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Harnessing Open European Data for a Data-Driven Approach to Enhancing Decarbonization Measurement in the Built Environment

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***Abstract* – To achieve climate neutrality by 2050, decarbonizing the building sector is crucial, as it currently contributes 36 % of greenhouse gas emissions in Europe. Monitoring decarbonization progress is essential for evaluating our trajectory towards long-term goals, facilitating informed decision-making. However, monitoring this issue is currently unfeasible due to a lack of real data. Despite challenges in data gathering, directives like Infrastructure for Spatial Information in Europe (INSPIRE) and the Energy Performance of Buildings Directive (EPBD) promote open data accessibility. To overcome this barrier, this paper suggests using georeferencing and automated cross-referencing of open building data to obtain data to monitor progress towards decarbonization effectively. This approach materializes in the proposal of a national-scale Urban Building Energy Model (UBEM) for Spain, which leverages data from Energy Performance Certificates (EPC) and potentially Digital Building Logbooks (DBL) to enhance it. The study demonstrates the considerable potential of this approach, not only in characterizing the energy performance of Spanish buildings based on location, type, and age but also in estimating energy consumption, carbon dioxide emissions, monitoring renovation progress, assessing energy savings, and identifying energy-inefficient building segments. Finally, this study compares the information obtained using the proposed model with the set of progress indicators of the EPBD recast for the new national building renovation plans, concluding that the UBEM model manages to provide data to collect 29 of the progress indicators and, when combined with a DBL, it would be able to provide 59. This framework holds promise for replication in other MS, offering valuable insights into the decarbonization of the European building stock.**

***Keywords* – Building decarbonization; Digital Building Logbook (DBL); digital transformation strategy; Open Big Data; Renovation; Urban Building Energy Modelling (UBEM).**

Nomenclature		
BRP	Building Renovation Plan	–
CNIG	National Centre for Geographic Information of Spain	–
CTE HE	Spain regulation on Energy Savings	–
DBL	Digital Building Logbook	–
DPP	Digital Product Passport	–
EC	European Commission	–

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EPBD	Energy Performance of Buildings Directive	–
EPC	Energy Performance Certificate	–
EU	European Union	–
GHG emissions	Greenhouse gas emissions	$kgCO_2eq/(m^2·y)$
GIS	Geographic information system	–
GWP	Global Warming Potential	$kgCO_2eq$
INE	National Statistics Institute of Spain	–
LCA	Life Cycle Assessment	–
LTRS	Long-term Renovation Strategy	–
MS	Member State	–
NRPEC	Non-renewable primary energy consumption	$kwh/(m^2·y)$
PSI	Public Sector Information	–
UBEM	Urban Building Energy Model	–

1. Introduction

The building sector plays a crucial role in mitigating greenhouse gas (GHG) emissions within the European Union (EU). With buildings accounting for a substantial 40 % of final energy consumption and a consequential 36 % of GHG emissions across the EU, this sector stands as a decisive frontline in the fight against climate change [1]. These emissions arise from various stages of the buildings' lifecycle, including construction, usage, renovation, and demolition processes, highlighting the multifaceted nature of the challenge. Addressing the environmental impact of buildings is imperative for achieving the EU's ambitious climate targets and fostering a sustainable future.

The development of European directives such as the Energy Performance of Buildings Directive (EPBD) [2], strategies such as the Renovation Wave [3], and sets of packages such as the *Fit for 55* [4], which aims to promote the decarbonization of the built stock in the EU. Being able to measure their effects is a necessity to understand how they are performing, and what actions have worked better or worse depending on the initial scenario, allowing data-driven policy making.

With this objective, the 2018 EPBD recast [5] introduced the request to each Member State (MS) to include in their Long-term Renovation Strategy (LTRS) a roadmap with nationally established targets and measurable progress indicators, serving as a guiding framework to measure advancements in the decarbonization of the national building stocks and its main associated benefits.

In the 2019 Commission Recommendation 2019/786 [6], the European Commission (EC) proposed a set of 71 progress indicators based on 12 thematic areas. This set varied in the different proposals for the EPBD recast until the final EPBD version, which defines 76 mandatory and 45 optional indicators based on 7 major thematic areas.

Measuring these progress indicators has been a challenge addressed by the MS governments and scientific literature. However, there is still a long way to go. As discussed in [7], only 7 of the 29 LTRS updates presented in 2020 provided more than 10 aligned with the directive and fully developed indicators, with several MS, such as France [8], Lithuania [9], and Bulgaria [8][9][10] highlighting the difficulty of data collection and development of progress indicators. Data collection is essential to understand the effectiveness of the policies that are being employed and the type of incentive to apply [11], and an essential aspect of developing these indicators involves initially assessing available data resources before embarking on potentially costly data collection efforts [12].

In scientific literature, contributions to develop many of the themes of the mentioned progress indicators can be found. Balode *et al.* [13] examine the impact of energy policies in the National Energy and Climate Plans using indicators, and Annibaldi *et al.* [14] evaluate the scientific production of the MS and best practices on renewable energy policies. Aboltins *et al.* [15] highlight in their analysis the importance of a comprehensive evaluation of the multifaceted factors involved in the Energy Efficiency Policy Instruments. Krumins *et al.* [16] develop a framework for a method to optimize energy efficiency in buildings by using a 3D model in IDA ICE, based on real performance measurements, to balance indoor climate and energy consumption. Grinevičiūtė *et al.* [17] evaluates the Lithuania's pioneering model of virtual prosumers using remote solar energy parks, assessing its effectiveness in reducing building carbon footprints.

In order to develop progress indicators, it is key to have open data sources that reliably offer large amounts of information on a multitude of topics [18]. In the EU, there is a strong awareness of this importance, which is why directives and strategies such as the Public Sector Information (PSI) Directive [19], the INSPIRE Directive [20], and the Data Act [21] have been developed to promote the collection and provision of open data. Opening access to data generated by the public sector and establishing standards for geospatial data interoperability in the EU not only facilitates the measurement of progress indicators but also promotes an ecosystem of shared and collaborative information. Furthermore, by providing a clear and transparent legal framework for data management in the digital society, the EU encourages trust and participation in the use and reuse of data, enhancing society's ability to address current and future challenges in an informed and effective manner. Ultimately, these measures not only drive evidence-based decision-making but also strengthen democracy by empowering citizens with information that enables them to actively participate in the formulation and evaluation of public policies and in the transition towards a greener and more resilient economy, as highlighted in [22], involving citizens, particularly young people, in decision-making is essential for creating a more sustainable and democratic future.

Using emerging technologies in recent years, it is possible to leverage open data in a new and more powerful way. In particular, the potential of new technologies can be applied to collect and process data that allow the measurement of the aforementioned progress indicators. For instance, Internet of Things (IoT) devices, sensors, and automated data collection tools continuously gather real-time data, diminishing the need for manual input and mitigating human errors [23]. The digitization of information and the automation of processes allows the generation of more complex multi-criteria analyses, which combined with advanced analytics and big data tools quickly process large datasets, uncovering patterns and anomalies that traditional methods might overlook. The potential applications of these technologies are vast, particularly in reducing carbon footprints [24]. Machine learning algorithms sustain data quality by identifying errors, inconsistencies, and outliers, and predicting missing values within datasets [25]. Furthermore, technologies facilitating data integration from diverse sources contribute to creating more comprehensive datasets, enhancing overall data quality [26]. The use of technologies such as Geographic information system (GIS) allows information to be georeferenced, adding spatial variables to the analysis, which is crucial for addressing renovation in buildings [27]. Integrating it with other data such as LiDAR data allows for the generation of different models to understand the solar potential of rooftops [28], [29] and assess the integration of renewable energies. When combining GIS with data on the energy performance of buildings, Urban Building Energy

Models (UBEM) are created, enabling the analysis and optimization of energy usage within urban buildings and their surrounding environment.

UBEMs provide a comprehensive assessment of a building's energy performance by combining various data sources to create individualized models for groups of buildings. These models serve as a powerful toolkit for enhancing energy efficiency, sustainability, and resilience within buildings and urban infrastructure. Additionally, they aid in planning decarbonization strategies based on data-driven insights derived from the model. For example, it is used to calculate the most optimal envelope renovation solution from the point of view of Life Cycle Assessment (LCA) [30] or in the evaluation of the environmental impact of buildings in future scenarios due to climate change [31].

Alongside the utilization of emerging technologies for data collection, there are also tools currently in development that are poised to revolutionize the accessibility of buildings open data. These include passports like the Digital Product Passport (DPP), the Renovation Passport, and the Digital Building Logbook (DBL) [32]. The combination of these tools will ideally enable access to all relevant information about a building from a single gateway. This includes its general and administrative data, construction and systems characteristics, energy performance, smart readiness, future renovation roadmap, and all information regarding the materials and products comprising it. Similarly, this information can be utilized on a large scale, contributing to the collection of the mentioned progress indicators [18].

The development and combination of these tools will increasingly enable a higher level of understanding of the built environment and allow for the development of progress indicators at levels previously impossible.

With the aim of exploring the capabilities of the UBEMS and their synergy with one of these tools -the DBL- in enhancing the collection of decarbonization progress indicators, this research paper focuses on:

- The identification of progress indicators for the decarbonization of the built environment in Spain according to the 2024 EPBD recast.
- The analysis of the potential of European open big data to generate a model that allows measuring them.
- The analysis of the potential of the DBL in improving the model.

Thus, the novelty of this paper lies in the exploration of the contribution of Open Data-based UBEMs and DBLs in the development of progress indicators outlined in the recent 2024 EPBD to monitor the decarbonization of the building stock in Spain. For the first time, the capabilities of a model leveraging European open big data is explored to derive these indicators, marking a significant advancement in the assessment of the decarbonization progress of the built environment.

The study takes into account the latest version of the Spanish LTRS [33] and is conducted based on two models: one already existing, called 'National-scale EPC-based UBEM' [34], which combines different sources of information to generate insights about the energy performance of buildings and their main characteristics, and a theoretical one where the first model is complemented with the potential offered by the DBL that is being proposed by the EC.

2. METHODS AND METHODOLOGY

The methodology used in this research is divided into the following stages.

2.1. Identification of Progress Indicators Included in the 2024 EPBD Recast and Application to a Case Study Country

The decarbonization indicators included in the 2024 EPBD recast are the result of decades of research. These indicators extend beyond merely measuring the direct decarbonization of the building stock; they encompass a broad range of factors identified over time as critical to an effective transition. Key aspects include the age and types of buildings within the stock, renovation rates, energy poverty levels, or national initiatives promoting energy efficiency (such as minimum energy performance standards for both new and existing buildings), among others. This comprehensive approach ensures that decarbonization efforts effectively address the diverse dimensions necessary for sustained, long-term impact. In this paper, we first compiled the progress indicators on decarbonization collected in the EPBD recast. Specifically, we refer to the set of mandatory and optional indicators present in the Template for the national building renovation plans (BRP), which is found in Annex II of the aforementioned directive [35]. Once all the indicators were listed, we assessed whether they can be measured in the MS used as a case study, Spain, using data from the latest update of the Spanish LTRS [33]. This is because the LTRS are the predecessor of the future national BRPs [7], so alignment with them is to be expected.

2.2. Identification of Open Data Sources Available in the Case Study Country

Next, due to the lack of data identified in the Spanish LTRS for measuring all progress indicators, other data sources that can complement the LTRS are included in the analysis. These are open data sources stemming from the transposition of various European directives into Spanish legislation. The data sources used, the open data they provide, and the directives from which they are derived are summarized in Table 1.

TABLE 1. OPEN DATA IDENTIFIED FOR SPAIN

Open data identified for Spain	**Open data sources in Spain**	**European directive from which the data sources are derived**
Georeferenced buildings	Spanish INSPIRE cadastre	Directive 2007/2/CE (INSPIRE) [20]
Alphanumeric information about buildings (use, year of construction, number of floors, etc.)	Spanish cadastre	Directive 2003/98/CE [36] Directive 2007/2/CE (INSPIRE) [20]
Energy Performance Certificates (Non-renewable primary energy consumption and GHG emissions)	Databases of EPCs	Directive (EU) 2018/844 (EPBD) [5]
Georeferenced shape of municipalities and regions	National Centre for Geographic Information (CNIG)	Directive 2007/2/CE (INSPIRE) [20]
Population in the municipalities	National Statistics Institute of Spain (INE)	Regulation (EU) 2016/679 [37] Directive (EU) 2019/1024 [19]
Digital Terrain Models	National Centre for Geographic Information (CNIG)	Directive 2007/2/CE (INSPIRE) [20]
Climate zones	Spain regulation on Energy Savings (CTE HE)	Directive (EU) 2018/844 [5]

Starting from the information provided by these sources, different data analyses can be conducted to obtain the remaining progress indicators. The information from these sources is generally presented at the building scale; however, it can be aggregated into different scales and classifications to meet the requirements of the desired analysis.

2.3. Generation of the UBEM Model on a National Scale and Identification of the Indicators that Can Be Developed with the Model

Thirdly, we utilize a UBEM model generated by some of the authors and presented in [34] to analyse what new progress indicators can be obtained by using this type of model. This model is called national-scale EPC-based UBEM and was developed using the open data identified in the previous sections. It will help us consolidate all that data into a single gateway and process it to derive new indicators. Although the data are available at the building scale, they can be aggregated and combined to derive indicators at any scale.

Fig. 1 shows a summary of the model, input and output data.

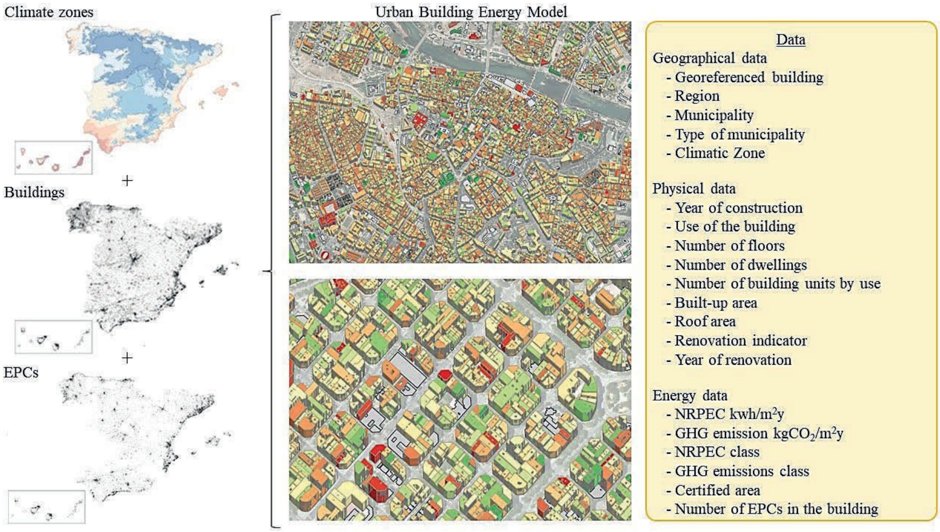

Fig. 1. Summary of model inputs and outputs.

This model takes the information sources listed in Table 1 and, based on the code published on GitHub [38], downloads, transforms, and analyses the data. The model uses as input data the geographic characteristics of the building's location (climate zone, region, municipality, and type of municipality) from the open geographic databases, the building's physical characteristics (year of construction, use, number of floors, etc.) from the Spanish cadastre, and the energy characteristics (non-renewable primary energy consumption and GHG emissions, etc.) from the Energy Performance Certificates (EPCs). Each data source is automatically processed to make it compatible with the rest of the information sources and is analysed to remove errors and anomalous values. The EPCs provide detailed information on the energy performance of buildings and are considered a valuable source for large-scale accurate estimates, and as mentioned in [39], EPCs represent a valuable information source for understanding the energy behaviour of the building stock, but it is necessary to carry out extensive analysis of the data to remove errors and unreasonable values that they sometimes contain. These combined data sources provide detailed information on the energy performance of buildings and are considered a valuable source for large-scale accurate estimates.

By relying on data from open data sources, the model offers a scalable and accurate solution for assessing building energy consumption in Spain and other European countries with limited computational resources, enabling the understanding of the physical characteristics of buildings based on publicly available data and the energy behaviour of certified buildings at a national scale. Using this model, the potential of these tools will be assessed to calculate progress indicators from the 2024 EPBD and measure the decarbonization process in the building stock.

2.4. Analysis of the Potential of the DBL to Enhance the Model to Obtain More Progress Indicators that Currently Cannot Be Obtained

As previously mentioned, the EC is taking steps to incorporate new information gathering tools for buildings. In this study, we investigate the contribution of the DBL, as ideally, it will serve as a gateway to access all other building information [40]. The DBL, highlighted in the 2024 EPBD recast [1], emerges as a central repository for all pertinent building data, encompassing EPCs, renovation passports, smart readiness indicators, and lifecycle Global Warming Potential (GWP) data. The primary objective of this tool, as per the directive, is to furnish information facilitating informed decisions regarding future interventions in buildings, while also enabling data sharing among various stakeholders in the construction sector, including public entities.

However, existing scientific literature already proposes additional functionalities for the DBL [40]. According to [18], these functionalities include collecting information on buildings to provide data which allow to measure the progress of the EU policy decarbonization objectives by means of progress indicators. The DBL is still in the design phase, and there is no official model yet. However, several initiatives have emerged from research projects and reports prepared for the EC [41]. In [18], it was identified that whether the DBL were to include the data fields proposed in these theoretical initiatives, it would already allow for a significant number of progress indicators to be measured. However, the developmental stage of the tool opens the door to the possibility of including specific data fields that would greatly contribute to measuring decarbonization progress, thus exponentially maximizing the initially envisioned potential of the tool [42].

For the purposes of this study, to account for the progress indicators that the DBL can help measure, the data fields proposed for the DBL in [18] and [43] have been utilized, which include: ‘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’, ‘EPC’, ‘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’. Based on these data fields, an analysis is conducted to determine whether their combination or simple calculations performed with them allow for the accounting of the previously identified progress indicators.

3. Results

Table 2 provides a summary of the set of indicators from the 2024 EPBD recast framework for the development of national BRPs, grouped by thematic areas and including the number of mandatory and optional indicators outlined in its framework. It also highlights the number of these indicators that Spain's LTRS has yet to develop. Furthermore, it indicates how many of these undeveloped indicators could be measured using the studied UBEM, and how many could be computed if data from the DBL were integrated into the model. The complete set of progress indicators, along with their relationship with Spain's LTRS, and the model both with and without the DBL contribution, can be found in the Annex Table A1.

As can be observed, out of the 121 progress indicators in the 2024 EPBD recast framework, the 2020 Spain's LTRS only covered 17 (14 %), leaving a large number currently undeveloped (86 %). Out of the 104 undeveloped indicators, 20 progress indicators can be obtained using the national-scale EPC-based UBEM, and if combined with the DBL, 50 additional indicators (41 %) could be obtained. This means that by combining the indicators currently collected by the Spanish LTRS with those gathered through the integration of the national-scale EPC-based UBEM and the DBL, it is possible to measure 55 % of the progress indicators from the 2024 EPBD recast framework for national BRPs. This would significantly improve the current landscape of data collection on the state of buildings.

TABLE 2. PROGRESS INDICATORS IN THE 2024 EPBD RECAST FRAMEWORK FOR NATIONAL BRPS

Progress indicators in the 2024 EPBD recast framework for national BRPs				
Subject	**Number of indicators (md-mandatory, op-optional)**	**Not developed in the LTRS of Spain**	**Not developed but collectable through the UBEM**	**Not developed but collectable through the UBEM+DBL**
(a) Overview of the national building stock	33 md + 29 op	52	16	28
(b) Roadmap for 2030, 2040, 2050	16 md + 7 op	19	0	0
(c) Overview of implemented and planned policies and measures	17 md + 9 op	26	2	20
(d) Outline of the investment needs, the budgetary sources and the administrative resources	4 md	1	0	0
(e) Thresholds of new and renovated zero-emission buildings, referred to in Article 11	4 md	4	0	0
(f) Minimum energy performance standards for non-residential buildings	1 md	1	1	1
(g) National trajectory for the progressive renovation of the residential building stock	1 md	1	1	1

Regarding the thematic areas of the progress indicators, the category where the combination of the national-scale EPC-based UBEM and the DBL can be most significant is ‘Overview of the National Building Stock’, where 28 new indicators (23 % of the total) can be measured. This is followed by ‘Overview of Implemented and Planned Policies and Measures’, which provides data to collect 20 new indicators (17 %). At the opposite end are categories ‘Outline of the investment needs, the budgetary sources and the administrative resources’ and ‘Thresholds of new and renovated zero-emission buildings, referred to in Article 11’, where these new tools do not provide data to measure more indicators.

When sorting by technologies, the national-scale EPC-based UBEM is particularly useful for collecting data that enables the measurement of indicators from the group ‘Overview of the national building stock’. In particular, its utility stands out in areas related to architectural and geographical data and the energy characteristics of the national built stock, with most of the indicators collectible by the model. This makes it a powerful tool for obtaining these indicators. However, concerning other topics, the tool is quite limited due to the lack of information on other fields or because the necessary information is protected data or cannot be obtained.

Regarding the contribution of the DBL, it complements the national-scale EPC-based UBEM, as it excels in collecting data for the category ‘Overview of implemented and planned policies and measures’, where the UBEM is not particularly useful. In addition, the DBL, by storing pre- and post-renovation information of buildings, will not only provide data characterizing the undertaken renovation interventions and their benefits but also offer real-time data on the evolution of the building stock. Specifically, it will enable tracking of achieved energy savings, a metric not directly obtainable through the UBEM. The DBL also stands out for its contribution to characterizing building systems and their energy sources, with particular emphasis on renewable energy sources and energy communities they are associated with. Additionally, by containing information on building materials and products, the DBL will provide necessary data for calculating building life cycle parameters, including GWP.

Regarding the open data sources of information, the main ones are those indicated in Table 1, with the Cadaster, the INE, and the CNIG standing out for their large quantity and quality of collected information, and the open EPC databases for providing a source of energy performance for buildings on a mass scale.

The UBEM model enables the calculation of various proposed progress indicators, such as the “Average primary energy use in kWh/(m^2·y) for residential buildings”. It can even provide greater detail than required by the 2024 EPBD, allowing, for instance, the analysis of building energy performance by climate zones to identify the worst-performing buildings. This level of specificity is highly valuable for effectively targeting renovation efforts. For example, Fig. 2 illustrates the model’s potential to support national-scale measurement of decarbonization of the building stock, showing the distribution of non-renewable primary energy consumption (NRPEC) in each climate zone of Spain.

The figure presents NRPEC values in kWh/(m^2·y) across various Spanish climate zones. Each box represents the middle 50 % (interquartile range, or IQR) of buildings’ energy consumption within a specific climate zone. The box's top and bottom edges show the 75th and 25th percentiles, respectively, indicating where most buildings fall in terms of energy use. The whiskers extend to the best and worst-performing buildings, while the line inside each box marks the median consumption for that climate zone, providing a benchmark between lower and higher energy-consuming buildings.

The results suggest that most buildings lie in the upper portion of each boxplot, indicating a generally inefficient building stock with high median energy consumption levels that would benefit from renovation. The notable gap between the upper range and the median underscores the potential for energy savings by improving efficiency toward the lower whiskers, which represent the most efficient buildings in each climate zone. The climate zones are ordered from warmest to coldest, and a comparison shows that NRPEC in colder climates is significantly higher than in warmer ones, highlighting a particularly strong potential for energy-saving through renovation efforts in these colder areas.

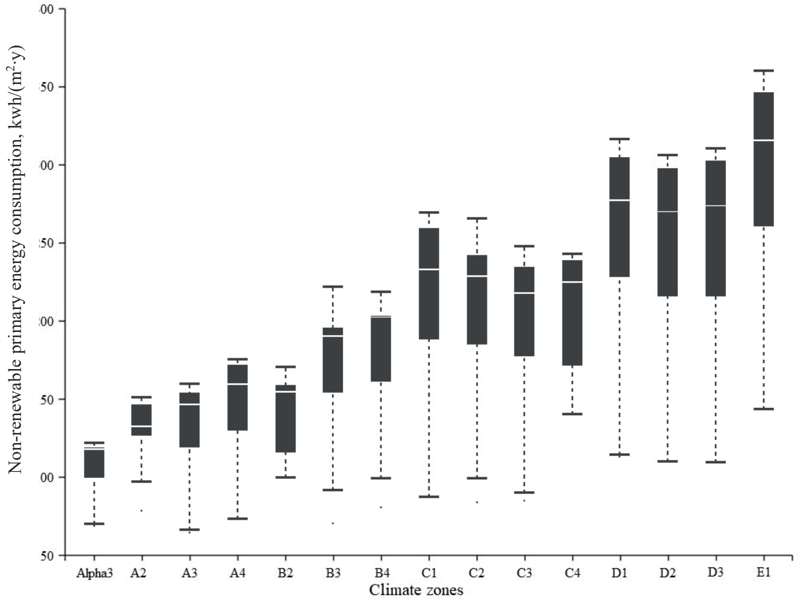

Fig. 2. Boxplot of the ranges of NRPEC (kwh/m^2·y) per climate zone in Spain.

4. CONCLUSIONS

Progress indicators are fundamental for tracking the progress of decarbonization in the built environment. In particular, they allow for the evaluation of the progress and benefits achieved through energy renovation, which is one of the cornerstones of the European policy to achieve climate neutrality by 2050. Therefore, being able to measure those indicators accurately across the multitude of areas they encompass is of great importance. Both governmental institutions that collect and publish information and researchers who can collaborate on new methodologies and support tools for their development are highly relevant in this challenge.

Open data sources play a crucial role in the development of progress indicators in the EU. Initiatives such as the PSI Directive, the INSPIRE Directive, and the Data Act are clear examples of the EU's commitment to promoting transparency, innovation, and sustainable development through access to and utilization of reliable and accessible data. These measures not only enhance decision-making at the political and business levels but also empower citizens by providing them with valuable information to understand and address current and future challenges.

Facing the challenge of collecting data for measuring decarbonization progress indicators is an overwhelming task, for which UBEMs have proven to be a valuable contribution by combining much of the information offered openly by various sources at a building-by-building scale. This allows the creation of a multicriteria model that integrates diverse information and enables the extraction of results on the broad topics covered by the progress indicators. As shown in Tables 2 and A1, for the case of Spain, out of the 121 indicators requested in the 2024 EPBD recast, a total of 29 progress indicators could be obtained with the EPC-based UBEM model, 20 of which are not provided in the current Spanish LTRS.

The UBEM model not only meets the established information requirements for the progress indicators but also provides an additional level of detail that allows for the identification of areas with the worst energy performance. This analytical capability can be helpful for developing data-driven policies that target renovation efforts towards the buildings that need it most, thereby optimizing resources and maximizing the impact of decarbonization initiatives. By focusing interventions on the least efficient buildings, significant improvements in non-renewable primary energy consumption and, consequently, in emission reductions can be achieved.

Additionally, as previously explained, the introduction of new tools enabling information retrieval at the product scale (such as DPPs) or at the building scale (such as renovation passports and DBLs) will significantly contribute to collect data for the measurement of a significant amount of additional progress indicators. Specifically, the contribution of the DBL has been studied, as it serves as a gateway for relevant data on buildings. The results indicate that through the DBL plus the national-scale EPC-based UBEM, 59 indicators can be obtained, with 50 (41 % of the total set of indicators) of them not provided in the current LTRS.

All of this demonstrates that, despite the significant contribution these tools make to data collection on the built environment, there is still a considerable effort needed to find new methods that provide more reliable and high-quality data about buildings and all related aspects. Furthermore, it is essential to promote the publication of this data as open data to maximize its utility.

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ANNEX

TABLE A1. LIST OF PROGRESS INDICATORS IN THE 2024 EPBD RECAST FRAMEWORK

Subject	**Progress indicator in the 2024 EPBD recast framework**	**Developed in the LTRS of Spain**	**Collectable through the UBEM**	**Collectable through the UBEM+DBL**
(a) Overview of the national building stock	No. of buildings and total floor area (m²): per building type	Yes	Yes	Yes
	No. of buildings and total floor area (m²): per energy performance class	No	Yes	Yes
	No. of buildings and total floor area (m²): nearly zero-energy buildings	No	Yes	Yes
	No. of buildings and total floor area (m²): worst-performing buildings	No	Yes	Yes
	No. of buildings and total floor area (m²): the 43 % worst-performing residential buildings	No	Yes	Yes
	No. of buildings and total floor area (m²): estimation of the share of buildings exempted pursuant to Article 9(6), p. (b)	Yes	Yes	Yes
	No. of energy performance certificates: per building type	No	Yes	Yes
	No. of energy performance certificates: per energy performance class	Yes	Yes	Yes
	Annual renovation rates: no. and total floor area (m²) per building type	Yes	Yes	Yes
	Annual renovation rates: no. and total floor area (m²) to nearly zero-energy and/or to zero-emission building levels	No	Yes	Yes
	Annual renovation rates: number and total floor area (m²) per renovation depth	No	Yes	Yes
	Annual renovation rates: number and total floor area (m²) public buildings	No	Yes	Yes
	Primary and final annual energy consumption (ktoe): per building type	Yes	Yes	Yes
	Primary and final annual energy consumption: per end use	No	No	Yes
	Energy savings: residential buildings	Yes	Yes	Yes
	Energy savings: non-residential buildings	Yes	Yes	Yes
	Energy savings: public buildings	No	No	Yes
	Average primary energy use in kWh/(m².y) for residential buildings	No	Yes	Yes
	Share of renewable energy in the building sector: for different uses	No	No	Yes
	Annual operational greenhouse gas emissions (kgCO2eq/(m²·y): per building type	No	Yes	Yes
	Annual operational greenhouse gas emission reduction (kgCO2eq/(m².y): per building type	No	Yes	Yes
	Market barriers and failures: split incentives	No	No	No
	Market barriers and failures: capacity of construction and energy sector	No	No	No

	Evaluation of the capacities in the construction, energy efficiency and renewable energy sectors	No	No	No
	Energy poverty: % of people affected by energy poverty	No	No	No
	Energy poverty: proportion of disposable household income spent on energy	No	No	No
	Energy poverty: population living in inadequate dwelling conditions or with inadequate thermal comfort conditions	No	No	No
	Primary energy factors: per energy carrier	No	No	Yes
	Primary energy factors: non-renewable primary energy factor	No	No	Yes
	Primary energy factors: renewable primary energy factor	No	No	Yes
	Primary energy factors: total primary energy factor	No	Yes	Yes
	Definition of nearly-zero energy building for new and existing buildings	No	No	No
	Cost-optimal minimum energy performance requirements for new and existing buildings	No	Yes	Yes
	No. of buildings and total floor area (m^2): per building age	Yes	Yes	Yes
	No. of buildings and total floor area (m^2): per building size	Yes	Yes	Yes
	No. of buildings and total floor area (m^2): per climatic zone	No	Yes	Yes
	No. of buildings and total floor area (m^2): demolition	No	No	No
	No. of energy performance certificates: per construction period	No	Yes	Yes
	Reduction in energy costs (EUR) per household (average)	No	No	Yes
	Primary energy use of a building corresponding to the top 15 % and the top 30 % of the national building stock	No	Yes	Yes
	Share of heating system in the building sector per boiler/heating system type	No	No	Yes
	Share of renewable energy in the building sector: on-site	No	No	Yes
	Share of renewable energy in the building sector: off-site	No	No	Yes
	Life cycle GWP ($kgCO2eq/m^2$) in new buildings: per building type	No	No	Yes
	Market barriers and failures: administrative	No	No	No
	Market barriers and failures: financial	No	No	No
	Market barriers and failures: technical	No	No	No
	Market barriers and failures: awareness	No	No	No
	Market barriers and failures: other	No	No	No
	Number of: energy service companies	No	No	No
	Number of: construction companies	No	No	No
	Number of: architects and engineers	No	No	No
	Number of: skilled workers	No	No	No
	Number of: one-stop shops	No	No	No
	No. of: SMEs in the construction/renovation sector	No	No	No

	No. of: renewable energy communities and …	No	No	Yes
	Projections of the construction workforce: retiring architects/engineers/workers	No	No	No
	Projections of the construction workforce: architects/ engineers/skilled workers entering the market	Yes	No	No
	Projections of the construction workforce: young people in the sector	No	No	No
	Projections of the construction workforce: women in the sector	No	No	No
	Overview and forecast of the evolution of prices of construction materials and national market developments	No	No	No
	Overview of the legal and administrative framework	No	No	No
(b) Roadmap for 2030, 2040, 2050	Targets for annual renovation rates: number and total floor area (m²): per building type	Yes	No	No
	Targets for annual renovation rates: nº and total floor area (m²): worst-performing buildings	No	No	No
	Targets for annual renovation rates: nº and total floor area (m²): the 43 % worst-performing residential buildings	No	No	No
	Information pursuant to Article 9(1): criteria to exempt individual non-residential buildings	No	No	No
	Information pursuant to Article 9(1): estimated share of exempted non-residential buildings	No	No	No
	Information pursuant to Article 9(1): estimation of equivalent energy performance improvements …	No	No	No
	Targets for expected primary and final annual energy consumption: per building type	Yes	No	No
	Targets for expected primary and final annual energy consumption: per end use	No	No	No
	Expected energy savings: per building type	No	No	No
	Targets for the increase in the share of renewable energy in accordance with Article 15a of Directive (EU) 2018/2001	No	No	No
	Numerical targets for the deployment of solar energy in buildings	No	No	No
	Targets for expected operational greenhouse gas emissions (kgCO2eq/(m².y)): per building type	No	No	No
	Targets for expected operational greenhouse gas emission reduction (%): per building type	No	No	No
	Expected wider benefits: % reduction of people affected by energy poverty	No	No	No
	The Member State's contribution to the Union's energy efficiency targets …	No	No	No

	The Member State's contribution to the Union's renewable energy targets …	No	No	No
	Targets for expected share (%) of renovated buildings: per building type	Yes	No	No
	Targets for expected share (%) of renovated buildings: per renovation depth	No	No	No
	Share of energy from renewable sources in the building sector	No	No	No
	Split between emissions …	No	No	No
	Targets for expected whole life-cycle greenhouse gas emission (kgCO2eq/(m².y) in new buildings: per building type	No	No	No
	Creation of new jobs	No	No	No
	Increase in GDP	Yes	No	No
(c) Overview of implemented and planned policies and measures	Policies and measures with regard to the following elements: (a) the identification of cost-effective approaches to renovation for different building types and climatic zones, …	No	No	Yes
	(b) national minimum energy performance standards pursuant to Article 9 …	No	Yes	Yes
	(c) the promotion of deep renovation of buildings, including staged deep renovation;	No	Yes	Yes
	(d) empowering and protecting vulnerable customers and the alleviation of energy poverty, …	No	No	No
	(e) the creation of one-stop shops or similar mechanisms …	No	No	Yes
	(f) the decarbonisation of heating and cooling, including through district heating and cooling networks…	No	No	Yes
	(g) prevention and high-quality treatment of construction and demolition waste …	No	No	Yes
	(h) the promotion of renewable energy sources in buildings…	No	No	Yes
	(i) the deployment of solar energy installations on buildings;	No	No	Yes
	(j) the reduction of whole life-cycle greenhouse gas emissions …	No	No	Yes
	(k) the promotion of district and neighbourhood approaches and integrated renovation programmes at district level …	No	No	Yes
	(l) the improvement of buildings owned by public bodies, …	No	No	Yes
	(m) the promotion of smart technologies and infrastructure for sustainable mobility in buildings;	No	No	Yes
	(n) addressing market barriers and market failures;	No	No	No
	(o) addressing skills gaps and promoting education, …	No	No	No
	(p) awareness raising campaigns and other advisory tools; and	No	No	No

	(q) promotion of modular and industrialised solutions for construction and building renovation.	No	No	Yes
	Policies and measures with regard to the following elements: (a) the increase in the climate resilience of buildings;	No	No	Yes
	(b) the promotion of the energy services market;	No	No	No
	(c) the increase in fire safety;	No	No	Yes
	(d) the increase in resilience against disaster risks, including risks related to intense seismic activity;	No	No	Yes
	(e) the removal of hazardous substances including asbestos;	No	No	Yes
	(f) accessibility for persons with disabilities;	No	No	Yes
	(g) the role of renewable energy communities …	No	No	Yes
	(h) addressing mismatches in human capacities; and	No	No	No
	(i) addressing the improvement of indoor environmental quality.	No	No	Yes
(d) … investment needs, …	total investment needs for 2030, 2040, 2050 (million EUR)	Yes	No	No
	public investments (million EUR)	Yes	No	No
	private investments (million EUR)	Yes	No	No
	budgetary resources	No	No	No
(e) Thresholds of new and renovated zero-emission buildings, …	operational greenhouse gas emissions thresholds of new zero-emission buildings;	No	No	No
	operational greenhouse gas emissions thresholds of renovated zero-emission buildings;	No	No	No
	annual primary energy use thresholds of new zero-emission buildings;	No	No	No
	annual primary energy use thresholds of renovated zero-emission buildings	No	No	No
(f) Minimum energy performance standards for non-residential buildings	maximum energy performance thresholds, pursuant to Article 9(1)	No	Yes	Yes
(g) National trajectory for the progressive renovation of the residential building stock	the national trajectory for the progressive renovation of the residential building stock, including the 2030 and 2035 milestones for average primary energy use in kWh/(m².y), pursuant to Article 9(2)	No	Yes	Yes