessed regarding data processability, georeferencing, and data update frequency. The results show pronounced challenges related to data availability in indicators concerning deep renovation of buildings and policies for mobilizing investments into building renovation. The diversity in data processing methods, with 42% indicators directly processable and 58% requiring indirect methods, underscores

M. Gómez-Gil · B. López-Mesa (✉)
Built4Life Lab, University of Zaragoza-I3A, 50018 Zaragoza, Spain
e-mail: belinda@unizar.es

M. Gómez-Gil
e-mail: m.gomez@unizar.es

M. Arbulu · R. J. Hernández-Minguillón
Department of Architecture, University of the Basque Country UPV/EHU, 20018 Donostia-San Sebastian, Spain
e-mail: markel.arbulu@ehu.eus

R. J. Hernández-Minguillón
e-mail: rufinojavier.hernandez@ehu.eus

B. López-Mesa and X. Oregi (eds.), *Assessing Progress in Decarbonizing Spain's Building Stock*, Digital Innovations in Architecture, Engineering and Construction,
https://doi.org/10.1007/978-3-031-51829-4_11

the complexity in obtaining and manipulating data. Additionally, the limited georeferencing (9%) and insufficient update frequencies (54% with update frequencies of more than five years) highlight areas for improvement.

1 Introduction

Building renovation and decarbonization are high on the European building political agenda as the EU governments seek to reduce wasteful energy consumption, strengthen energy security and cut greenhouse gas (GHG) emissions. Policy monitoring and evaluation has a critical role to play in the design, implementation and delivery of public policies and services. Ensuring that building renovation and decarbonization policy making is informed by sound evidence on the state of the building stock, the decarbonization needs and potential, solutions feasibility, failures, risks, etc. is essential to achieve key long-term objectives. The so-called measurable progress indicators (European Parliament and the Council of the European Union 2018) play an important role in this sense, since they are quantitative or qualitative variables to measure progress towards the long-term 2050 goal of reducing GHG emissions in the European Union (EU) and ensuring a highly energy-efficient and decarbonized national building stock, helping us understand the system, compare it, and improve it.

In order to develop indicators, we need data (International Energy Agency 2014). One of the fundamental principles in indicators development is to identify which data already exist before embarking on a costly data collection (International Energy Agency 2014). On the other hand, good decisions require appropriate indicators populated with the best available data (NHS Institute for Innovation and Improvement 2017). A poorly chosen indicator with reliable data and a well-chosen indicator with unreliable or untimely data have both little value. Therefore, the quality of the data is another important issue to address. The objective of this chapter is to study the availability of data for the measurable indicators and the quality of these data.

In previous chapters of this book (Beltrán-Velamazán et al. 2024a, Gómez-Gil et al. 2024a, 2024b, Arbulu et al. 2024a, Beltrán-Velamazán et al. 2024b, Gómez-Gil et al. 2024c, 2024d, 2024e, Arbulu et al. 2024b), a set of indicators to assess the effectiveness of building renovation policies and the progress of decarbonization was selected (Table 3 in Appendix A) to study their data needs, the potential sources of information, and develop them when data were available. The selection of indicators was based on the frameworks of indicators proposed by the European Commission in:

- Article 2a of the Commission Recommendation (EU) 2019/786 of May 2019 on the renovation of buildings (referred to as 2019 EPBD-related Recommendation in this book) (European Commission 2019).
- Annex II of the Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council

on the energy performance of buildings (recast) (European Parliament 2023) (referred to as 2023 EPBD Proposal recast in this book).

In this chapter, we will focus on the assessment of the availability of data for these specific measurable indicators and the quality of the data for the case of Spain, as Member State (MS) of the EU.

2 Methodology

The methodology for this objective consisted of defining, first of all, some criteria to analyze the availability of data and its quality. Secondly, we studied the potential data sources in Spain, developed the indicators when possible, and analyzed them and the sources following the previously defined criteria. And finally, we carried out an accounting of the results to reach conclusions. Next, we describe the criteria defined to analyze the data availability and quality.

In order to measure the data availability at the indicator scale, we used the concept of indicator developability, by which we refer to the degree of ease of collecting data on an indicator for its development. To measure this concept, we use three parameters (Fig. 1), whose meanings in this book are given next:

- Data availability. It is a measure of to what degree the data required for the indicator development is available to be used. We have considered three possible levels of data availability: fully available, partially available, and non-available. 'Partially available' is used when it is possible to obtain some of the variables of the indicator but not others, or when data is missing in the timeline, making it difficult to analyze the evolution of the indicator.
- Processing method. It is a measure of the degree of processing that the data from the source(s) requires to be converted into the indicator data. Two degrees of processing are considered here: direct and indirect. 'Direct' means that the indicator data is published as is by the source. 'Indirect' means that the data from the source requires some processing to convert it into indicator data. For example, in the case of an indicator that is expressed as a percentage of the population, if the percentage is published by the data source the method is direct, however, if to obtain the percentage one has to collect data on affected population and total population and divide one by another, then the method is indirect.
- Data processability. It is a measure of ease of conversion of raw data from the available sources to machine-readable form and its subsequent processing. We have considered three possible levels of ease of conversion: yes, partially, and no. 'Yes' is used when all the data to develop the indicator is in a format that is machine-readable, such as comma-separated values (CSV), JavaScript Object Notation (JSON) or Extensible Markup Language (XML). 'No' is used when none of the data available is machine-readable. Partially is used when part of the data is machine-readable and part is not.

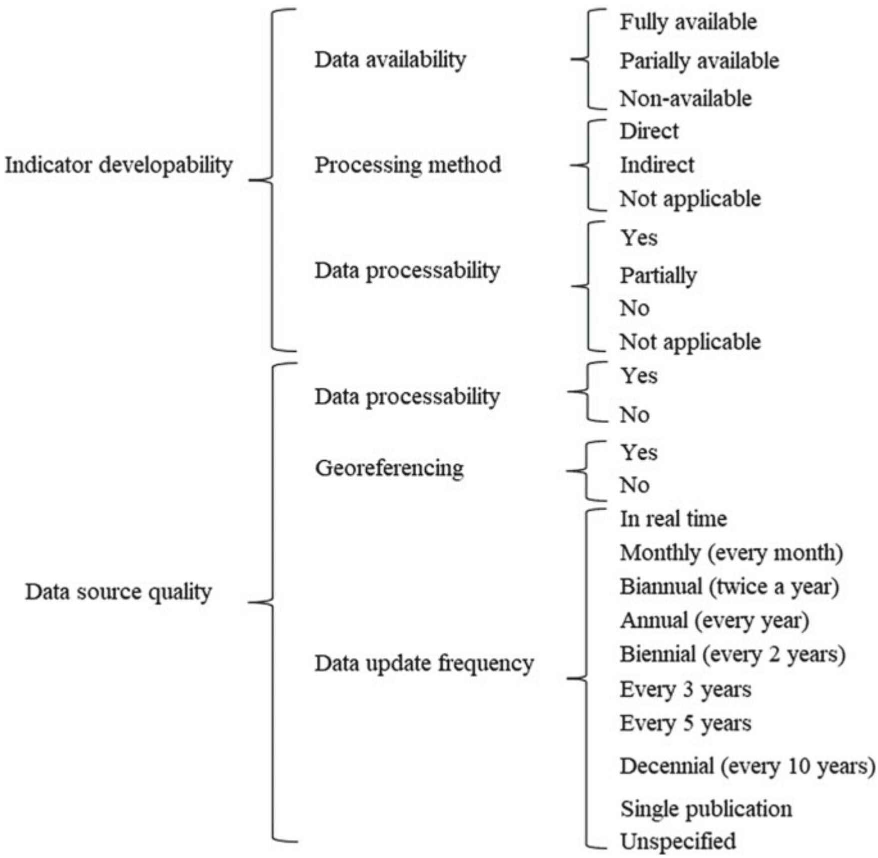


Fig. 1 Parameters considered to study the indicator developability and the data source quality. *Source* own creation

In order to measure the data source quality we used the following three parameters:

- Data processability. It is a measure of ease of conversion of the source raw data to machine-readable form and its subsequent processing. We have considered two possible levels of ease of conversion: yes, and no. 'Yes' is used when the source data to develop the indicator is in a format that is machine-readable. 'No' is used when it is not.
- Georeferencing. It is a measure of whether the data are georeferenced or not. We considered two possible levels of georeferencing: yes or no.
- Data update frequency. It is a measure of how often the source data is available to be used. We found the sources of information for the case of the studied indicators in Spain had ten possible data update frequencies, which are shown in Fig. 1.

3 Results

3.1 Developability of Indicators

Table 1 shows a summary of the developability of the selected indicators in Spain. Complete information on the developability of each indicator is shown in Table 3 in Appendix A.

As can be seen in Table 1, 17% of the indicators are fully available, 41% are partially available and 42% are non-available. The subjects in which there are less data available are 'An overview of deep renovation of buildings', in which 70% of indicators cannot be developed, and 'Policies and measures for the mobilization of investments into the renovation of buildings' with 85% of non-developable indicators. Among the indicators that can be developed totally or partially, data processing is direct in 42% of the indicators and indirect in the remaining 58%. On the other hand, among the indicators that can be developed totally or partially, the data are fully processable in 61% of the indicators, partially in 5%, and are not in 34%.

3.2 Quality of Indicator Sources

Table 2 shows the sources of information in Spain for the selected indicators, which were applied to the case of Spain and two of its regions, Aragon and the Basque Country. As can be seen in Table 2, the sources of information which provide data for more indicators (three or more indicators) are, at the national level, the National Institute of Statistics, the Ministry of Transport, Mobility and Urban Agenda, The Ministry of Ecological Transition and Demographic Challenge, the Institute for Energy Diversification and Savings, the 3R City Observatory, the Ministry of Finance and Civil Service, and the Spanish Cadaster. At the regional level, for the case of Aragon, we find the Aragon Institute of Statistics, the Government of Aragon, and the portal Aragon Open Data. At the regional level, for the case of the Basque Country, the main sources of information are the Basque Government and the Basque Institute of Statistics. At the international and European scale, Eurostat is the main source of information to measure the progress of renovation and decarbonization of the building stock.

Table 4 in Appendix A shows the analysis of the quality of the data sources for the selected indicators in Spain according to the criteria previously defined. As can be seen in Table 4, 63% of the sources data used to develop the indicators were processable and the remaining 37% were not. On the other hand, only 9% of the data were georeferenced. Figure 2 shows the update frequency of the data used for the development of the selected indicators. The 46% of the data have a sufficient update

Table 1 Summary of Indicators Developability for Spain. *Source* own creation

Subject	Data availability		Processing method		Data processability	
An overview of the general characteristics of the national building stock	Fully available	4	Direct	5	Yes	12
	Partially available	9	Indirect	8	Partially	1
					No	0
	Non-available	1	–	–	–	–
An overview of the energy characteristics of the national building stock	Fully available	0	Direct	4	Yes	2
	Partially available	5	Indirect	1	Partially	0
					No	3
	Non-available	1	–	–	–	–
An overview of deep renovation of buildings	Fully available	1	Direct	1	Yes	3
	Partially available	2	Indirect	2	Partially	0
					No	0
	Non-available	7	–	–	–	–
An overview of worst performing segments of the national building stock, rented properties and energy poverty	Fully available	3	Direct	4	Yes	2
	Partially available	2	Indirect	1	Partially	0
					No	3
	Non-available	1	–	–	–	–
An overview of the capacities in the construction, energy efficiency and renewable energy sector	Fully available	0	Direct	1	Yes	2
	Partially available	4	Indirect	3	Partially	1
					No	1
	Non-available	2	–	–	–	–
An overview of actual energy savings and wider benefits of renovation of buildings	Fully available	3	Direct	6	Yes	3
	Partially available	4	Indirect	1	Partially	0
					No	4
	Non-available	7	–	–	–	–
Evidence based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation	Fully available	1	Direct	1	Yes	0
	Partially available	1	Indirect	1	Partially	0
					No	2
	Non-available	0	–	0	–	0
Policies and measures for the mobilization of investments into the renovation of buildings	Fully available	0	Direct	2	Yes	1
	Partially available	2	Indirect	0	Partially	0
					No	1
	Non-available	11	–	–	–	–

Table 2 Sources of information for the selected indicators applied to the case of Spain and the regions of Aragon and Basque Country, type of source, and number of indicators they are useful for. *Source* own creation

Sources of information	Type of source	No. of indicators
IEA: International Energy Agency	International	1
Eurostat: European Statistical Office	European	3
EHUrOPE: EHU European Projects Office	European	1
EPOV: EU Energy Poverty Observatory	European	1
INE: Spain's National Institute of Statistics	National	23
MITMA: Ministry of Transport, Mobility and Urban Agenda	National	12
MITERD: Ministry of Ecological Transition and Demographic Challenge	National	10
IDAE: Spain's Institute for Energy Diversification and Savings	National	6
3R: 3R City Observatory	National	4
MH: Ministry of Finance and Civil Service	National	4
SC: Spanish Cadaster	National	3
MISAN: Ministry of Health	National	2
CSCAE: Superior Council of Professional Colleges of Architects of Spain	National	1
GBCe: Green Building Council	National	1
MEFP: Ministry of Education and Vocational Training	National	1
MINCOTUR: Ministry of Industry, Trade and Tourism	National	1
MINECO: Ministry of economic affairs and Digital Transformation	National	1
MU: Ministry of Universities	National	1
OMR: Municipal Renovation Observatory	National	1
IAEST: Aragon Institute of Statistics	Regional—A	15
GA: Government of Aragon	Regional—A	8
AOD: Aragon Open Data	Regional—A	3
UNIZAR: University of Zaragoza	Regional—A	1
BG: Basque government	Regional—BC	15
EUSTAT: Basque Institute of Statistics	Regional—BC	13
AC: Alava Cadaster	Regional—BC	1
BHO: Basque Housing Observatory	Regional—BC	1
GC: Gipuzkoa Cadaster	Regional—BC	1
VC: Vizcaya Cadaster	Regional—BC	1
IREC: Catalonia Institute for Energy Research	Regional—Other regions	2

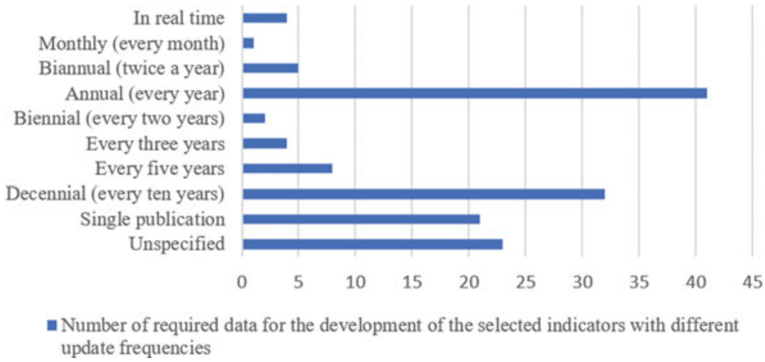


Fig. 2 Update frequency of the data used for the development of the selected indicators for the case of Spain. *Source* own creation

frequency (ranging from 'in real time' to 'every five years'). The frequency of 'Every five years' is considered the limit of sufficiently good update frequency because these indicators will belong to a document named National Building Renovation Plans which are meant to be updated every five years. However, 23% of the data are updated every ten years and 31% of the data belong to single publication documents or the frequency is unspecified. These latter frequencies are not good enough for policy monitoring and evaluation. In any case, the recommended update frequency is at least annual. Only 36% of the data are updated with this recommended frequency.

4 Conclusions

The analysis of the availability of data in Spain for the development of indicators to assess building renovation policies and the progress of decarbonization highlights a significant need for enhancing data availability. Approximately 17% of the indicators are fully available, offering a robust foundation for assessing and monitoring progress in some of the topics. Another 41% are partially available, meaning they can be developed but may require additional data sources or refinement. The remaining 42% are non-available, highlighting areas where data availability needs significant improvement.

In terms of data processing, direct processing is applicable to 42% of the indicators, while the remaining 58% require indirect data processing methods. This variation underscores the diversity in data sources and the complexity in obtaining and manipulating data.

Furthermore, the quality of data sources plays a crucial role in the reliability of indicators. A significant portion of data sources (63%) is deemed processable, while 37% are not, highlighting the importance of improving data quality and accessibility. Georeferencing, a critical component for spatial analysis and geographic-based indicators, is found in only 9% of the data sources, suggesting room for enhancement in this aspect.

The update frequency of data sources is another vital consideration. Only 46% of the data sources exhibit sufficient update frequencies, ranging from 'in real time' to 'every five years', 36% have a recommendable update frequency, ranging from 'in real time' to 'annual (every year)'. However, a substantial portion (23%) is updated only every ten years, and 31% belong to single publication documents or have unspecified update frequencies. This problem in update frequency can impact the effectiveness of policy monitoring and evaluation, emphasizing the need for more timely and frequent data updates.

The availability and quality of data depends on the subject of the indicator:

- In the case of indicators regarding an overview of the general characteristics of the national building stock, 29% of the indicators are fully available, while 64% can be developed but require additional data sources or refinement, and the remaining 7% are non-available. In chapter 3 of this book (Gómez-Gil et al. 2024a), the authors concluded that while Spain offers substantial information sources for indicators to gauge the general characteristics of buildings, the requirement to consult varied sources depending on the specific information needed leads to discrepancies in cross-referencing data, resulting in some indicators being only partially developed. It is therefore important to improve the collection of data on buildings in Spain so that it is at least annual and the procedures of different institutions are homogenized at a conceptual and methodological level.
- As for indicators related to an overview of the energy characteristics of the national building stock, 0% of the indicators are fully available, 83% can be developed with additional data sources or refinement, and the remaining 17% are non-available. In Chap. 4 of this book, the authors (Gómez-Gil et al. 2024b) concluded that while Spain possesses national information sources on energy consumption, EPCs, and energy ratings, the data are managed and published at a regional level, offering heterogeneous information, hindering the development of indicators based on good quality data in this subject; furthermore, there is a lack of data on nZEB buildings crucial for the country's decarbonization objectives. Therefore, it is necessary to improve the homogenization of the data published by the different regions of Spain from the EPCs, and to begin collecting information on nZEBs.
- With respect to indicators on an overview of deep renovation of buildings, 10% are fully available, 20% partially available, and the remaining 70% are non-available. In chap. 5, the authors (Arbulu et al. 2024a) concluded that insufficient data

sources in this country hinder the development of a comprehensive overview of deep building renovations, as the consulted sources lack categorization based on energy savings depth, posing challenges in distinguishing deep renovations from other types, and emphasizing the necessity for centralized data collection to mitigate discrepancies among sources. It is, therefore, crucial that data collection from now on, in Spain, distinguishes between light, medium and deep renovations, so that the evaluation of public policies on building renovation can be aligned with the general objectives of decarbonization of the building stock.

- Regarding indicators related to an overview of the worst-performing segments of the national building stock, rented properties and energy poverty, 50% are completely available, 33% are partially available, and the remaining 17% are non-available. According to the authors of chap. 6 (Beltrán-Velamazán 2024b), Spain has robust data sources for developing energy poverty indicators, but there is room for improvement in systematically collecting information on the percentage of the population residing in inadequately thermally conditioned housing during summer and on the energy efficiency of rented properties that could be affected by the split-incentives dilemma. Additionally, the authors of chap. 6 agree with those of chapter 4 in pointing out that there is a need to enhance and standardize the publication of information from energy certificates across different regions of Spain. Hence, it would be beneficial to enhance not only the standardization of data published by various regions of Spain through Energy Performance Certificates (EPCs) but also to gather information facilitating the cross-referencing of this data with the type of housing tenure (rental or ownership).
- In relation to indicators regarding an overview of the capacities in the construction, energy efficiency, and renewable energy sector, 0% are fully available, 67% are partially available, and the remaining 33% are non- available. As per the authors of chap. 7 (Gómez-Gil et al. 2024c), it is essential to guarantee that university studies and training programs consistently align with the evolving actual requirements of the sector, while simultaneously emphasizing the importance of enhancing data collection on the adoption of smart technologies, engagement with energy communities, and evaluating administrative capacity. Therefore, it is necessary to begin adequate data collection in Spain in these aspects mentioned.
- With regard to indicators regarding an overview of actual energy savings and wider benefits of renovation of buildings, 21% of the indicators are fully available, while 29% can be developed but require additional data sources or refinement, and the remaining 50% are non-available. As outlined by the authors in chap. 8 (Gómez-Gil et al. 2024d), the absence of comprehensive data hinders the attainment of a detailed and accurate understanding of the savings and benefits derived from building renovation activities, emphasizing the need for improved data collection and analysis in this context.

- When it comes to indicators related to evidence-based estimates of expected energy savings and of reduction of costs for health systems from buildings renovation, 50% of the indicators are fully available and 50% partially available. As indicated by the authors in chap. 9 (Gómez-Gil et al. 2024e), while existing data sources offer reasonably robust information on expected energy savings, there remains a deficiency in the available information to establish precise targets related to the reduction of health costs linked to energy efficiency measures and enhancements in air quality. This underscores the necessity for research and enhanced data sources on this field to effectively evaluate the holistic benefits of energy efficiency measures.
- And finally, regarding indicators on policies and measures for the mobilization of investments into the renovation of buildings, 0% are fully available, 15% partially available, and the remaining 85% are non-available. As outlined by the authors in chap. 10 (Arbulu et al. 2024b), the limited accessibility of information sources in Spain impedes the creation of most indicators intended to measure the mobilization of investments in building renovations. As also pointed out by the authors of chap. 5, their work concludes that the absence of differentiation in the collected data regarding the energy depth of renovations impedes the derivation of conclusive insights into the efficacy of policies and measures intended to stimulate investments in building renovation initiatives.

In conclusion, the assessment of indicators to evaluate the effectiveness of building renovation policies in Spain highlights both strengths and areas for improvement. Indicators related to deep renovation of buildings and policies for mobilizing investments into building renovation are the ones facing greater challenges regarding data availability, with the majority of the indicators being non-available. Addressing these data gaps and enhancing data quality, including georeferencing capabilities, will be pivotal for accurate and comprehensive policy monitoring, particularly in the context of building renovation and decarbonization. Policymakers, researchers, and data providers must collaborate to ensure a more robust and reliable data ecosystem, enabling evidence-based decision-making and policy evaluation for Spain's and Europe's sustainable development goals.

Acknowledgements This work was funded by the MINISTRY OF SCIENCE AND INNOVATION OF SPAIN, grant number PID2019-104871RB-C21/AEI/10.13039/501100011033 and by GOBIERNO DE ARAGÓN, grant number T37_23R: Built4Life Lab.

Appendix A

Table 3 Developability of selected indicators for the case of Spain. *Source* own creation

Subject	Indicator	Data availability	Processing method	Data processability
An overview of the general characteristics of the national building stock	Number of buildings per building type	Fully available	Indirect	Yes
	Number of buildings per building age	Partially available	Direct	Yes
	Number of buildings per building size	Fully available	Direct	Yes
	Number of buildings per climate zone	Partially available	Indirect	Yes
	Number of dwellings per type of residential building	Partially available	Indirect	Yes
	Number of dwellings per type of building (Occupancy)	Fully available	Direct	Yes
	Number of dwellings per building age	Partially available	Direct	Yes
	Number of dwellings per size (Surface area)	Fully available	Direct	Yes
	Number of dwellings per building size	Partially available	Indirect	Yes
	Number of dwellings per climate zone	Partially available	Indirect	Yes
	M^2 per building type	Partially available	Indirect	Partially
	M^2 per building age	Partially available	Indirect	Yes
	M^2 per building size	Non-available	–	–
	M^2 per climatic zone	Partially available	Indirect	Yes
An overview of the energy characteristics of the national building stock	Annual energy consumption per building type	Partially available	Direct	Yes
	Annual energy consumption per end use	Partially available	Direct	Yes
	Number of energy performance certificates (EPCs) per building type	Partially available	Direct	No

(continued)

Table 3 (continued)

Subject	Indicator	Data availability	Processing method	Data processability
	Number of energy performance certificates (EPCs) per energy class	Partially available	Indirect	No
	Number of nearly zero-energy buildings (nZEBs) per building sector	Partially available	Direct	No
	m^2 of nearly zero-energy buildings (nZEBs) per building sector	Non-available	–	–
An overview of deep renovation of buildings	Annual percentage of renovated buildings per renovation type	Partially available	Indirect	Yes
	Annual percentage of renovated buildings per building sector—residential/non-residential	Fully available	Indirect	Yes
	Renovated m^2 per building type	Non-available	–	–
	Renovated m^2 per building size	Non-available	–	–
	Renovated m^2 per building age	Non-available	–	–
	Total and annual proportion of buildings undergoing deep and nZEB renovation	Partially available	Direct	Yes
	Energy savings from deep renovations	Non-available	–	–
	m^2 of renovated public buildings per building type	Non-available	–	–
	m^2 of renovated public buildings per building size	Non-available	–	–
	m^2 of renovated public buildings per climatic zone	Non-available	–	–
An overview of worst performing segments of the national building stock, rented properties and energy poverty	Number, total floor area, percentage of buildings in lowest energy classes	Partially available	Indirect	No
	Percentage of rented dwellings with EPCs below a certain performance level	Non-available	–	–

(continued)

Table 3 (continued)

Subject	Indicator	Data availability	Processing method	Data processability
	Energy poverty indicators: Percentage of people affected by energy poverty	Fully available	Direct	No
	Energy poverty indicators: Proportion of disposable household income spent on energy	Fully available	Direct	Yes
	Energy poverty indicators: Arrears on utility bills	Fully available	Direct	No
	Energy poverty indicators: Population living in inadequate dwelling conditions or with inadequate heating and cooling	Partially available	Direct	Yes
An overview of the capacities in the construction, energy efficiency and renewable energy sector	Number of buildings equipped with building energy management systems (BEMSs) or similar smart systems per building type (focus on non-residential)	Non-available	–	–
	Citizens participating in energy communities	Non-available	–	–
	Number of graduated students from university courses with focus on energy efficiency and related smart technologies	Partially available	Indirect	Yes
	Number of graduated students from professional/technical training (EPC certifiers, HVAC inspectors, etc.)	Partially available	Indirect	Yes
	Number of installers skilled in new technologies and working practices	Partially available	Direct	Partially

(continued)

Table 3 (continued)

Subject	Indicator	Data availability	Processing method	Data processability
	Participation of national universities in international scientific research projects on energy efficiency in buildings-related topics	Partially available	Indirect	No
An overview of actual energy savings and wider benefits of renovation of buildings	Reduction in energy costs per household (average)	Partially available	Direct	No
	Decrease in energy poverty	Fully available	Indirect	No
	Actual energy savings achieved	Partially available	Direct	No
	Average / aggregate indoor air quality indices (IAQIs)	Non-available	–	–
	Thermal comfort index (TCI)	Non-available	–	–
	Cost of avoided illnesses	Non-available	–	–
	Reduction on whole life carbon	Non-available	–	–
	Disability adjusted life year (Daly) / Quality adjusted life year (QALY) improvements attributable to improvement of building stock and living conditions	Non-available	–	–
	Labor productivity gains from better working environment and improved living conditions	Non-available	–	–
	Reduction of emissions	Partially available	Direct	No
	Number of jobs created per EUR million invested in the sector	Partially available	Direct	Yes
	GDP increase in the building sector	Fully available	Direct	Yes
	Percentage of energy imports for the member state	Fully available	Direct	Yes
	Removal/prevention of accessibility barriers for persons with disabilities	Non-available	–	–

(continued)

Table 3 (continued)

Subject	Indicator	Data availability	Processing method	Data processability
Evidence-based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation	Expected energy saving per building sector and type	Fully available	Direct	No
	Expected reduction in health costs attributable to energy efficiency measures and improved air quality	Partially available	Indirect	No
Policies and measures for the mobilization of investments into the renovation of buildings	Cost-effectiveness of main renovation measures per building type	Non-available	–	–
	Cost-effectiveness of main renovation measures per climatic zone	Non-available	–	–
	Public incentives for deep renovation	Partially available	Direct	No
	Public and private investments in deep renovations	Partially available	Direct	Yes
	Public investments in policy addressing the issues mentioned (split incentives, energy poverty, etc.)	Non-available	–	–
	Public and private investments in smart technologies (including smart grids)	Non-available	–	–
	Budget of national research programs in the field of building energy efficiency	Non-available	–	–
	Public investments as percentage of total investment in energy saving	Non-available	–	–
	Public–private partnership initiatives	Non-available	–	–
	Investment in energy efficiency renovations on the public building stock	Non-available	–	–
	One-stop-shop initiatives in place	Non-available	–	–
	Awareness raising initiatives (number, target audience reached, target audiences taking action)	Non-available	–	–
	Number of integrated / aggregated projects	Non-available	–	–

Table 4 Sources of information, data processability, georeferencing and data update frequency of the indicators proposed in this book. *Source* own creation

Indicator	Source	Data processability	Georeferencing	Data update frequency
Number of buildings per building type	INE	Yes	No	Decennial
	MITMA	Yes	No	Unspecified
	IAEST	Yes	No	Decennial
	EUSTAT	Yes	No	Decennial
	BG	No	No	Single publication
Number of buildings per building age	INE	Yes	No	Decennial
	MITMA	Yes	No	Unspecified
	SC	Yes	Yes	Biannual
	IAEST	Yes	No	Decennial
	EUSTAT	Yes	No	Decennial
	BG	No	No	Single publication
Number of buildings per building size	INE	Yes	No	Decennial
	MITMA	Yes	Yes	Unspecified
Number of buildings per climate zone	INE	Yes	No	Decennial
	IDAE	No	No	Unspecified
	IAEST	Yes	No	Decennial
	EUSTAT	Yes	No	Decennial
Number of dwellings per type of residential building	INE	Yes	No	Decennial
	IAEST	Yes	No	Decennial
	EUSTAT	Yes	No	Annual
Number of dwellings per type of building (Occupancy)	INE	Yes	No	Decennial
	MITMA	Yes	No	Decennial
	IAEST	Yes	No	Decennial
	EUSTAT	Yes	No	Biennial
Number of dwellings per building age	INE	Yes	No	Decennial
	SC	Yes	Yes	Biannual
	IAEST	Yes	No	Decennial
	EUSTAT	Yes	No	Every five years
Number of dwellings per size (Surface area)	INE	Yes	No	Decennial
	IAEST	Yes	No	Decennial
	EUSTAT	Yes	No	Every five years
Number of dwellings per building size	INE	Yes	No	Decennial
	EUSTAT	Yes	No	Annual

(continued)

Table 4 (continued)

Indicator	Source	Data processability	Georeferencing	Data update frequency
Number of dwellings per climate zone	INE	Yes	No	Decennial
	IDAE	No	No	Decennial
	IAEST	Yes	No	Decennial
	EUSTAT	Yes	No	Annual
Number of m^2 per building type	SC	Yes	Yes	Biannual
	BG	No	No	Single publication
Number of m^2 per building age	SC	Yes	Yes	Biannual
	BG	No	No	Single publication
Number of m^2 per building size	–	–	–	–
Number of m^2 per climate zone	IDAE	No	No	Unspecified
	SC	Yes	Yes	Biannual
	AC	Yes	Yes	Unspecified
	VC	Yes	Yes	Unspecified
	GC	Yes	Yes	Unspecified
Annual energy consumption per building type	IDAE	Yes	–	Annual
	MITMA	No	–	Every three years
	EUSTAT	Yes	–	Annual
Annual energy consumption per end use	IDAE	Yes	–	Annual
	MITMA	No	–	Every three years
Number of energy performance certificates (EPCs) per building type	MITERD	No	No	Annual
	AOD	Yes	No	In Real Time
	BG	No	No	Biannual
Number of energy performance certificates (EPCs) per energy class	MITERD	No	No	Annual
	AOD	Yes	No	In Real Time
	BG	No	No	Biannual
	GeoEuskadi	No	No	Unspecified
Number of nearly zero-energy buildings (nZEBs) per building sector	Zebra 2020	No	Yes	Unspecified
m^2 of nearly zero-energy buildings (nZEBs) per building sector	–	–	–	–

(continued)

Table 4 (continued)

Indicator	Source	Data processability	Georeferencing	Data update frequency
Annual percentage of renovated buildings per renovation type	INE	Yes	–	Decennial
	MITMA	Yes	–	Annual
	IAEST	Yes	–	Decennial
	EUSTAT	Yes	–	Unspecified
Annual percentage of renovated buildings per building sector—residential/ non-residential	INE	Yes	-	Decennial
	MITMA	Yes	-	Annual
	IAEST	Yes	–	Decennial
	EUSTAT	Yes	–	Every five years
Renovated m^2 per building type	–	–	–	–
Renovated m^2 per building size	–	–	–	–
Renovated m^2 per building age	–	–	–	–
Total and annual proportion of buildings undergoing deep and nZEB renovation	Zebra 2020	Yes	Yes	Unspecified
	INE	Yes	No	Decennial
	IAEST	Yes	No	Unspecified
	EUSTAT	Yes	No	Decennial
Energy savings from deep renovations	–	–	–	–
m^2 of renovated public buildings per building type	–	–	–	–
m^2 of renovated public buildings per building size	–	–	–	–
m2 of renovated public buildings per climatic zone	–	–	–	–
Number, Total floor area, Percentage of buildings in lowest energy classes	MITERD	No	No	Annual
	AOD	Yes	No	In real time
	BG	No	No	Biannual
	GeoEuskadi	No	No	Unspecified

(continued)

Table 4 (continued)

Indicator	Source	Data processability	Georeferencing	Data update frequency
Percentage of rented dwellings with EPCs below a certain performance level	Alokabide	No	No	Single publication
	Etxebide	No	Yes	Unspecified
Energy poverty indicators: Percentage of people affected by energy poverty	MITERD	No	No	Every five years
Energy poverty indicators: Proportion of disposable household income spent on energy	INE	Yes	No	Annual
Energy poverty indicators: Arrears on utility bills	MITERD	No	No	Every five years
Energy poverty indicators: Population living in inadequate dwelling conditions or with inadequate heating and cooling	INE	Yes	No	Annual
	MITERD	No	No	Every five years
Number of buildings equipped with building energy management systems (BEMSs) or similar smart systems per building type (focus on non-residential)	–	–	–	–
Citizens participating in energy communities	–	–	–	–
Number of graduated students from university courses with focus on energy efficiency and related smart technologies	MU	Yes	No	Annual
	GA	Yes	No	Annual
	EUSTAT	Yes	No	Annual

(continued)

Table 4 (continued)

Indicator	Source	Data processability	Georeferencing	Data update frequency
Number of graduated students from professional/technical training (EPC certifiers, HVAC inspectors, etc.)	MEFP	Yes	No	Annual
	Vocational Training Observatory	No	No	Annual
	GA	No	No	Every three years
	EUSTAT	Yes	No	Annual
Number of installers skilled in new technologies and working practices	MINECO	Yes	No	Daily
	MINCOTUR	Yes	No	Unspecified
	GA	No	No	Every three years
	GB	No	No	Unspecified
Participation of national universities in international scientific research projects on energy efficiency in buildings-related topics	UNIZAR	No	No	Annual
	EHUrOPE	No	No	Annual
Reduction in energy costs per household (average)	MITMA	No	No	Every three years
	BG	No	No	Single publication
Decrease in energy poverty	MITERD	No	No	Every five years
Actual energy savings achieved	3R	No	No	Single publication
Average/aggregate indoor air quality indices (IAQIs)	INE	Yes	No	Annual
	IAEST	Yes	No	Unspecified
	GA	No	Yes	In Real Time
	BG	No	Yes	In Real Time
Thermal comfort index (TCI)	EPOV	Yes	No	Annual
	INE	Yes	No	Annual
	MITERD	No	No	Single publication
Cost of avoided illnesses	IEA	No	No	Single publication
	INE	Yes	No	Every five years
	MISAN	Yes	No	Annual

(continued)

Table 4 (continued)

Indicator	Source	Data processability	Georeferencing	Data update frequency
	IREC	No	No	Single publication
	EUSTAT	Yes	No	Biennial
Reduction on whole life carbon	–	–	–	–
Disability adjusted life year (Daly)/ Quality adjusted life year (QALY) improvements attributable to improvement of building stock and living conditions	Eurostat	Yes	No	Annual
	INE	Yes	No	Unspecified
	MISAN	Yes	No	Single publication
Labor productivity gains from better working environment and improved living conditions	–	–	–	–
Reduction of emission	3R	No	No	Single publication
Number of jobs created per EUR million invested in the sector	INE	Yes	No	Quarterly
	IAEST	Yes	No	Decennial
	EUSTAT	Yes	No	Annual
GDP increase in the building sector	Eurostat	Yes	No	Unspecified
	INE	Yes	No	Quarterly
	IAEST	Yes	No	Unspecified
	EUSTAT	Yes	No	Annual
Percentage of energy imports for the member state	Eurostat	Yes	No	Unspecified
	MITERD	Yes	No	Annual
	INE	No	No	Annual
	IAEST	No	No	Annual
	EUSTAT	Yes	No	Annual
Removal/ prevention of accessibility barriers for persons with disabilities	3R	No	No	Single publication
	INE	Yes	No	Decennial
	IAEST	No	No	Decennial

(continued)

Table 4 (continued)

Indicator	Source	Data processability	Georeferencing	Data update frequency
	EUSTAT	Yes	No	Decennial
	BHO	No	No	Single publication
Expected energy saving per building sector and type	MITERD	No	–	Single publication
	MITERD	No	–	Single publication
	A3e	No	–	Single publication
	GA	No	–	Single publication
	BG	No	–	Single publication
Expected reduction in health costs attributable to energy efficiency measures and improved air quality	IREC	No	No	Single publication
Cost-effectiveness of main renovation measures per building type	–	–	–	–
Cost-effectiveness of main renovation measures per climatic zone	—	–	–	–
Public incentives for deep renovation	MH	No	No	Annual
	BG	No	No	Annual
Public and private investments in deep renovations	MH	Yes	No	Daily
	BG	No	No	Annual
Public investments in policy addressing the issues mentioned (split incentives, energy poverty, etc.)	–	–	–	–
Public and private investments in smart technologies (including smart grids)	–	–	–	–

(continued)

Table 4 (continued)

Indicator	Source	Data processability	Georeferencing	Data update frequency
Budget of national research programs in the field of building energy efficiency	MH	Yes	No	Annual
	GA	No	No	Annual
	BG	No	No	Annual
Public investments as percentage of total investment in energy saving	MH	Yes	No	Annual
	GA	No	No	Annual
	BG	No	No	Annual
Public–private partnership initiatives	–	–	–	–
Investment in energy efficiency renovations on the public building stock	–	–	–	–
One-stop-shop initiatives in place	CSCAE	No	No	Unspecified
	BG	No	No	Unspecified
Awareness raising initiatives (number, target audience reached, target audiences taking action)	MITMA	–	–	–
	IDAE	–	–	–
	OMR	–	–	–
	3R	–	–	–
	GBCe	–	–	–
	GA	–	–	–
	BG	–	–	–
	Others	–	–	–
Number of integrated/ aggregated projects	-	–	–	–

Legend: 3R: 3R City Observatory, A3e: Spain's Association of Energy Efficiency Companies, AC: Alava's Cadaster, AOD: Aragon Open Data, BG: Basque government, BHO: Basque Housing Observatory, CSCAE: Superior Council of Professional Colleges of Architects of Spain, EHUrOPE: EHU European Projects Office, EPOV: EU Energy Poverty Observatory, Eurostat: European Statistical Office, EUSTAT: Basque Institute of Statistics, GA: Government of Aragon, GBCe: Green Building Council Spain, GC: Gipuzkoa's Cadaster, IAEST: Aragon Institute of Statistics, IDAE: Spain's Institute for Energy Diversification and Savings, IEA: International Energy Agency, INE: Spain's National Institute of Statistics, IREC: Catalonia Institute for Energy Research, MEFP: Ministry of Education and Vocational Training, MH: Ministry of Finance and Civil Service, MINECO: Ministry of economic affairs and Digital Transformation, MINCOTUR: Ministry of Industry, MITERD: Ministry of Ecological Transition and Demographic Challenge, MISAN: Ministry of Health, MITMA: Ministry of Transport, Mobility and Urban Agenda, MU: Ministry of Universities, OMR: Municipal Renovation Observatory, SC: Spain's Cadaster, UNIZAR: University of Zaragoza, VC: Vizcaya's Cadaster, Trade and Tourism.

References

Arbulu, M., Gómez-Gil, M., González-González, F. J., Espinosa-Fernández, A.: Indicators and data in Spain for an overview of deep renovation of buildings. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 127-155. Springer Nature, Cham (2024a).

Arbulu, M., Gómez-Gil, M., Rueda-Esteban, M., Monzón-Chavarrías, M., Espinosa-Fernández, A.: Indicators and data in Spain regarding policies and measures for the mobilization of investments into the renovation of buildings. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 261-289. Springer Nature, Cham (2024b).

Beltrán-Velamazán, C., Gómez-Gil, M., López-Mesa, B.: Analysis of institutional frameworks of indicators to measure the effectiveness of building renovation policy and decarbonization progress in Europe. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 17-55. Springer Nature, Cham (2024a).

Beltrán-Velamazán, C., Arbulu, M., Gómez-Gil, M., Rueda-Esteban, M., Espinosa-Fernández, A., López-Mesa, B.: Indicators and data in Spain regarding an overview of worst performing segments of the national building stock, rented properties and energy poverty. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 157-178. Springer Nature, Cham (2024b).

European Commission: COMMISSION RECOMMENDATION (EU) 2019/786 of 8 May 2019 on building renovation. Official Journal of the European Union (2019: L 127), 34–79 (2019)

European Parliament: Energy performance of buildings (recast) Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (COM(2021)0802 – C9–0469/2021 – 2021/0426(COD)). Strasbourg (2023).

European Parliament, Council of the European Union: 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. Official Journal of the European Union (2018: L 156), 75–91 (2018).

Gómez-Gil, M., Etxebarria-Mallea, M., Arbulu, M., Oregi-Isasi, X., Espinosa-Fernández, A., Monzón-Chavarrías, M.: Indicators and data in Spain for an overview of the general characteristics of the national building stock. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 57-105. Springer Nature, Cham (2024a).

Gómez-Gil, M., Espinosa-Fernández, A., López-Mesa, B., Monzón-Chavarrías, M.: Indicators and data in Spain for an overview of the energy characteristics of the national building stock. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 107-126. Springer Nature, Cham (2024b).

Gómez-Gil, M., Arbulu, M., Rueda-Esteban, M., Monzón-Chavarrías, M., Beltrán-Velamazán, C., González-González, F. J.: Indicators and data in Spain regarding an overview of the capacities in the construction, energy efficiency and renewable energy sector. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 179-200. Springer Nature, Cham (2024c).

Gómez-Gil, M., Arbulu, M., Oregi-Isasi, X., Monzón-Chavarrías, M., Beltrán-Velamazán, C., González-González, F. J.: Indicators and data in Spain for an overview of actual energy savings and wider benefits of renovation of buildings. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 201-243. Springer Nature, Cham (2024d).

Gómez-Gil, M., Etxebarria-Mallea, M., Arbulu-Dudagoitia, M., Grijalba-Aseguinolaza, O., Espinosa-Fernández, A., Monzón-Chavarrías, M.: Indicators and data in Spain regarding evidence-based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 245-259. Springer Nature, Cham (2024e).

International Energy Agency: Energy Efficiency Indicators: Fundamentals on Statistics. International Energy Agency, Paris (2014).

NHS Institute for Innovation and Improvement: The Good Indicators Guide: Understanding how to use and Choose Indicators. NHS Institute for Innovation and Improvement, Coventry (2017).

New Approaches to Generate Data to Measure the Progress of Decarbonization of the Building Stock in Europe and Spain

Belinda López-Mesa, Carlos Beltrán-Velamazán, Marta Gómez-Gil, Marta Monzón-Chavarrías, and Almudena Espinosa-Fernández

Abstract The European Commission has initiated efforts to establish indicator frameworks for monitoring building renovation policies and the decarbonization progress of the building stock, to be developed by EU Member States. The chapter suggests that the use of emerging technologies can improve the quality and availability of data for this purpose, focusing on two specific technologies whose potential is explored for the case of Spain. These technologies are, on one hand, georeferencing and automated cross-referencing of existing data, and, on the other, the Digital Building Logbook (DBL). The results of the study show that georeferencing and automated cross-referencing applications include calculating solar potential and estimating energy production, consumption, and emissions using Urban Energy Models (UBEMs). The UBEM, applied to Spain, enables the collection of previously unavailable indicators, improving data availability and quality mainly in the subjects of 'An overview of the general characteristics of the national building stock' and 'An overview of the energy characteristics of the national building stock'. Examining the feasibility of collecting indicators through the DBL indicates that close to 69% of all necessary indicators for monitoring building renovation policies can be obtained. However, challenges in realizing DBL's full potential involve undefined tool models,

B. López-Mesa (✉) · C. Beltrán-Velamazán · M. Gómez-Gil · M. Monzón-Chavarrías · A. Espinosa-Fernández
Built4Life Lab, University of Zaragoza-I3A, 50018 Zaragoza, Spain
e-mail: belinda@unizar.es

C. Beltrán-Velamazán
e-mail: cbeltran@unizar.es

M. Gómez-Gil
e-mail: m.gomez@unizar.es

M. Monzón-Chavarrías
e-mail: monzonch@unizar.es

A. Espinosa-Fernández
e-mail: almudenaef@unizar.es

B. López-Mesa and X. Oregi (eds.), *Assessing Progress in Decarbonizing Spain's Building Stock*, Digital Innovations in Architecture, Engineering and Construction,
https://doi.org/10.1007/978-3-031-51829-4_12

owner awareness, funding uncertainties, regulatory alignment, and technical hurdles for large-scale implementation.

1 Introduction

While building renovation and decarbonization have been significant topics on the European political agenda since 2012, it is only recently that the European Commission (EC) has actively initiated efforts to create indicator frameworks for monitoring the effectiveness of building renovation policies and the decarbonization progress, as indicated in Chap. 1 of this book (López-Mesa et al. 2023). The utilization of indicators for assessing progress and policy effectiveness is a valuable instrument to ensure that building renovation policies are efficient, effective, and in harmony with overarching sustainability and climate objectives. It facilitates decision-making based on evidence, accountability, the attainment of long-term decarbonization goals, and it educates and involves the public in these significant initiatives (López-Mesa et al. 2023).

One of the key principles in the development of indicators is to ascertain the availability of existing data before initiating a costly data collection process (International Energy Agency 2014). Beltrán-Velamazán et al. (2023a), in Chap. 2 of this book, identified the subjects data collection should focus on first. These subjects follow next and have been developed in each of the chapters of this book:

- An overview of the general characteristics of the national building stock, in Chap. 3 (Gómez-Gil et al. 2023a).
- An overview of the energy characteristics of the national building stock, in Chap. 4 (Gómez-Gil et al. 2023b).
- An overview of deep renovation of buildings, in Chap. 5 (Arbulu-Dudagoitia et al. 2023a).
- An overview of worst performing segments of the national building stock, rented properties, and energy poverty, in Chap. 6 (Beltrán-Velamazán et al. 2023b).
- An overview of the capacities in the construction, energy efficiency and renewable energy sector, in Chap. 7 (Gómez-Gil et al. 2023c).
- An overview of actual energy savings and wider benefits of renovation of buildings, in Chap. 8 (Gómez-Gil et al. 2023d).
- Evidence-based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation, in Chap. 9 (Gómez-Gil et al. 2023e).
- Policies and measures for the mobilization of investments into the renovation of buildings, in Chap. 10 (Arbulu-Dudagoitia et al. 2023b).

The assessment of data availability and quality in Spain for the development of indicators within these subjects to measure the effectiveness of building renovation policy and the progress of decarbonization of the building stock, conducted by (Gómez-Gil et al. 2023f) in Chap. 11 of this book, reveals that there is great room for improvement in terms of data quality and availability. Only around 17% of the indicators are fully available, providing a strong foundation for evaluating and monitoring progress in certain areas. Another 41% are partially accessible, which means they can be developed, but additional data sources or refinement are necessary. Finally, the remaining 42% are unavailable, underscoring a significant need for improvements in data availability. On the other hand, georeferencing, a critical component for spatial analysis and geographic-based indicators, was found in only 9% of the data sources, suggesting room for enhancement in this aspect (Gómez-Gil et al. 2023f). Furthermore, a significant segment (54%) of data sources is updated at intervals of a decade, consists of single publication documents, or lacks specific update frequencies, and this issue in data update frequency can affect the efficiency of policy monitoring and evaluation, underscoring the necessity for more frequent and timely data updates (Gómez-Gil et al. 2023f).

The availability and quality of data depends on the subject of the indicator, as shown in Table 1, created from data in (Gómez-Gil et al. 2023f). The development of indicators associated with deep renovation and policies for the mobilization of investments were found to encounter the highest obstacles, as a great deal of these indicators are non-available. For other indicators, such as for those related to the general characteristics of the national building stock, there are more data available, however, many of their data sources have a very low frequency of updating given that they are published every ten years.

New emerging technologies have the potential to significantly enhance data availability and quality in various ways. For example, technologies such as Internet of Things (IoT) devices, sensors, and automated data collection tools can continuously gather real-time data, reducing the reliance on manual data entry and minimizing human error (e.g. Valinejadshoubi et al. 2021). Advanced analytics and big data tools can process large volumes of data quickly and efficiently, identify patterns and anomalies that might not be evident through traditional methods. The potential uses of these technologies in the context of reducing carbon footprints in buildings are extensive (Sandaruwan et al. 2023). Machine learning algorithms can improve data quality by detecting errors, inconsistencies, and outliers in datasets. They can also predict missing data values and impute them (e.g. Zhang et al. 2023). Technologies that facilitate the integration of data from diverse sources can enhance data quality by creating a more comprehensive and cohesive dataset (e.g. Anand and Deb 2023). Remote Sensing and Satellite Technology can provide valuable data for various applications, such as environmental monitoring and infrastructure assessment (e.g. Anand and Deb 2023). Government and industry-led open data initiatives can promote data sharing, increasing data availability for public and private sector use (e.g. Gómez-Gil et al. 2023g). Edge computing brings data processing closer to the data source, reducing latency and improving the availability of real-time data (e.g. Amadeo et al. 2023).

The objective of this chapter is to propose new approaches that can be useful to improve the availability and quality of data to develop indicators to measure the effectiveness of building renovation policies and the progress of decarbonization of the building stock in Europe, and to explore their potential.

Table 1 Number of indicators on building stock renovation and decarbonization, classified by subjects, whose data are collectable nowadays in Spain from existing sources. *Source* own creation from data in (Gómez-Gil et al. 2023f)

Subject	No. of indicators	Fully collectable	Partially collectable	Not collectable
An overview of the general characteristics of the national building stock	14	5	8	1
An overview of the energy characteristics of the national building stock	6	4	1	1
An overview of deep renovation of buildings	10	1	0	9
An overview of worst performing segments of the national building stock, rented properties and energy poverty	6	3	2	1
An overview of the capacities in the construction, energy efficiency and renewable energy sector	6	2	2	2
An overview of actual energy savings and wider benefits of renovation of buildings	14	4	7	3
Evidence based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation	2	1	1	0
Policies and measures for the mobilization of investments into the renovation of buildings	13	0	2	11

2 Methodology

The methodology followed in this chapter started with the selection of two novel approaches for data enhancement. These approaches have been studied in the context of one of the research projects of which this book is the result, project LocalREGEN-A (LocalREGEN 2023). The first one is the georeferencing and automatized cross-referencing of open data as a tool to generate enriched data. The second one is a government-led information repository, the Digital Building Logbook (DBL), promoted by the European Commission that will collect all the information that is generated along the life cycle of each building and will be connected to existing data sources in the different countries of the European Union (EU), to emerging European data sources, and to new technologies, such as smart monitoring, which is also being studied in the mentioned project.

Once the two main approaches were identified, the following steps followed to study the potential of georeferencing and automatized cross-referencing in the improvement of data availability and quality of the indicators:

- We first studied the regulation and initiatives on georeferencing and automatized cross-referencing in Europe and Spain as well as the existing data sources in Spain with georeferenced data on buildings.
- Then we identified the indicators whose data could be enhanced by means of georeferencing and automatized cross-referencing. Afterwards we selected one of them as case study to show an example in this book.
- This indicator was developed with the support of an Urban Building Energy Model (UBEM) that has been developed in the context of the research project LocalREGEN-A.

To study the potential of the government-led information repository name the Digital Building Logbook (DBL) the following steps were undertaken for this chapter:

- We first described the characteristics of the DBL by means of a literature review.
- Then we identified the indicators whose data will be possible to collect from data collected in the DBL.
- Third, we identified the data fields that the DBL should contain to allow it.

Finally, in this chapter conclusions are drawn regarding the potential of these two technologies in improving data quality and availability.

3 New Approaches

3.1 Georeferencing and Automatized Cross-Referencing of Open Data as a Tool to Generate Enriched Data

In the digital age, data has become an invaluable resource that drives decision-making, innovation, and societal progress. Open data, in particular, has emerged as a catalyst for transparency, collaboration, and innovation. Georeferencing and automatized cross-referencing of open data are pivotal tools in enhancing the value of available information by adding spatial context and interconnecting disparate datasets, transforming them into a coherent and interrelated source of information.

This subsection explores the significance of georeferencing and automatized cross-referencing as tools to generate enriched data. An application example is created to show the potential in the development of indicators to measure the effectiveness of building renovation policy and the decarbonization progress.

3.1.1 Georeferencing: Adding Spatial Context

Georeferencing is the process of associating data with geographic coordinates, allowing information to be placed on maps and analyzed in a spatial context. This spatial context allows the use of geographic information systems (GIS) helping to uncover patterns, relationships, and trends that might not be apparent when looking at data in isolation. Over time, these types of spatial analyzes have become crucial for a wide range of applications, from urban planning to environmental monitoring.

In the European context, there is a directive that is crucial in this topic, the Infrastructure for Spatial Information in the European Community (INSPIRE) Directive (European Parliament and the Council of the European Union 2007). It is based on the premise that geospatial information is fundamental for decision-making in a wide range of areas and was designed to establish a common framework for geospatial data at the European level with the aim of facilitating the exchange of geospatial information among EU Member States (MSs) and improving cooperation in the 34 spatial data themes which covers.

This directive establishes harmonized regulatory frameworks for the entire EU and establishes synchronized national Spatial Data Infrastructures (SDIs) that serve as centralized access points for geospatial data. These SDIs facilitate the search and access of geographic information, promoting cooperation and evidence-based decision-making through accurate and up-to-date geospatial data across the EU.

To achieve and measure the decarbonization objectives in Europe the INSPIRE Directive plays a crucial role in the European context of decarbonizing buildings for several reasons. On one hand, the standardization of the data and metadata across EU is essential for collecting, analyzing, and sharing data related to buildings, their energy performance, their carbon footprint and the renewable energy potential across borders. On the other hand, standardized data ensures consistency and comparability across different regions and countries, facilitating effective decarbonization strategies, supporting holistic approaches to decarbonization that consider regional and transnational factors.

Decarbonizing buildings requires detailed spatial analysis. Analyzing geospatial data related to buildings, such as their location, size, climate areas, and potential to generate renewable energy on-site is crucial for identifying areas with the greatest potential for energy efficiency improvements and renewable energy adoption.

Also mapping the energy performance of the building and the actual and potential energy efficiency supports the creation of maps and spatial visualizations, which can help policymakers, businesses, and citizens identify energy-efficient and energy-inefficient areas. This can lead to targeted decarbonization efforts where they are needed most.

In Spain, there are several databases containing georeferenced information about buildings. Some of the main databases georeferenced information in Spain include:

- The Spanish Cadaster. It is an administrative register with a fiscal origin, with an inventory of buildings and real estate properties. It contains physical, legal and economic information (General Directorate of the Cadaster 2023) covering the entire national territory except the Basque Country and Navarre. There are two main sets of information, georeferenced files and tabular files.

- Tabular files are not georeferenced and contain a lot of useful information with higher level of detail than georeferenced files. Part of this information is protected and cannot be widely accessed. It is important to highlight that the tabular information from the Spanish Cadaster can be downloaded by province using some forms on the Electronic Headquarters of the Cadaster website. This means that there is no direct application programming interface (API) for automated download, what would facilitate to easily and quickly update data and make large-scale analysis.
- INSPIRE Cadastral Mapping Services. A special mention deserves the INSPIRE service of the Spanish Cadaster. It offers the georeferenced Spanish Cadaster data in an automated way through the ATOM download service at the municipality level, with georeferenced information and with the structure indicated by the INSPIRE directive. It allows for automation of large-scale data analysis in a much more efficient way, however, the data they offer for each building is a summary of what is openly available in the cadaster.

• Spain's National Centre for Geographic Information (CNIG). It is a government agency responsible for the management, development, and dissemination of geospatial information in Spain. CNIG is responsible for the collection, storage, and management of a wide range of geospatial data, including topographic maps, land use data, geographic databases, Digital Elevation Models and aerial imagery and offers them in open access from its Download Center (Spain's National Geographic Institute 2023).
• Regional and municipal information sources. There is a wide variety of open information that is offered by regional or municipal entities, such as the portal 'Aragon Open Data' by the Government of Aragon or 'GeoEuskadi', an initiative of the Government of the Basque Country. However, the information is not always georeferenced and is not homogenized between different regions or municipalities, thus it cannot be analyzed on larger scales.

3.1.2 Automatized Cross-Referencing: Creating Data Synergy.

Cross-referencing open data from multiple sources is a crucial strategy to generate enriched information. By merging related datasets, the resulting information becomes more comprehensive and valuable. Automatized cross-referencing simplifies this process and ensures data synergy.

This cross-referencing is particularly relevant when dealing with open data, as it transforms disparate datasets into a coherent and interrelated source of information. This integration of datasets allows for a more holistic view of the subject matter, filter inconsistencies and errors, leading to higher data quality, enhancing the reliability and accuracy of the information. This combined information allows more elaborate analyzes to be carried out, revealing insights that were previously hidden and promoting transparency and accountability, giving rise to data-based actions for both public authorities and citizens.

In the EU, the leadership in promoting open data is a collaboration between the EU institutions, MSs and a wide range of stakeholders working together to foster transparency, innovation, and access to information. The European Commission, through its various directorates-general and expert groups, plays a central role in coordinating and guiding these efforts at EU level.

In this context, there are several directives that play a key role in the development of this open data infrastructure. The aforementioned INSPIRE directive (European Parliament and the Council of the European Union 2007) focuses on geographic information related to the environment and spatial planning, the Public Sector Information (PSI) Directive (European Parliament and the Council of the European Union 2013), repealed by the Directive 2019/1024 on open data and the re-use of public sector information (European Parliament and the Council of the European Union 2019), encourages the re-use of public sector information, including open data. The European strategy for data (European Commission 2020b) is currently being developed with the Data Act (European Commission 2022) a key pillar of the European strategy for data laying down harmonized rules on fair access to and use of data.

The advance of these European regulations and their transposition into the laws of the member countries has led to significant progress in the quantity and accessibility of data. For example, the EU Open Data Portal and national open data portals initiatives offer a one-stop shop for discovering and accessing open data sets that greatly facilitates access to information.

In the Spanish context, the Open Data Initiative of the Government of Spain (Ministry of economic affairs and Digital Transformation 2023) provides a broad repository with access to open data provided by multiple public entities of different levels, greatly facilitating access to the data.

3.1.3 Applications and Benefits

The utilization and advantages of georeferencing and automated cross-referencing of open data are extensive and have wide-ranging implications. These techniques find various applications, in the particular context of assessing the effectiveness of building renovation policies and monitoring progress in decarbonization, which are presented next.

One of these applications is in the field of renewable energy, particularly in the calculation of solar potential on building roofs. This application is especially significant as it directly contributes to one of the mandatory indicators within the Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (European Parliament 2023), the 'Share of renewable energy in the building sector: on-site'. This indicator holds key importance in assessing a building's capacity to autonomously generate electricity from renewable sources. This calculation is key for the EU as it strives to advance its renewable energy goals and georeferencing and data integration are relevant tools in addressing this challenge. As discussed in Beltran-Velamazan et al. (2021), it is possible to generate 3D models of neighborhoods and cities automatically and use them to calculate the photovoltaic potential on roofs, capitalizing on the georeferencing capabilities enabled by openly available data and Geographic Information System (GIS) tools. These models offer a multitude of benefits. Firstly, they allow for the accurate assessment of a building's solar energy generation potential, taking into account factors such as building orientation, shading, and local climate conditions. Additionally, the use of 3D models offers a higher degree of precision and realism, as they consider the three-dimensional aspects of buildings and their surroundings, resulting in more reliable estimates of solar energy potential for smaller areas than the 2D models. Additionally, 3D models offer accurate analysis with low computing costs and times, being suitable for urban scales.

Another possible application of georeferencing and automatized cross-referencing is the estimation of energy production, consumption and associated emissions. According to Beltran-Velamazan et al. (under review) it is possible, for example, to develop Urban Energy Models (UBEMs) on a national scale in Spain using openly available data sources. UBEMs are computational energy models used to analyze and simulate energy production, consumption and emissions within urban areas for multiple energy-driven applications, for instance, energy planning, energy supply–demand calculation, retrofit analysis, forecasting, renewable energy impact, emission reduction, and optimization (Ali et al. 2021).

Within the context of the research project of which this book is a result, we developed an UBEM of the country of Spain following the methodology described in (Beltran-Velamazan et al. under review). The model is named EPC-based national-scale UBEM. It combines building information from various sources: the Spanish tabular cadaster, the INSPIRE cadaster, the regional registries of Energy Performance Certificates and others, and leverages georeferencing capabilities. This UBEM has multiple applications useful for the energy diagnosis of national building stocks and to establish national renovation trajectories in Spain and its different regions. For this chapter, we studied what indicators, among those proposed in this book, can be developed with the EPC-based national-scale UBEM developed for Spain. The results can be found in detail in Table 4 in Appendix A, and are summarized in Table 2. As can be observed, all the indicators under categories 'An overview of the general characteristics of the national building stock', 'An overview of the energy characteristics of the national building stock' can be obtained. Furthermore, certain additional indicators from other categories are obtainable, including the indicators 'Number, total floor area, percentage of buildings in lowest energy classes', 'Reduction of emissions', and 'Expected energy saving per building sector and type'.

As an example of the enhanced data this model is capable of generating, we developed for this chapter one of the indicators that could only be partially developed using the open data sources currently available in Spain, as discussed in Chap. 6 of this book (Beltrán-Velamazán et al. 2023b). The indicator is 'Number, total floor area, and percentage of buildings in lowest energy classes'. In Chap. 6, we found that the only information available is the percentage of certified new and existing buildings in

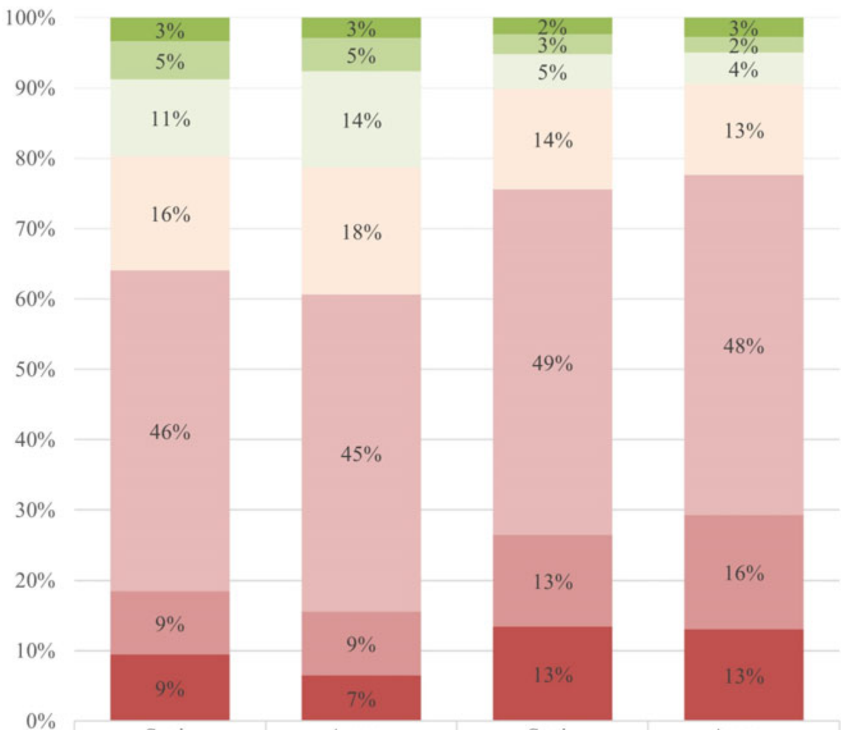
Table 2 Number of indicators on building stock renovation and decarbonization, classified by subjects, that are collectable using the EPC-based national-scale UBEM for Spain (Beltran-Velamazan et al. under review). *Source* own creation

Subject	No. of indicators	Collectable through data from EPC-based national-scale UBEM	
An overview of the general characteristics of the national building stock	14	14	0
An overview of the energy characteristics of the national building stock	6	6	0
An overview of deep renovation of buildings	10	0	10
An overview of worst performing segments of the national building stock, rented properties and energy poverty	6	1	5
An overview of the capacities in the construction, energy efficiency and renewable energy sector	6	0	6
An overview of actual energy savings and wider benefits of renovation of buildings	14	1	13
Evidence based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation	2	1	1
Policies and measures for the mobilization of investments into the renovation of buildings	13	0	13

the lowest energy classes. This percentage information is interesting, but it does not allow us to define with great precision the real size of the decarbonization challenge, since for this, we would need to know the square meters that should be decarbonized as a priority. However, with the georeferenced EPC-based national-scale UBEM, it becomes feasible to generate all the total floor area of certified buildings and building units in the worst performing segments in Spain and its regions (corresponding to the energy letter E, F, and G) and extrapolate this data to estimate the total floor area to renovate in Spain. Furthermore, the data are not contingent on periodic ministry publications, as the construction of UBEMs can be automated taking real time data from the open sources.

Figure 1 shows the total floor area of certified buildings and the complete buildings certified in Spain and in the region of Aragon in each of the energy classes, and the percentage they represent. The obtained data reveals a notable concentration of building stock in the least favorable energy classes (E, F, and G) at present. These categories encompass 64% of Spain's certified surface area and 75% of fully certified buildings. In Aragon, a comparable scenario exists, with 61% of the certified surface area and 77% of fully certified buildings falling into these energy classes.

The UBEM model allows us to obtain the quantity of buildings and their corresponding square footage in Spain and its regions, excluding those of Navarra and the



	Spain	Aragon	Spain	Aragon
	Certified area [m²]		Complete buildings certified [Number]	
Class A	16,571,040	535,363	14,745	425
Class B	26,166,558	874,545	17,693	354
Class C	53,125,350	2,532,594	30,555	694
Class D	79,163,902	3,336,175	90,154	2,009
Class E	222,418,253	8,333,756	307,597	7,534
Class F	43,749,279	1,683,230	81,647	2,526
Class G	46,150,747	1,203,279	84,321	2,042

Fig. 1 Distribution of square meters (m^2) and complete buildings certified by energy class in Spain and Aragon. *Source* own creation from data in (Beltran-Velamazan et al. under review)

Basque Country, as they are not accounted for in the Spanish Cadaster. This analysis reveals a total of 9,301,130 buildings in Spain, encompassing a built-up area of 3,851,560,898 square meters, and 300,554 buildings in Aragon, accounting for a total area of 132,161,106 m^2.

We can make an estimation of worst-performing buildings in Spain and Aragon by extrapolating the data from certified buildings to the entire building stock. By doing so, we estimated that 6,975,847 buildings and 2,464,998,974 square meters are in the worst energy classes in Spain. In Aragon, the estimation is that a total of 231,426 buildings and 80,008,274 square meters are in the worst energy classes. These findings underscore the considerable challenge of decarbonization of the building stock in Spain.

In summary, the development of UBEMs through georeferencing and automated cross-referencing of open data presents a transformative approach with wide-ranging applications, making it a powerful tool for addressing urban energy efficiency, sustainability, and the pursuit of a low-carbon future.

3.2 The Digital Building Logbook as a Tool to Increase Data Availability for the Development of Measurable Progress Indicators

In addition to improving data availability and quality using state-of-the-art technologies that leverage open data, we can further enhance data through government-led information repositories, like the Digital Building Logbook (DBL) promoted by the European Commission. To frame and understand the DBL, it is necessary, first and foremost, to introduce the Building Renovation Passport (BRP).

The concept of a building passport is not new, since it has been used in Europe for decades (Blum 2001, 2008) as a tool for collecting and exchanging information about buildings (Gómez-Gil et al. 2022a). However, it is in recent years that it has been increasingly focused on renovation (Fabbri et al. 2016, Sesana and Salvalai, 2018, Sesana et al. 2020), giving rise to the concept of the BRP. This is due to the increasing concern about accelerating building renovation pace. Despite the widely acknowledged benefits of renovation, especially of energy renovation, at various levels such as energetic, environmental, social, and economic, the annual renovation rate in Europe falls well below the recommended level by the European Commission, an annual rate of 3% (European Parliament and the Council of the European Union 2018). The BRP is positioned within this context as a tool that can assist in raising both the rate and quality of renovations.

The BRP was first introduced in European legislation through Directive (EU) 2018/844 (European Parliament and the Council of the European Union 2018), and although its structure was not specified in that text, there is sufficient consensus in the research field that this passport should consist of two parts: a DBL and a renovation roadmap.

Recently, the European Commission has recognized the potential of the passport if its model was unified at the scale of the entire EU. This aligns with the goal of creating a collaborative European environment where data is shared and compared among MSs to establish common improvement targets.

However, in parallel, the potential of the logbook to operate independently was also identified. In this regard, the European-scale DBL first emerged as a standalone tool through the Renovation Wave strategy (European Commission 2020a) published in October 2020. Subsequently, in 2023, the European DBL was officially defined in the Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast) as a "common repository for all relevant building data, including data related to energy performance such as energy performance certificates, renovation passports and smart readiness indicators, as well as on the life-cycle GWP and indoor environmental quality, which facilitates informed decision making and information sharing within the construction sector, among building owners and occupants, financial institutions and public authorities" (European Parliament 2023).

A great amount of data is generated during a building's life cycle, at the design and construction phases, during its use stage, when it is renovated and when its life comes to an end. The 2021 Proposal for a Directive of the European Parliament and of the Council on the Energy Performance of Buildings (Recast) (European Commission 2021) highlights the importance of collecting and managing these data in an effective way. In this sense, Gómez-Gil et al. (2023g) propose that the DBL should be linked to other existing data sources, such as national cadasters, Energy Performance Certificate (EPC) registries, technical inspections reports, or building renovation passports, as well as to new emerging sources in development, such as the Smart Readiness Indicator (SRI), the Environmental Product Declaration (EPD) or the Level(s) assessment framework. These will all be valuable sources of information that will feed data to the DBL in order to develop an interoperable, homogeneous, and coherent national database on energy efficiency. Additionally, the DBL can benefit from new technologies, such as the Internet of Things (IoT), Artificial Intelligence (AI), Building Information Modelling (BIM) or smart monitoring, what could help to considerably increase real-time data gathering (Gómez-Gil et al. 2022b).

After the DBL was defined, efforts are currently underway through initiatives such as European research projects and individual endeavors in the development of a DBL model. Despite the absence of a standardized model being adopted yet, there are similarities among the initiatives that have already emerged, particularly in the categories of data that the tool should gather. After examining four of the leading DBL initiatives to date—iBRoad-Log, ALDRAN BuildLog, X-Tendo Logbook, and the Study on the Development of a European Union Framework for Buildings' Digital Logbook-Gómez-Gil et al. (2022a) categorized them into: 'general and administrative information', 'construction information and materials', 'building technical systems and smart readiness', 'energy performance, operation and use' and 'finance'. Under these categories, data should be grouped to address the problem of data loss and unavailability due to the current asymmetric and outdated way of gathering data practiced by numerous stakeholders of the construction sector (Davidson and Skibniewski 1995).

According to the most known functionality identified for the DBL, those data would be mainly used to design the building's renovation roadmap, tailored to both the building and its users' needs. This way, by streamlining and customizing the renovation processes, it is expected to significantly increase the pace of these endeavors. However, Gómez-Gil et al. (2022a, 2022b, 2023a) point out new uses for the tool, such as gathering information to create building maintenance plans or to assess the progress of decarbonization in the building sector.

This latter issue is of particular relevance for collecting measurable indicators on the decarbonization of the construction sector, as indicated in Gómez-Gil et al. (2024). In said study, the main decarbonization objectives related to the building sector in Europe were identified and prioritized. Measurable progress indicators were assigned to these objectives, derived from various sources in the literature, including the 2023 proposal for the EPBD recast and European Recommendation (EU) 2019/786. Within those progress indicators, a selection and prioritization were made to establish the most relevant ones for the EU and Spain. For the EU, those stemming from the 2023 proposal for the EPBD recast were considered, and for Spain, they were identified through a survey conveyed among sector experts. Once the framework of the most relevant indicators for both cases was defined, an analysis was conducted to determine which of them could be obtained using the DBL. For those that could be collected through this tool, a study was carried out on what data the DBL should gather to make it possible.

In this chapter, we analyzed whether the indicators selected for development in this book (Beltrán-Velamazán et al. 2023a, 2023b) (Gómez-Gil et al. 2023a, 2023b, 2023c, 2023d, 2023e) (Arbulu et al. 2023a, 2023b) can be or not obtained using data collected in the DBL. Table 5 in Appendix A shows this information in detail. Table 3 shows the same information summarized, deploying the number of indicators that are collectable and non-collectable organized by subjects. This study is based on a previous analysis in which part of the indicators had already been examined (Gómez-Gil et al. 2024).

The analysis of the whole set of indicators proposed in this book (Table 3) shows that nearly 68% of all the indicators can be collected using data sourced from the DBL. As can be seen in the table, 100% of the indicators in subjects 'An overview of the general characteristics of the national building stock', 'An overview of the energy characteristics of the national building stock', and 'An overview of deep renovation of buildings' can be collected by means of the DBL. The high percentage is due to the fact that these categories gather indicators that solely refer to building characteristics. In subjects 'An overview of actual energy savings and wider benefits of renovation of buildings', 'Evidence based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation', and 'Policies and measures for the mobilization of investments into the renovation of buildings' the percentage is around 50%. In these categories, indicators related to buildings are mixed with others related to other aspects of the construction sector, which cannot be captured by the logbook. Finally, in categories 'An overview of worst performing segments of the national building stock, rented properties and energy poverty' and 'An overview of the capacities in the construction, energy efficiency and renewable energy sector' only 33% of the indicators could be collected using data from the DBL. This is due not only to the fact that some indicators do not pertain to building characteristics, but also because there may be data protection conflicts that hinder the collection and processing of data, as is the case with indicators related to energy poverty.

With the aim that the DBL contains the necessary information for the 68% of the indicators, it will be required that it includes the following data fields:

Table 3 Number of indicators on building stock renovation and decarbonization, organized by subjects, which would be collectable using data stored in the DBL classified by subjects. *Source* own creation

Subject	No. of indicators	Collectable through data from the DBL	Not collectable through data from the DBL
An overview of the general characteristics of the national building stock	14	14	0
An overview of the energy characteristics of the national building stock	6	6	0
An overview of deep renovation of buildings	10	10	0
An overview of worst performing segments of the national building stock, rented properties and energy poverty	6	2	4
An overview of the capacities in the construction, energy efficiency and renewable energy sector	6	2	4
An overview of actual energy savings and wider benefits of renovation of buildings	14	7	7
Evidence based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation	2	1	1
Policies and measures for the mobilization of investments into the renovation of buildings	13	6	7

- Date of construction
- Location of the building.
- Climate zone where the building is located
- Main use of the building
- Area of the building
- Number of dwellings
- Occupancy status
- Energy consumption (pre and post renovation) by source
- GHG emissions (pre and post renovation)
- Amount of on-site renewable energy generation and type
- Energy performance certificate
- Energy performance class
- Is this building renovated? If yes, year, type, and depth of the renovation
- Was the renovation process aggregated with that of other buildings to make the operation feasible?
- Is this building a nZEB?
- LCA Report (pre and post renovation)
- Is this building equipped with smart systems? If yes, which ones?
- Is this building fully accessible? If not, which barriers does it have?
- Total budget of the renovation

- Were public funds used in the renovation?
- District heating access
- Saving water strategies implemented in the renovation
- Monitoring data (Temperature, CO_2, RH)

It should be emphasized that the collection of these indicators through data from the DBL, in most cases, will not be carried out directly. Instead, mathematical operations or even the combination of different data fields from the tool's database are necessary to obtain the desired progress indicator. However, this involves a straightforward data processing task that can be swiftly accomplished through automatable computational processes or by using tools like Geographic Information Systems (GIS), which also enable the georeferencing of all data.

Nevertheless, for the logbook to fully develop the functionality of allowing the collection of decarbonization progress indicators, it would be necessary for all buildings to have a DBL. However, achieving this in the short term seems challenging due to a series of barriers. These include the current lack of a defined model of the tool, owners' lack of awareness about its benefits, debates about who should fund it, its alignment with international and national regulations, and the technical challenges of large-scale implementation.

4 Conclusions

The European Commission has proactively launched initiatives to establish indicator frameworks for monitoring the effectiveness of building renovation policies and the progress of decarbonization of the building stock (López-Mesa et al., 2023), which are to be developed by the EU MSs. Utilizing indicators to assess progress and policy effectiveness in building renovations is crucial for ensuring efficiency, effectiveness, alignment with sustainability goals, facilitating evidence-based decision-making, promoting accountability, supporting long-term decarbonization objectives, and engaging the public in these initiatives (López-Mesa et al., 2023). However, the development of these indicators poses a significant data collection challenge for member countries, for which they may not be adequately prepared.

In this chapter, we propose that emerging technologies have the capacity to notably improve data availability and quality, thereby aiding MSs in facing this challenging task, and we explored this through two technologies in particular, applied to the case of Spain, one of the MSs of the EU. One of these technologies is georeferencing and automated cross-referencing of open data. The second technology is the Digital Building Logbook (DBL), a government-led information repository endorsed by the European Commission.

On one hand, the chapter explored the applications and advantages of georeferencing and automated cross-referencing of open data in assessing building renovation policies and monitoring decarbonization progress through the use of indicators, and identified two applications: the calculation of solar potential on building roofs, and the estimation of energy production, consumption, and emission reductions using an EPC-based national-scale Urban Energy Model (UBEM) built from open data. This second application was further explored in the chapter. By employing this UBEM, it becomes possible to gather data to develop sixteen indicators that were only partially available and two indicators that were previously unavailable. This implies an important improvement in the availability of data, particularly significant in the areas of 'An overview of the general characteristics of the national building stock' and 'An overview of the energy characteristics of the national building stock'.

On the other hand, an analysis was conducted to determine the feasibility of obtaining the indicators selected for development in this book using data from the DBL. The comprehensive examination showcased that nearly 68% of all indicators can be collected from DBL data. By employing the DBL, it would be possible to generate data to develop 22 indicators that are nowadays only partially available and 20 indicators that are unavailable. Notably, subjects such as 'An overview of the general characteristics of the national building stock,' 'An overview of the energy characteristics of the national building stock,' and 'An overview of deep renovation of buildings' demonstrated a 100% collectability rate, given their focus on building characteristics. In subjects like 'An overview of actual energy savings and wider benefits of renovation of buildings,' 'Evidence-based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation' and 'Policies and measures for the mobilization of investments into the renovation of buildings,' the collectability rate hovers around 50%. These categories incorporate indicators related to both buildings and other aspects of the construction sector, limiting their capture by the DBL. In categories such as 'An overview of worst-performing segments of the national building stock, rented properties, and energy poverty' and 'An overview of the capacities in the construction, energy efficiency, and renewable energy sector,' only 33% of indicators could be collected due to data protection conflicts and non-building-related indicators.

The EPC-based national-scale UBEM holds immediate potential as it enriches existing data sources through georeferencing and automated cross-referencing. However, realizing the full potential of the DBL in collecting indicators for evaluating the effectiveness of building renovation policies and the decarbonization of the building stock encounters diverse challenges. These challenges encompass the absence of a clearly defined tool model, owners' lack of awareness regarding its benefits, uncertainty on who should fund the deployment of the tool, alignment issues with regulations, and technical obstacles in implementing it on a large scale. Achieving comprehensive DBL coverage in the short term is considered to be a challenging endeavor.

Acknowledgements This work was founded by the MINISTRY OF SCIENCE AND INNOVATION OF SPAIN, grant number PID2019-104871RB-C21/AEI/10.13039/501100011033 and by GOBIERNO DE ARAGÓN, grant number T37_23R: Built4Life Lab.

Appendix A

See Tables 4 and 5.

Table 4 Analysis of the indicators on building stock renovation and decarbonization, organized by subject, with a focus on their feasibility for collection through the use of the ECP-based national-scale UBEM developed for the country of Spain (Beltran-Velamazan et al. under review). *Source* own creation

Subject	Progress indicator	Is the indicator collectable through an UBEM?
Overview of the general characteristics of the national building stock	Number of buildings per building type	Yes
	Number of buildings per building age	Yes
	Number of buildings per building size	Yes
	Number of buildings per climate zone	Yes
	Number of dwellings per type of residential building	Yes
	Number of dwellings per type of building (Occupancy)	Yes
	Number of dwellings per building age	Yes
	Number of dwellings per size (Surface area)	Yes
	Number of dwellings per building size	Yes
	Number of dwellings per climate zone	Yes
	Number of m^2 per building type	Yes
	Number of m^2 per building age	Yes
	Number of m^2 per building size	Yes
	Number of m^2 per climatic zone	Yes
Overview of the energy characteristics of the national building stock	Annual energy consumption per building type	Yes
	Annual energy consumption per end use	Yes
	Number of energy performance certificates (EPCs) per building type	Yes

(continued)

Table 4 (continued)

Subject	Progress indicator	Is the indicator collectable through an UBEM?
	Number of energy performance certificates (EPCs) per energy class	Yes
	Number of nearly zero-energy buildings (nZEBs) per building sector	Yes
	m^2 of nearly zero-energy buildings (nZEBs) per building sector	Yes
Overview of deep renovation of buildings	Annual percentage of renovated buildings per renovation type	No
	Annual percentage of renovated buildings per building sector—residential/non-residential	No
	Renovated m^2 per building type	No
	Renovated m^2 per building size	No
	Renovated m^2 per building age	No
	Total and annual proportion of buildings undergoing deep and nZEB renovation	No
	Energy savings from deep renovations	No
	m^2 of renovated public buildings per building type	No
	m^2 of renovated public buildings per building size	No
	m^2 of renovated public buildings per climatic zone	No
An overview of worst performing segments of the national building stock, rented properties and energy poverty	Number, total floor area, percentage of buildings in lowest energy classes	Yes
	Percentage of rented dwellings with EPCs below a certain performance level	No
	Energy poverty indicators: Percentage of people affected by energy poverty	No
	Energy poverty indicators: Proportion of disposable household income spent on energy	No
	Energy poverty indicators: Arrears on utility bills	No

(continued)

Table 4 (continued)

Subject	Progress indicator	Is the indicator collectable through an UBEM?
	Energy poverty indicators: Population living in inadequate dwelling conditions or with inadequate heating and cooling	No
An overview of the capacities in the construction, energy efficiency and renewable energy sector	Number of buildings equipped with building energy management systems (BEMSs) or similar smart systems per building type (focus on non-residential)	No
	Citizens participating in energy communities	No
	Number of graduated students from university courses with focus on energy efficiency and related smart technologies	No
	Number of graduated students from professional/technical training (EPC certifiers, HVAC inspectors, etc.)	No
	Number of installers skilled in new technologies and working practices	No
	Participation of national universities in international scientific research projects on energy efficiency in buildings-related topics	No
An overview of actual energy savings and wider benefits of renovation of buildings	Reduction in energy costs per household (average)	No
	Decrease in energy poverty	No
	Actual energy savings achieved	No
	Average/aggregate indoor air quality indices (IAQIs)	No
	Thermal comfort index (TCI)	No
	Cost of avoided illnesses	No
	Reduction on whole life carbon	No
	Disability adjusted life year (Daly)/Quality adjusted life year (QALY) improvements attributable to improvement of building stock and living conditions	No

(continued)

Table 4 (continued)

Subject	Progress indicator	Is the indicator collectable through an UBEM?
	Labor productivity gains from better working environment and improved living conditions	No
	Reduction of emissions	Yes
	Number of jobs created per EUR million invested in the sector	No
	GDP increase in the building sector	No
	Percentage of energy imports for the member state	No
	Removal/ prevention of accessibility barriers for persons with disabilities	No
Evidence-based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation	Expected energy saving per building sector and type	Yes
	Expected reduction in health costs attributable to energy efficiency measures and improved air quality	No
Policies and measures for the mobilization of investments into the renovation of buildings	Cost-effectiveness of main renovation per building type	No
	Cost-effectiveness of main renovation measures per climatic zone	No
	Public incentives for deep renovation	No
	Public and private investments in deep renovations	No
	Public investments in policy addressing the issues mentioned (split incentives, energy poverty, etc.)	No
	Public and private investments in smart technologies (including smart grids)	No
	Budget of national research programs in the field of building energy efficiency	No
	Public investments as percentage of total investment in energy saving	No

(continued)

Table 4 (continued)

Subject	Progress indicator	Is the indicator collectable through an UBEM?
	Public–private partnership initiatives	No
	Investment in energy efficiency renovations on the public building stock	No
	One-stop-shop initiatives in place	No
	Awareness raising initiatives (number, target audience reached, target audiences taking action)	No
	Number of integrated/ aggregated projects	No

Table 5 Analysis of the indicators on building stock renovation and decarbonization, organized by subject, with a focus on their feasibility for collection through the use the DBL. *Source* own creation expanding upon data in Gómez-Gil et al. (2024)

Subject	Progress indicator	Is the indicator collectable through data from the DBL?
Overview of the general characteristics of the national building stock	Number of buildings per building type	Yes
	Number of buildings per building age	Yes
	Number of buildings per building size	Yes
	Number of buildings per climate zone	Yes
	Number of dwellings per type of residential building	Yes
	Number of dwellings per type of building (Occupancy)	Yes
	Number of dwellings per building age	Yes
	Number of dwellings per size (Surface area)	Yes
	Number of dwellings per building size	Yes
	Number of dwellings per climate zone	Yes
	Number of m^2 per building type	Yes

(continued)

Table 5 (continued)

Subject	Progress indicator	Is the indicator collectable through data from the DBL?
	Number of m^2 per building age	Yes
	Number of m^2 per building size	Yes
	Number of m^2 per climatic zone	Yes
Overview of the energy characteristics of the national building stock	Annual energy consumption per building type	Yes
	Annual energy consumption per end use	Yes
	Number of energy performance certificates (EPCs) per building type	Yes
	Number of energy performance certificates (EPCs) per energy class	Yes
	Number of nearly zero-energy buildings (nZEBs) per building sector	Yes
	m^2 of nearly zero-energy buildings (nZEBs) per building sector	Yes
Overview of deep renovation of buildings	Annual percentage of renovated buildings per renovation type	Yes
	Annual percentage of renovated buildings per building sector—residential/non-residential	Yes
	Renovated m^2 per building type	Yes
	Renovated m^2 per building size	Yes
	Renovated m^2 per building age	Yes
	Total and annual proportion of buildings undergoing deep and nZEB renovation	Yes
	Energy savings from deep renovations	Yes
	m^2 of renovated public buildings per building type	Yes

(continued)

Table 5 (continued)

Subject	Progress indicator	Is the indicator collectable through data from the DBL?
	m^2 of renovated public buildings per building size	Yes
	m^2 of renovated public buildings per climatic zone	Yes
An overview of worst performing segments of the national building stock, rented properties and energy poverty	Number, total floor area, percentage of buildings in lowest energy classes	Yes
	Percentage of rented dwellings with EPCs below a certain performance level	Yes
	Energy poverty indicators: Percentage of people affected by energy poverty	No
	Energy poverty indicators: Proportion of disposable household income spent on energy	No
	Energy poverty indicators: Arrears on utility bills	No
	Energy poverty indicators: Population living in inadequate dwelling conditions or with inadequate heating and cooling	No
An overview of the capacities in the construction, energy efficiency and renewable energy sector	Number of buildings equipped with building energy management systems (BEMSs) or similar smart systems per building type (focus on non-residential)	Yes
	Citizens participating in energy communities	Yes
	Number of graduated students from university courses with focus on energy efficiency and related smart technologies	No
	Number of graduated students from professional/technical training (EPC certifiers, HVAC inspectors, etc.)	No

(continued)

Table 5 (continued)

Subject	Progress indicator	Is the indicator collectable through data from the DBL?
	Number of installers skilled in new technologies and working practices	No
	Participation of national universities in international scientific research projects on energy efficiency in buildings-related topics	No
An overview of actual energy savings and wider benefits of renovation of buildings	Reduction in energy costs per household (average)	Yes
	Decrease in energy poverty	No
	Actual energy savings achieved	Yes
	Average/aggregate indoor air quality indices (IAQIs)	Yes
	Thermal comfort index (TCI)	Yes
	Cost of avoided illnesses	No
	Reduction on whole life carbon	Yes
	Disability adjusted life year (Daly)/Quality adjusted life year (QALY) improvements attributable to improvement of building stock and living conditions	No
	Labor productivity gains from better working environment and improved living conditions	No
	Reduction of emissions	Yes
	Number of jobs created per EUR million invested in the sector	No
	GDP increase in the building sector	No
	Percentage of energy imports for the member state	No
	Removal/ prevention of accessibility barriers for persons with disabilities	Yes
Evidence-based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation	Expected energy saving per building sector and type	Yes
	Expected reduction in health costs attributable to energy efficiency measures and improved air quality	No

(continued)

Table 5 (continued)

Subject	Progress indicator	Is the indicator collectable through data from the DBL?
Policies and measures for the mobilization of investments into the renovation of buildings	Cost-effectiveness of main renovation measures per building type	No
	Cost-effectiveness of main renovation measures per climatic zone	No
	Public incentives for deep renovation	Yes
	Public and private investments in deep renovations	Yes
	Public investments in policy addressing the issues mentioned (split incentives, energy poverty, etc.)	No
	Public and private investments in smart technologies (including smart grids)	No
	Budget of national research programs in the field of building energy efficiency	No
	Public investments as percentage of total investment in energy saving	Yes
	Public–private partnership initiatives	Yes
	Investment in energy efficiency renovations on the public building stock	Yes
	One-stop-shop initiatives in place	No
	Awareness raising initiatives (number, target audience reached, target audiences taking action)	No
	Number of integrated/aggregated projects	Yes

References

Ali, U., Shamsi, M. H., Hoare, C., Mangina, E., O'Donnell, J.: Review of urban building energy modeling (UBEM) approaches, methods and tools using qualitative and quantitative analysis. Energy and Buildings, 246, 111073. (2021). ISSN 0378–7788, https://doi.org/10.1016/j.enbuild.2021.111073

Amadeo M., Cicirelli F., Guerrieri A., Ruggeri G., Spezzano G., Vinci A.: When edge intelligence meets cognitive buildings: The COGITO platform. Internet of Things (Netherlands), 24, art. no. 100908. (2023). doi: https://doi.org/10.1016/j.iot.2023.100908

Anand A., Deb C.: The potential of remote sensing and GIS in urban building energy modelling. Energy and Built Environment. (2023). doi: https://doi.org/10.1016/j.enbenv.2023.07.008

Arbulu, M., Gómez-Gil, M., González-González, F. J., Espinosa-Fernández, A.: Indicators and data in Spain for an overview of deep renovation of buildings. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 127–155. Springer Nature, Cham (2024a).

Arbulu, M., Gómez-Gil, M., Rueda-Esteban, M., Monzón-Chavarrías, M., Espinosa-Fernández, A.: Indicators and data in Spain regarding policies and measures for the mobilization of investments into the renovation of buildings. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 261–289. Springer Nature, Cham (2024b).

Beltran-Velamazan, C., Monzón-Chavarrías, M., López-Mesa, B.: A Method for the Automated Construction of 3D Models of Cities and Neighborhoods from Official Cadaster Data for Solar Analysis. Sustainability 13(11):6028. https://doi.org/10.3390/su13116028 (2021).

Beltran-Velamazan, C., Monzón-Chavarrías, M., López-Mesa, B.: Estimación del potencial solar de las cubiertas y fachadas de ciudades desde modelos 3D y desde modelos GIS bidimensionales en España [Estimation of the solar potential of roofs and facades in cities using 3D models and two-dimensional GIS models in Spain]. In: International Congress on Energy Efficiency and Sustainability in Architecture and Urbanism EESAP, San Sebastián, Spain, (2022).

Beltrán-Velamazán, C., Gómez-Gil, M., López-Mesa, B.: Analysis of institutional frameworks of indicators to measure the effectiveness of building renovation policy and decarbonization progress in Europe. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 17-55. Springer Nature, Cham (2024a).

Beltrán-Velamazán, C., Arbulu, M., Gómez-Gil, M., Rueda-Esteban, M., Espinosa-Fernández, A., López-Mesa, B.: Indicators and data in Spain regarding an overview of worst performing segments of the national building stock, rented properties and energy poverty. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 157-178. Springer Nature, Cham (2024b).

Beltran-Velamazan, C., Monzón-Chavarrías, M., López-Mesa, B.: A new approach for national-scale Building Energy Models based on Energy Performance Certificates in European countries: the case of Spain. Heliyon 10(3), e25473 (2024). https://doi.org/10.1016/j.heliyon.2024.e25473.

Blum, A.: "Building passport"— A tool for Quality, Environmental Awareness and Performance in the Building Sector. In: Proceedings of the OECD/IEA Joint Workshop on the Design of Sustainable Building Policies, Paris, France (2001).

Blum, A.: Documentation, assessment and labelling of building quality. The German 'building passport' issue. In: Vreeker, R., Deakin, M., Curwell, S., (eds.) SUSTAINABLE URBAN DEVELOPMENT, vol. 3, pp. 156–173. Routledge Taylor & Francis Group. (2008).

Davidson, I.N., Skibniewski, M.J.: Simulation of Automated Data-collection in Buildings. Journal of Computing in Civil Engineering 9, 9–20 (1995).

European Commission: Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - A Renovation Wave for Europe - greening our buildings, creating jobs, improving lives (2020a).

European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS A European strategy for data. COM/2020/66 final. Brussels (2020b).

European Commission: Proposal for a Directive of the European Parliament and of the Council on the energy performance of buildings (recast). COM/2021/802. Brussels (2021).

European Commission: Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on harmonised rules on fair access to and use of data (Data Act) {SEC(2022) 81 final} - {SWD(2022) 34 final} - {SWD(2022) 35 final}. COM/2022/68 final. Brussels (2022).

European Parliament, Council of the European Union: 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. Official Journal of the European Union (2018: L 156), 75–91 (2018).

European Parliament, Council of the European Union: DIRECTIVE 2007/2/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 14 March 2007 establishing an Infrastructure for Spatial Information in the European Community (INSPIRE). Official Journal of the European Union (2007: L 108), 1–04 (2007).

European Parliament, Council of the European Union: DIRECTIVE 2013/37/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 June 2013 amending Directive 2003/98/EC on the re-use of public sector information. Official Journal of the European Union (2013: L 175), 1–8 (2013).

European Parliament, Council of the European Union: DIRECTIVE (EU) 2019/1024 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 20 June 2019 on open data and the re-use of public sector information (recast). Official Journal of the European Union (2019: L 172), 56–172 (2019).

European Parliament: Energy performance of buildings (recast) Amendments adopted by the European Parliament on 14 March 2023 on the proposal for a directive of the European Parliament and of the Council on the energy performance of buildings (recast) (COM(2021)0802 – C9–0469/2021 – 2021/0426(COD)). Strasbourg (2023).

Fabbri, M., de Groote, M., Rapf, O.: Building Renovation Passports—Customised Roadmaps towards Deep Renovation and Better Homes (2016).

General Directorate of the Cadaster: Help for Cadastral Electronic Site (SEC), https://www.catastro.meh.es/ayuda/english_ovc.htm, last accessed 2023/09/20.

Spain's National Geographic Institute: National Centre for Geographic Information, https://www.ign.es/web/ign/portal/qsm-cnig, last accessed 2023/09/20.

Gómez-Gil, M., Espinosa-Fernández, A., López-Mesa, B.: Review and Analysis of Models for a European Digital Building Logbook. Energies 15(6), 1994 (2022a). https://doi.org/10.3390/en15061994.

Gómez-Gil, M., Espinosa-Fernández, A., López-Mesa, B.: Contribution of New Digital Technologies to the Digital Building Logbook. Buildings 12, 2129 (2022b). https://doi.org/10.3390/buildings12122129.

Gómez-Gil, M., Etxebarria-Mallea, M., Arbulu, M., Oregi-Isasi, X., Espinosa-Fernández, A., Monzón-Chavarrías, M.: Indicators and data in Spain for an overview of the general characteristics of the national building stock. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 57-105. Springer Nature, Cham (2024a).

Gómez-Gil, M., Espinosa-Fernández, A., López-Mesa, B., Monzón-Chavarrías, M.: Indicators and data in Spain for an overview of the energy characteristics of the national building stock. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 107-126. Springer Nature, Cham (2024b).

Gómez-Gil, M., Arbulu, M., Rueda-Esteban, M., Monzón-Chavarrías, M., Beltrán-Velamazán, C., González-González, F. J.: Indicators and data in Spain regarding an overview of the capacities in the construction, energy efficiency and renewable energy sector. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 179-200. Springer Nature, Cham (2024c).

Gómez-Gil, M., Arbulu, M., Oregi-Isasi, X., Monzón-Chavarrías, M., Beltrán-Velamazán, C., González-González, F. J.: Indicators and data in Spain for an overview of actual energy savings and wider benefits of renovation of buildings. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 201-243. Springer Nature, Cham (2024d).

Gómez-Gil, M., Etxebarria-Mallea, M., Arbulu, M., Grijalba-Aseguinolaza, O., Espinosa-Fernández, A., Monzón-Chavarrías, M.: Indicators and data in Spain regarding evidence-based estimate of expected energy savings and of reduction of costs for health systems from buildings renovation. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 245-259. Springer Nature, Cham (2024e).

Gómez-Gil, M., Arbulu, M., Hernández-Minguillón, R. J., López-Mesa, B.: On the availability and quality of data in Spain for the development of progress indicators to measure building renovation policies effectiveness and the decarbonization of the building stock. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 291-316. Springer Nature, Cham (2024f).

Gómez-Gil, M., Sesana, M. M., Salvalai, G., Espinosa-Fernández, A., López-Mesa, B.: The digital building logbook as a gateway linked to existing national data sources: The cases of Spain and Italy. Journal of Building Engineering, 63(A), 105461 (2023g). https://doi.org/10.1016/j.jobe.2022.105461

Gómez-Gil, M., Espinosa-Fernández, A., López-Mesa, B.: A new functionality for the Digital Building Logbook: Assessing the progress of decarbonisation of national building sectors. Environmental Impact Assessment Review, 105, 107393 (2024). https://doi.org/10.1016/j.eiar.2023.107393

International Energy Agency: Energy Efficiency Indicators: Fundamentals on Statistics. International Energy Agency, Paris (2014).

LocalREGEN: http://www.localregen.net, last accessed 2023/09/20.

López-Mesa, B., Hernández-Minguillón, R. J., Gómez-Gil, M., Arbulu, M.: Assessing the effectiveness of building renovation policies and decarbonization progress: a review of European legislation. In: López-Mesa, B., Oregi-Isasi, X. (eds.), Assessing Progress in Decarbonizing Spain's Building Stock - Indicators and Data Availability, pp. 1–16. Springer Nature, Cham (2024).

Ministry of economic affairs and Digital Transformation: Open data initiative of the Government of Spain, https://datos.gob.es/en/?_33_redirect=%2Fweb%2Fguest%2Findex, last accessed 2023/09/20.

Sandaruwan, I.P., Janardana, J.A.B., Waidyasekara, A.: Data science applications for carbon footprint management in buildings: A systematic literature review. In: Proceedings of the 11th World Construction Symposium. (2023). Sri Lanka, pp. 446–459. Doi: https://doi.org/10.31705/WCS.2023.37

Sesana, M.M., Salvalai, G.: A review on Building Renovation Passport: Potentialities and barriers on current initiatives. Energy and Buildings 173, 195–205 (2018). https://doi.org/10.1016/j.enbuild.2018.05.027.

Sesana, M.M., Rivallain, M., Salvalai, G.: Overview of the available knowledge for the data model definition of a building renovation passport for non-residential buildings: The ALDREN project experience. Sustainability 12(2), 642 (2020). https://doi.org/10.3390/su12020642.

Valinejadshoubi M., Moselhi O., Bagchi A., Salem A.: Development of an IoT and BIM-based automated alert system for thermal comfort monitoring in buildings. Sustainable Cities and Society 66, 102602. (2021). ISSN 2210–6707, doi: https://doi.org/10.1016/j.scs.2020.102602

Zhang Z., Chen M., Zhong T., Zhu R., Qian Z., Zhang F., Yang Y., Zhang K., Santi P., Wang K., Pu Y., Tian L., Lü G., Yan J.: Carbon mitigation potential afforded by rooftop photovoltaic in China: Nature Communications, 14 (1), 2347. (2023). doi: https://doi.org/10.1038/s41467-023-38079-3