Development of the Whole Life Carbon baseline for buildings in Spain

Key aspects and recommendations for stakeholders

INDICATE

GBCe

UNIVERSIDAD DE SEVILLA

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This report outlines the political conclusions derived from the INDICATE-Spain project, based on the analysis of a broad number of synthetic or theoretical cases systematically developed to reflect the behaviour of Spanish building practices, contrasted with a smaller number of real cases carried out by the sector. For further context, the BPIE report, which analyses real cases collected by INDICATE Ireland, Czechia, and Spain, can be consulted. "BPIE (Buildings Performance Institute Europe) (2024). How to establish Whole Life Carbon benchmarks: Insights and lessons learned from emerging approaches in Ireland, Czechia, and Spain." Available at:
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Clarification on the use of INDICATE-ES results

The results of this project should be considered as a preliminary approch within a research project that created an initial reference framework and consolidated a reflection group around the methodology followed in the context of the project. Any use of the data/methodology outside the project context should be analysed based on the specific objective. The use of ratios for regulatory applications or in public tenders would require further refinement, clarification, and adjustment of certain aspects. This is important not only to ensure proper implementation, acceptance, and confidence from the sector but also to avoid potential inconsistencies with applicable regulations or standards.

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Acronyms

CPR	Construction Products Regulation
CEE	Energy Efficiency Certificate (Certificado de Eficiencia Energética)
CRCF	Carbon Removals and Carbon Farming
CSRD	Corporate Sustainability Reporting Directive
CTE	Technical Building Code (Código Técnico de la Edificación)
EED	Energy Efficiency Directive
EPBD	Environmental Performance of Buildings Directive
EPD	Environmental Product Declaration
ESG	Environmental, Social and Governance
GPP	Green Public Procurement
GHG	Greenhouse Gas
GWP	Global Warming Potential
INE	National Institute of Statistics (Instituto Nacional de Estadística)
LCA	Life Cycle Assessment
PNIEC	National Energy and Climate Plan (Plan Nacional de Energía y Clima)
SFRD	Sustainable Finance Disclosure Regulation
WLC	Whole Life Carbon

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1. Executive Summary

The INDICATE project aims to establish a **baseline for life cycle carbon emissions** for newly constructed residential and office buildings in Spain. In the absence of an official method, a proprietary open and automated methodology has been developed that can be updated to align with a future official methodology. It is designed as a transparent system that allows other projects to build on the lessons learned. The analysis methodology was co-created with the participation of a group of expert collaborators who validated the methodology and provided data.

The analysis is based on **synthetic and real data**. On the one hand, **126 LCAs (Life Cycle Assessments) of theoretical** or synthetic buildings allow for the construction of a range of values for each typology based on four variables: construction solution, data source, thermal resistance, and mechanical resistance by seismic zone. On the other hand, **53 LCAs of real buildings**, previously carried out by collaborators using different methods, hypotheses, software, and scopes, offer a representative sample of typologies, climates, and seismic zones, as well as of the values that can be obtained with existing methods, software and data. Both data sources allow for better understanding and cross-validation of the results. The box plot diagrams that display the results can help define a future progressive roadmap, by allowing for the visual identification of the worst-performing samples, which can be progressively limited. The results show that **the average values obtained for synthetic cases are higher than those of real cases**. Real cases show a range of results that clearly depends on the number of cases.

The data dispersion highlights the **need for an official harmonised methodology** and a default environmental database. **At this time, the synthetic data is regarded as more reliable**, harmonised according to a methodology validated by the collaborators and including a component list based on the Level(s) framework, with cradle-to-grave scope (A1-A5, B1-B5, C1-C4), separately quantifying benefits beyond the system (D). In any case, this is an initial approach in an iterative process of continuous data quality improvement. It will be necessary to collect building-level LCA data based on an official harmonised method that aligns the results of real and synthetic cases, providing a statistical framework that can be used for the future roadmap for the implementation of progressive limits.

Various functional equivalents are analysed to better compare the results between typologies, Table 1 summarises the most important values considering the gross floor area (GFA).

Table 1 - Summary of values obtained by typology and type of case (synthetic and real).

Kg CO_2 eq/m² Gross Floor Area (GFA)		Single-family detached house	Single-family row house	Multifamily houses < 3 floors	Multifamily houses > 3 floors	Multifamily houses Tower > 3 floors	Office	Parking	Total LCAs
Synthetic Cases	Range	570- 1.463	473- 1.114	634- 1.402	413- 919	393- 935	874- 1.499	128-464	
	Average value	1.005	794	1.024	672	666	1.177	334	
	n° of cases	18	18	18	18	18	18	18	126
	number of storeys	2	2	3	6	10	3	2	
Real cases	Range	402-811	596-171	290-842	205-1.587	348-822	266-1.061	-	
	Average value	564	542	523	769	544	605	-	
	n° of cases	5	10	6	21	4	7	-	53

The variables applied to the synthetic cases prove valid for generating ranges. The importance of data sources and specific product data (EPDs) is highlighted, as they will also assist manufacturers in decarbonising their products. The seismic zone has a significant influence on the results, a factor that should be considered when establishing future limits and from the initial reporting. Thermal resistance does not affect the results as much as the type of construction solution and its thermal mass, which is a key factor. In fact, the results obtained for Spain are not directly transferable to other countries, as the local construction tradition is adapted to a climate where outdoor temperatures are largely within the comfort zone, and a strategy based on thermal mass complements the thermal resistance of the building envelope.

The results show that the most impactful decisions are those made in the early stages of the project, affecting volume, typology, and basic decisions on structure and envelope. It is therefore important to incorporate LCA methodology as a design tool in the project's initial stages. To achieve efficient decarbonisation, it is essential to focus on the key aspects identified, especially considering that the product stage has fewer uncertainties and more data available.

The behaviour of real and synthetic data shows the same relative trends. Regarding typologies, terraced single-family houses have less impact per unit of surface than detached ones, due to a smaller envelope and a more compact configuration. In multifamily buildings, taller buildings have less relative impact than shorter ones, as the structure and envelope impacts are allocated over a larger surface area. An indicator based on heated surface area, which assigns the entire building's impact (including interior common areas) to the dwellings, allows for better comparison of the impact between different housing typologies. Moreover, when examining the per capita impact, detached single-family houses have a higher impact than multifamily houses, although this difference diminishes in terraced single-family houses, indicating the need to consider city-scale impacts. In summary, there is a need to report multiple indicators to accurately reflect the decarbonisation strategies of the building stock, especially as the trend is to build houses with increasingly larger areas per occupant.

The product stage (A1-A3) accounts for the highest percentage of embodied carbon, followed by replacements (B4). In B4, the set of impacts across all stages of the life cycle of new replacement products is included. B4 has a significant impact on products with more replacements, such as interior finishes and installations, so durability, design for disassembly, and adaptability will reduce the impact of these elements. As for the building elements, the structure and foundation, as well as the envelope, play a significant role in the distribution of impacts. Outdoor pavements also have a notable impact due to replacements. Replacing them with green areas not only contributes to decarbonisation but also provides other co-benefits such as health and climate resilience.

Spain is considering early implementation of the Energy Performance of Buildings Directive (EPBD), which would involve measuring the building's carbon footprint by 2026, ,two years earlier than what is specified in the EPBD, integrating it into the Spanish Technical Building Code (CTE) through a new Basic Document on Environmental Sustainability (DB-SA). The objective is to gather information that will allow the establishment of a progressive roadmap with limit values from 2030 onwards.

An official cradle-to-cradle LCA methodology should facilitate flexible decarbonisation, allowing all products, systems, and strategies in the project and construction phases to demonstrate their strengths. At the same time, it must account for the temporal value of carbon, which provides more time in the face of the climate emergency and highlights the importance of prioritising the reduction

It is necessary to support innovation in decarbonised products and systems and to promote renovation to make the most of the carbon investment already made in the existing building stock. It is also essential to support the development of the circular economy, which maximises the retention of resource value, either during the building's lifetime through durability promotion or beyond the building system, transforming it into a future material bank.

It is urgent to raise awareness and provide training across the entire value chain in the life cycle approach and LCA because decarbonisation requires the collaboration of all stakeholders. It involves a holistic vision that encompasses all scales. Although INDICATE is mainly developed at the building scale, the implications of its results for decarbonising the construction sector cover all scales, from product and building to city and territory. At the urban scale, decarbonisation is affected by the impact of different typologies and the urban and mobility models they imply, and it becomes evident that large-scale renovation is needed to amortize the carbon already embedded in existing inadequate housing. At a territorial scale, the innovation required for decarbonisation can generate co-benefits for cohesion, creating new opportunities in depopulated areas. This, in turn, could address the geographic inadequacy of vacant homes in these areas and prevent the abandoned carbon they represent.

It is crucial to understand decarbonisation as an opportunity to unlock innovation and improve the competitiveness of the sector, at all scales and for the entire value chain. We must not forget that decarbonisation is the only way to address the need for affordable housing within planetary boundaries.

2. Introduction INDICATE-Spain

2.1 Why measure the life cycle carbon of a building?

The European Green Deal is a package of policy initiatives that places the transition to climate neutrality by 2050 at the heart of all strategic decisions in the EU. The European economy is being reoriented towards a more sustainable, resilient, inclusive, and competitive future. The revision of the Energy Performance of Buildings Directive (EPBD) [1] is part of the legislative and regulatory framework aimed at advancing climate neutrality and focuses on buildings, which are responsible for 39% of Global Greenhouse Gas (GHG) emissions [2].

Successive policies have limited the scope to emissions produced during the building's operation — operational carbon — which accounts for 28% of GHG emissions. However, it is also necessary to consider the emissions from materials throughout the building's life cycle — embodied carbon — which accounts for 11% of GHG emissions and is increasingly significant. It is essential to measure both operational and embodied carbon to truly decarbonise buildings. Life Cycle Assessment (LCA) allows for the measurement of Global Warming Potential (GWP), which reports on the building's carbon footprint, or life cycle carbon.

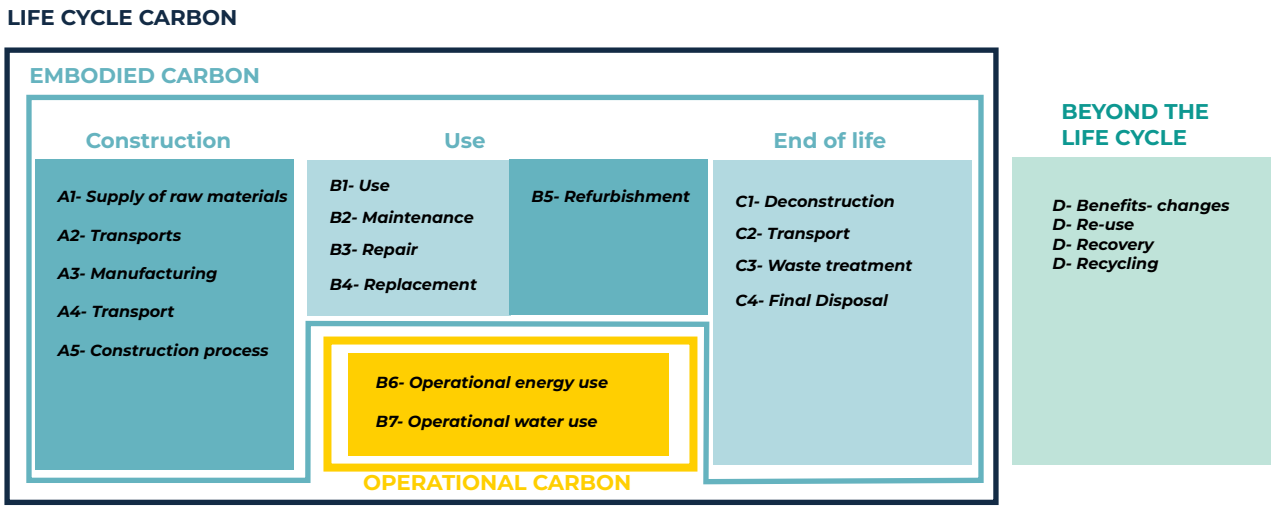

Figure 1 - Terminology used in the document regarding the life cycle stages and carbon emissions.

The life cycle approach, "from cradle to cradle," which analyses the construction, use, end-of-life stages, and beyond the system, is essential for achieving the real decarbonisation of the sector:

- **It enables flexible decarbonisation, involving the entire sector.** It allows for the recognition of decarbonisation strategies that are reflected in different stages, from selecting low-impact manufacturing products, high-durability or low-maintenance materials, to reuse or recycling, among others.
- **It recognises the "temporal value of carbon".** "Since emissions are cumulative and we have limited time to reduce them, carbon reductions now are more valuable than carbon reductions in the future" [3]. The carbon emitted in the product and construction stages (A1-A3, A4, and A5) represents a very high initial peak that occurs even before the building is occupied. This cannot be reversed, unlike

emissions throughout the building's entire life. **Reducing the initial carbon peak is a priority due to its volume and temporal value**, which provides additional time to implement mitigation and adaptation policies during a time of urgent climate crisis.

- **It avoids the shifting of burdens between life cycle stages:** for example, the incorporation of passive measures and renewable energy systems reduces operational carbon but can increase embodied carbon.

With the revision of the EPBD and the obligation to report—and later limit—total life cycle carbon, embodied carbon is being addressed for the first time, and the life cycle approach is being incorporated into construction practice. The European Commission will publish a guide to help Member States integrate the disclosure requirements and life cycle carbon limit values into their regulations. The timeline for the application of the life cycle carbon provisions in the EPBD is as follows:

Figure 2 - Timeline for the application of the EPBD. Source: BPIE.

Climate change, land use changes, pollution, biodiversity impacts, and other issues are planetary systems that have been severely breached, and the construction sector has a significant impact on them. In addition to Global Warming Potential, which affects climate change, LCA (Life Cycle Assessment) methodology includes other environmental indicators defined by standards [4,5].

Progressively incorporating these indicators can help avoid "**carbon tunnel vision**", which may lead to **shifting burdens towards other impacts**, such as decarbonisation at the expense of generating toxic substances. **The extensive media attention on climate change presents a great opportunity to bring attention to the broader impacts of construction**.

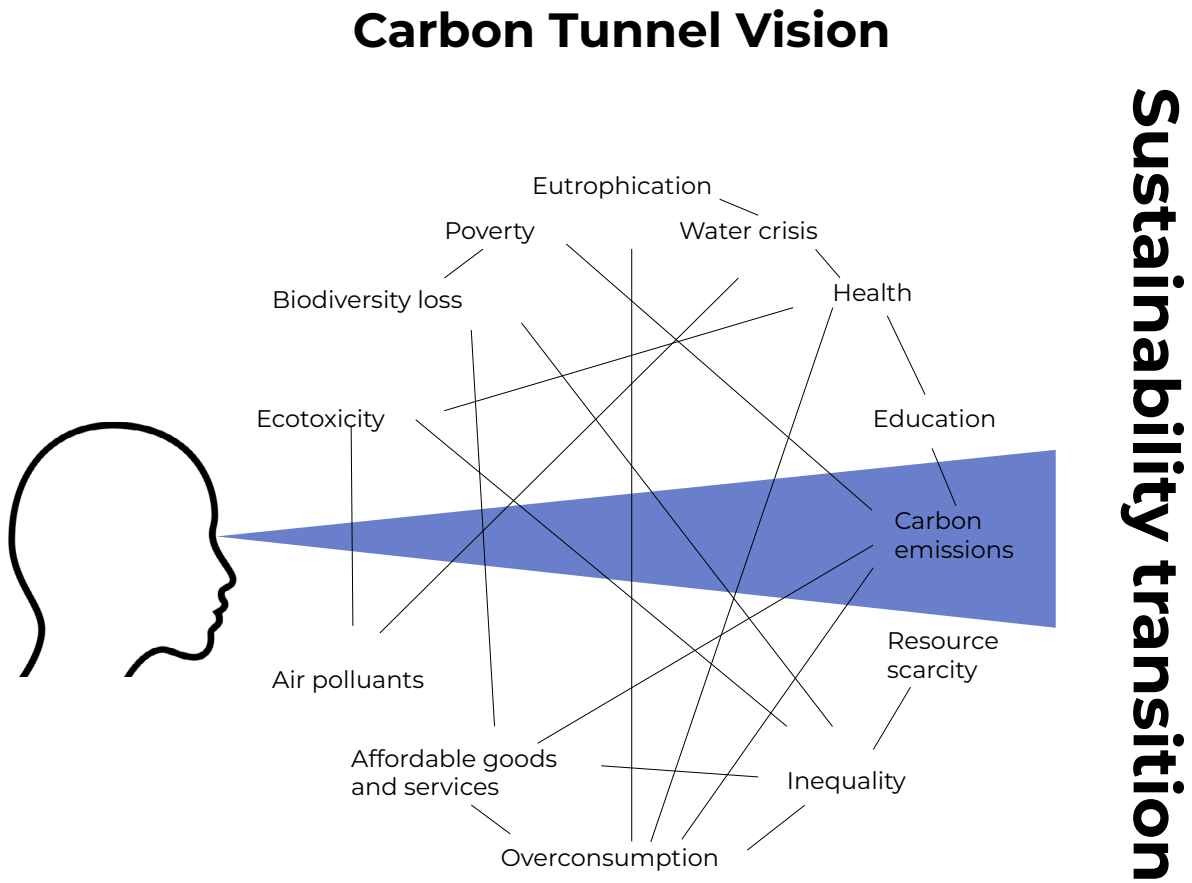

Figure 3 - "Carbon Tunnel Vision" according to Jan Konietzko.

The life cycle approach represents a paradigm shift that is expected to remain, and it also extends to the social and economic components of sustainability. It is essential for informed decision-making at all scales, product, building, neighbourhood, city, and territory to address environmental emergencies while responding to societal needs, such as housing. **Measuring life cycle carbon is the beginning of this paradigm shift and will help unlock innovation and improve the competitiveness of the sector.**

2.2 What is INDICATE-Spain?

INDICATE Data [6] is a European project aimed at improving the availability of LCA data at the building level. It **seeks to establish reference values for the life cycle carbon emissions of newly constructed residential and office buildings currently built in Ireland, the Czech Republic, and Spain.**

The project is funded by the Laudes Foundation, managed by the Danish consultancy Smith Innovation, with technical support from BPIE, KU Leuven, and WorldGBC The working methodology of each pilot is open and flexible. INDICATE-Spain (ES) is co-financed by GBCE, and its Spanish partners are the University of Seville and GBCE. INDICATE-ES has followed a strong **co-creation approach**, supported by the collective intelligence of a wide network of collaborators, who are leading experts in building-level LCA in Spain. They have validated a consensus methodology for the development of theoretical LCAs of "synthetic" buildings. It has also benefited from the support of collaborators and data owners who have contributed LCA data of real buildings, performed with different scopes, software, data sources, and assumptions (see Annex Collaborators).

The analysis of both synthetic and real data sources allows the establishment of **reference values** that should be understood as the beginning of an iterative process of continuous improvement. **A modifiable tool** has been developed to obtain the data, allowing for adjustments to the assumptions and premises considered. The data obtained by INDICATE is a snapshot reflecting the methodology and assumptions of INDICATE at the time of the project's completion (december 2024). Future developments of INDICATE will refine its results and adapt to an official methodology, which will be defined before the next revision of the Spanish Technical Building Code (CTE) in 2026. Therefore, it is an **improbable and adaptable methodology, transparent, traceable, and automated** to avoid becoming obsolete at inception. Due to its flexibility, it could serve as a test for the effectiveness of various decarbonisation policies.

In addition to the data obtained and the supporting tool, INDICATE provides the **identification of aspects that an official methodology should consider** and offers a transparent and temporary solution: the INDICATE-Spain methodology. While not an official methodology, it aims to be useful in its development. The Ministry of Housing and Urban Agenda (MIVAU), responsible for the CTE, is present as an observer and has been informed of the project's development and main findings. The work has been recognised as highly useful by MIVAU officials, as it has taken place alongside the development of the future regulatory framework for the inclusion of GWP, which they are currently working on. The government's presence as a neutral observer enhances the project's utility at a time when measuring life cycle carbon is urgent. Moreover, the Instituto Torroja de la Construcción, the technical arm of MIVAU in drafting the CTE, is one of the project's collaborators.

Another key outcome of the project is the creation of a consolidated working group comprising reference stakeholders in the field of building life cycle assessments (LCAs). Through a collaborative co-creation process, involving multiple meetings and surveys throughout the project, this group has helped ensure broad acceptance of the results as a starting point. Additionally, it has highlighted potential areas for improvement to guide future developments.

2.3 International Political Context

To facilitate a common European language, the Level(s) sustainability assessment framework [7] defines key indicators relating to the sustainability of buildings. Indicator 1.2 examines the Global Warming Potential (GWP) of the life cycle, aligned with the EN-15.804 and EN-15.978 standards. At the legislative and regulatory level, in addition to the Energy Performance in Buildings Directive (EPBD), other European frameworks set their objectives on decarbonisation and sustainability in construction.

From the supply side of decarbonised products and buildings, in addition to the Energy Performance of Buildings Directive (EPBD):

- **Directive (EU) 2023/1791 on Energy Efficiency (EED)** [8]. This seeks to reduce energy consumption in buildings and other sectors to contribute to the EU's climate objectives. It focuses on operational carbon emissions but also considers public procurement as an opportunity to address embodied carbon in buildings throughout their life cycle.
- **Regulation (EU) 2024/3110 on Construction Products (CPR)** [9]. It will improve the availability of specific data by requiring environmental information on construction products to obtain CE marking.
- **Regulation (EU) 2024/1781 on Ecodesign** [10]. This will establish requirements relating to construction end products when it is unlikely that the obligations set by the RPC and its compliance will sufficiently

achieve sustainability objectives.

- **Directive (EU) 2023/959 on the emissions trading system** [11]. It has included on-site heating emissions in a specific regime for buildings. It should be noted that cement, steel, and glass are already part of the Emissions Trading System (ETS) [12], and the implementation of the EPBD Directive provides them with market demand. The life cycle carbon reporting for buildings could facilitate its potential future inclusion in the emissions trading scheme.
- **Provisional agreement on the Regulation concerning Carbon Removals and Carbon Farming Certification (CRCF)** [13]. This creates the first voluntary framework at the EU level for the certification of carbon removal and storage in products across Europe and considers, among other factors, carbon-storing elements in wood-based and biobased construction products.

From the demand side:

- **Sustainable Finance Taxonomy Regulation** [14]. This defines sustainable activities as those that Substantially Contribute (SC) to one of the six defined environmental objectives, without causing significant harm (DNSH) to the others. It includes reporting on Global Warming Potential (GWP) aligned with indicator 1.2 of the Level(s) framework and with the EN-15978 standard. It applies to buildings larger than 5,000 m^2 under the environmental mitigation objective, and to all buildings under the environmental circular economy objective. It must be disclosed to investors and clients upon request.
- **Directive (EU) 2022/2464 on Corporate Sustainability Reporting (CSRD)** [15]. The presentation of sustainability information by companies requires them to disclose detailed information on their direct GHG emissions (Scope 1), indirect emissions (Scope 2), and indirect emissions from their supply chain (Scope 3). The EEBD will facilitate the provision of information regarding the emissions of buildings that companies construct or promote.
- **Sustainable Finance Disclosure Regulation (SFDR)** [16]. This establishes that all participants in financial markets whose products are marketed in the EU have a legal obligation to provide transparent and accurate data on the ESG performance of the investment fund. Those funds promoting investments with social and environmental qualities must report in accordance with the sustainable finance taxonomy.
- **Green Public Procurement (GPP).** Although not regulatory, GPP has become a driver of ecological transformation since Directive 2014/24 [17] by enabling the introduction of social and environmental requirements into public procurement criteria. Given that it involves public capital and constitutes nearly one-fifth of the EU's GDP, it is a tool with a high capacity for transforming the sector and serves as a powerful example to stimulate demand and support innovation. The European Commission has developed voluntary criteria for various product groups, including offices. The Joint Research Centre (JRC) will publish criteria for educational buildings, offices, and social housing throughout 2024, aligned with the taxonomy and Level(s), which will be reviewed every four years. There are no limits on life cycle carbon due to a lack of data.

This international legislative framework shows the importance of European policies focused on the decarbonisation of buildings, from supply and demand, and points the way to **guarantee the competitiveness of the Spanish construction sector**. Its implementation justifies the interest in generating relevant data with a lifecycle approach.

2.4 National Policy Context

Regulation, Policies, and Key Initiatives

At the State Level

In Spain, the decarbonisation policy in the construction sector has been reinforced, ranging from promoting the rehabilitation and new construction of highly energy-efficient buildings to introducing the life cycle approach. The priorities revolve around decarbonisation and improving efficiency, both in new construction policies and in renovation efforts:

- **Inclusion of the Global Warming Potential (GWP) indicator in the spanish Technical Building Code (CTE) for certain buildings in an early implementation of the EPBD.**
  The Technical Building Code (CTE) establishes the basic quality requirements to meet the safety and habitability set out in the Building Regulation Act (LOE) (Law 38/1999). Within the CTE, the Basic Document on Energy Saving (CTE DB-HE) refers solely to energy efficiency in the usage phase. Recently, the Ministry of Housing and Urban Agenda (MIVAU) has publicly announced the forthcoming inclusion in the CTE of a new Basic Document on Environmental Sustainability (DB-SA) [18], which will include new sustainability requirements and indicators, such as the Global Warming Potential throughout the life cycle of the building, in addition to modifications to the current DB-HE and Part 1 of the CTE. **The CTE update would contemplate the mandatory declaration of life cycle carbon starting in 2026**. The aim is to gather data to establish, before 2027, the roadmap for introducing limit values for GWP starting in 2030, as established by the EPBD. This first phase of reporting, still under study, is proposed for specific elements of certain buildings and only for some stages (A1-A3 and B4). The remaining stages and elements would be completed through voluntary declaration, or with default data. To this end, the Torroja Institute of Construction with the support of the University of Seville are compiling a list of generic default environmental data.As stipulated by the EPBD, the GWP declaration is expected to be completed alongside the Energy Efficiency Certificate (EPC). Therefore, its registration will be the responsibility of each autonomous community. Currently, information on residential and tertiary EPC is collected in a geographic information portal based on the open data catalogue of the Autonomous Communities.
- **Inclusion of other environmental indicators in the CTE.**
  During the “Conference on the Inclusion of Global Warming Potential and Other Indicators in the CTE,” the possibility of including other environmental indicators was discussed, particularly the water footprint given concerns over drought, as 74% of the territory is susceptible to desertification [19]. Participants showed support for its inclusion, even limiting it in the usage phase, and also mentioned the building’s impact throughout its life cycle on water pollution. However, no announcement regarding its inclusion has been made yet.
- **Plans to direct decarbonisation efforts in the built environment in Spain:** Implementation of the **National Integrated Energy and Climate Plan** (Plan Nacional Integrado de Energía y Clima (PNIEC)) [20]. In this plan for the decarbonization of the economy by 2030, the GWP indicator of buildings has been included. **The National Building Renovation Plan** [21] is a large-scale rehabilitation plan that must be integrated into the PNIEC.

Other initiatives at the Regional and Local level

Multiple initiatives are being implemented to include life cycle carbon accounting in the official documentation of projects and in public administration.

CATALUÑA (Catalonia)

- **Statistical tool for measuring the carbon footprint in permitting.**
  As part of an initiative by the 'Architects and Sustainability Association' (AUS) of the Catalonia Architects' Association (COAC), a tool has been developed by the Institute of Construction Technology of Catalonia (ITeC) that will be made available to all COAC-registered architects throughout 2024. This tool for voluntary use will help complete the mandatory statistical information linked to building permits [22], while generating data on life cycle carbon based on this information. Its aim is to raise awareness and generate interest in the life cycle approach. It will also help **establish an order of magnitude** about GWP in the sector. It will be updated annually and will initially report CO2 emissions from the manufacturing and construction stages. AUS and ITeC are collaborators of INDICATE-ES (see Annex Initiatives COAC-1/ITEC-7).

- **Sustainability protocol for project and works tenders from AMB and IMPSOL.**
  The Metropolitan Area of Barcelona (AMB) and the Metropolitan Institute for Land Promotion and Asset Management (IMPSOL), with the support of ITeC, have incorporated life cycle carbon limits into their protocol. This applies to stages A1-A3, A4, and A5 with progressively more restrictive limits. The protocol has been a finalist for the Bauhaus Awards 2024. AMB and ITeC are collaborating entities of INDICATE-ES (see Annex Initiatives AMB/ITeC-1).

COMUNIDAD VALENCIANA (Valencian Community)

- **TURIA Tool.**
  This is a free LCA tool published in 2024 with environmental information from the Construction Database of the Valencian Institute of Building (IVE) as an **instrument for Green Public Procurement (GPP)**. It allows the inclusion and assessment of environmental criteria in building and civil engineering tenders and facilitates the selection of options with lower environmental impact for designers and companies. It covers stages A1-A3, A4, and A5 and **provides indicators** on resource use (water footprint, materials consumed, and integrated energy), environmental impact (GWP), and resource circularity. IVE is a collaborating entity of INDICATE-ES (see Annex Initiatives IVE-1).

BALEARES (Balearic Islands)

- **ARV Catalogue of low environmental impact constructive solutions in the Balearic Islands.**
  The Balearic Institute of Housing (IBAVI) has initiated the search for unconventional materials in response to the climate emergency and the scarcity of raw materials. Their tenders prioritise the use of existing resources on the islands and the reduction of environmental impact. In this context, the development of the ARV Catalogue is underway. IBAVI is a collaborating entity of INDICATE-ES. (see Annex Initiatives IBAVI-1)

The progress towards decarbonisation-focused policies is evident at the state, regional, and local levels and underscores the need for benchmark values as an initial step towards informed decarbonisation. **INDICATE is well-positioned to address current needs in the field.**

Parallel Projects and Initiatives Focused on Carbon Footprint

INDICATE-ES has benefited from the knowledge gained from previous and current projects, with a long track record related to life cycle carbon in which its partners and collaborators have participated, directly or indirectly.

Notable previous initiatives focused on the development of Life Cycle Assessment (LCA) tools and data include: **SOFIAS** (2011-2014), a tool linked to the energy efficiency certificate (EPC) and the calculation of constructive solutions from the Catalogue of Building Elements of the CTE; **HCE-arCO2** (2014), which was later developed into Ecómetro-ACV; and **OerCO2** (2016-2018), an online educational resource for calculating the LCA of common constructive solutions (see Annex, "Parallel projects").

From the University of Seville team, international research on LCA methodology is relevant, such as **IEA EBC Annex 72, IEA EBC Annex 89**, and others. The GBCE highlights the **Building Life project** to promote climate action in the building sector and achieve decarbonisation of the built environment throughout its life cycle, taking into account the results of this project in the actions of its roadmap. Additionally, other past and future projects such as **LifeLevel(s), More Life to Level(s)**, among others, address decarbonisation and the training of the sector (see Annex Initiatives GBCE and University of Seville). On the other hand, the **certification area of GBCE** has a long track record in integrating LCA into its tools. In the case of GBCE's VERDE tool, part of the score is currently awarded based on comparison with a reference building, which could be replaced in future versions by the reference values obtained in INDICATE or in its possible further developments..

Moreover, INDICATE collaborators are pioneers in decarbonisation and are currently developing **high-impact parallel initiatives,** enriching INDICATE with their knowledge. These initiatives are shared in the annex under the premise that "**if one can, others can too**", acting as interconnected vessels that can facilitate the gradual and collective approach of the sector towards the goal of decarbonisation through examples and best practices. Many initiatives stand out for their **replicability, scalability, and transformative capacity**, not only in Spain but also at the European level. They reflect the concerns and lines of action of the collaborators and are aligned with some of the recommendations of this report.

Other policy priorities for buildings

The ultimate goal of obtaining reference values for buildings is the decarbonisation of the sector. At the same time, there is a high demand for decent housing. It is necessary to prioritise the most effective strategies to simultaneously address both objectives. And for this, data is needed.

Energy Poverty

9.1% of the Spanish population lives in energy poverty and cannot maintain an adequate temperature in their houses [23].

Scarce Social Housing

The **percentage of social housing in Spain is 2.5%**, ranking 18th in the European Union, with the Netherlands leading at 30% and Austria at 24% [24]. In response to this situation, the Government of Spain has committed to incentivising or directly constructing social rental housing, creating a specific line in the Next Generation Funds [25]. At the autonomous level, especially in the Pais Vasco (Basque Country), Cataluña (Catalonia), Andalucía (Andalusia), and Madrid (Madrid), actions are also being undertaken to alleviate this lack of social housing.

Housing Trends

Statistics from the INE indicate that houses are becoming larger for the same number of occupants [26].

Imbalance Between Housing Supply and Demand

According to the Bank of Spain's Annual Report for 2023 [27] and data from the INE [28]:

- **600,000 houses are needed** to meet demand and balance the market by 2025.
- **3.8 million houses are unoccupied**

Status of Unoccupied Houses

- 450,000 are newly built and unsold.
- Many require energy rehabilitation or accessibility improvements.

Unoccupied Houses and t heir geographic inadequacy

According to the same report, of the 3.8 million unoccupied houses:

- 45% (1.7 million) are in municipalities with fewer than 10,000 inhabitants (20.3% of the population).
- 10.5% (400,000) are in municipalities with more than 250,000 inhabitants (23.8% of the population).

In Spain, the rural population has decreased by 40% in the second half of the 20th century [29]. 16% of the population lives in rural municipalities that occupy 84% of the territory [30]. This "**emptied Spain**", characterised by significant territorial imbalances, leads to a "geography of discontent" [31], generating euroscepticism that threatens support for the European Green Deal. The lack of services, isolation, fragmented governance, and low-income levels push young people to migrate to cities, perpetuating a vicious cycle of decline and resulting in the geographic **inadequacy of empty houses**.
In response to this situation, which is common in Europe, promoting territorial cohesion and developing rural areas are political priorities in the EU. **Cohesion policy** accounts for one-third of its budget. Its aim is to strengthen economic, social, and territorial cohesion by reducing disparities between regions, with particular attention to rural areas, areas affected by industrial transition, and regions suffering from severe and permanent natural or demographic disadvantages. On the other hand, the **Common Agricultural Policy (CAP)** is also a priority and represents another third of the European budget. Its goal is to ensure food security, support the primary sector, and promote rural development.

This brief overview of housing supply and demand shows that the solution to the housing emergency does not solely rely on the construction of new houses. **Understanding the emissions from newly constructed buildings allows for valuing actions aimed at offsetting the carbon already used in underutilised buildings due to inadequacy, whether due to lack of habitability, geographic** territories that concentrate unoccupied houses facilitates the territorial restructuring of demand.

Furthermore, the lack of social housing highlights the need for an exemplary public sector that can address the housing emergency without neglecting the climate emergency.

2.5 Market Penetration of Life Cycle Assessment (LCA)

To obtain appropriate reference values for life cycle carbon emissions, it is necessary to have data produced according to an LCA methodology that ensures comparability, using appropriate calculation tools and sufficient, reliable environmental data. Additionally, it is essential to identify LCA data providers at the building level.

LCA Methodology in Spain

There is no national methodology or harmonised method for calculating LCA at the building level. Various methodological options are decided at the discretion of the LCA professional, depending on the purpose of the LCA, whether for a specific sustainability certificate, for the CPE, or as a design or communication tool. This results in limited comparability of results and significant variability in outcomes.

Available Software

There are four commercial LCA tools available: TCQi-GMA from ITeC, Cype, OneClick LCA, and Ecómetro-ACV. Recently, the Valencian Institute of Building has launched the free TURIA tool (March 2024). On the other hand, some consultants use their own tools and spreadsheets.

Existing EPDs

There are two EPD programme operators in Spain: DAPconstrucción® [32], operated by the College of Quantity Surveyors of Barcelona (CATEB), which has recently reached a mutual recognition agreement with the French database INIES, and GlobalEPD [33], operated by AENOR. There are other products manufactured in Spain whose EPDs have been carried out by other European operators such as Environdec (International EPD) or other programme operators (IBU and others) that could include construction products manufactured in Spain. In recent years, the declaration of EPDs has spread in Spain. Currently, the number of national products with EPD is over 400 [34]. In INDICATE-Spain, 133 EPDs have been used. Whenever possible, the EPDs correspond to the current version of the standard, EN 15.804-A2. It is assumed that those EPDs made according to the previous version of the standard (15.804-A1) will need to be updated in any future developments of INDICATE.

Generic Data

There are no generic data from official sources, although there is the precedent of the OpenDap database (CSIC-Torroja Institute of Construction) [35], which contained generic information developed in various research projects. However, it currently functions as a repository for EPDs. Each of the LCA tools available in Spain contains its own generic data to fill the gap of EPDs. The most widely used inventory databases are ECOINVENT and GABI. Currently, the Torroja Institute and MIVAU are developing a list of generic default environmental data, which will be published in 2025. The University of Seville has supported this task.

Availability of LCA Data at the Building Level

In Spain, there is no LCA repository at the building level. As indicated in the EPBD, the life cycle carbon report will be collected through the energy efficiency certificate (EPC). In Spain, the registration of the EPC is the responsibility of the 17 autonomous communities [36], and the geoportal “efficient buildings” of the Spanish government centralises the information [37]. It would be advisable to centralise life cycle carbon data as well.

Service Providers and Sector Training

LCA calculations at the building level are generally subcontracted by project teams or certification auditors to specialised consultancies, which are currently scarce due to a lack of demand. There is a growing need for training in the field of specialisation in LCA calculations for construction to meet

expected demand. The absence of a harmonised methodology and the lack of widespread training among sector professionals hinder the implementation of life cycle carbon measurement and the acquisition of data to establish reference values.

2.6 Availability of Life Cycle Assessment (LCA) Data at the Building Level to Establish Reference Values

To establish the current situation regarding life cycle carbon emissions from new construction in Spain, it is necessary to identify the sources of data currently available.

Certification Schemes for Building Sustainability

Sustainability certifications incorporate a life cycle approach and can be a potential source of data to help establish life cycle carbon reference values for new buildings currently in Spain. This represents a sample of buildings that, due to their sustainable vocation, could provide a biased view of reality; therefore, to obtain realistic reference values, it is advisable to diversify the statistical sample.

In Spain, more than 3,000 buildings have some form of sustainability certificate, and another 1,000 are in the registration process. The English BREEAM certificate leads the market, followed by the American LEED, which has a significant presence in Spain and ranks as the top country in Europe for LEED certifications. GBCE also provides support to developers, both public and private, to progressively implement VERDE criteria by raising awareness and training their technicians and managers. Its impact extends beyond the developer itself through the conditions outlined in their tender documents. (see Annex. Certification Schemes in Spain).

Other Sources of LCA Data at the Building Level

Beyond obtaining a sustainability certificate, there are other motivations for conducting LCAs:

- As a design tool and/or for communicating the building's sustainability, integrated into the practice of some architectural firms, sustainability consultancies, and developers.
- The Level(s) framework: some architectural firms and sustainability consultancies, without the intention of certifying their results by third parties, directly follow the European Level(s) framework guidelines to establish their sustainability indicators.
- Green Public Procurement in cases of particularly aware administrations, as is the case with some of the INDICATE-ES collaborators (see Annex Initiatives).

To identify LCA data at the building level, the main sources are specialised consultancies and public or private developers and architectural firms that are particularly aware of these issues. It is expected that, in the near future, the taxonomy of sustainable finance and corporate and financial reporting will provide relevant information. In any case, MIVAU's political will to implement the EPBD early, starting in 2026, will result in greater availability of information and allow for the gradual refinement of reference values based on data from typical buildings, those without a specific environmental focus.

3. Methods and data collection

Since Spain does not yet have a harmonised LCA methodology for buildings, and various tools and methods for LCA coexist, INDICATE-ES aims to build a data infrastructure that addresses these particularities, based on two main aspects. First, it focusses on the development of harmonised data based on a consensus-based LCA method, co-created with the main stakeholders working on this topic in Spain, to obtain LCA values for buildings that reflect the key characteristics of the buildings being constructed. Second, it seeks to collect LCA data from real buildings, developed using existing tools and methods.

3.1 Description of Case Studies

To define the case studies, relevant criteria affecting carbon emissions throughout the life cycle of the building are incorporated.

- Previous studies [38,39] indicate that building typologies and building geometry configurations strongly influence the impacts generated by buildings throughout their life cycle.
- The constructive characteristics of buildings are significant factors [40] and a specific approach to structural systems and different materials is recommended.
- Furthermore, the importance of considering climate zones, due to their impact on the building envelope, and seismicity, due to its impact on the structure, has been demonstrated when defining reference values for the embodied and operational impacts generated by buildings throughout their life cycle [39].

In this study, to develop the data infrastructure on the impacts generated by buildings, the following variables are addressed:

1. Intrinsic characteristics: related to the typology and program of the building, as well as types of construction.
2. Modifiable characteristics: related to the typical use of the building.
3. Environmental characteristics: such as thermal resistance, addressed by incorporating the diversity of climate zones in Spain, and mechanical resistance, addressed by including both areas within the mandatory scope of the NCSE 02 seismic-resistant design code (with a basic seismic acceleration greater than or equal to 0.08g), and those that are not.

In line with the above, this study focusses on developing data for five types of residential buildings, office buildings, and the disaggregated quantification of underground parking buildings, all of which are newly constructed (Table 2).

Table 2 - Building Types Included in the Study.

Residential Building Type	Non-Residential Building Type
Detached single-family home	Office block
Terraced house (row)	Underground car park
Multi-family building < 3 storeys	-
Multi-family building > 3 storeys	-
Tower block >3 storeys	-

3.2 LCA of Case Studies

The INDICATE-ES methodology for developing the data infrastructure and defining reference values and ranges is based on obtaining two types of data from two different sources:

- **Real cases:** These consist of LCA data from real buildings developed in Spain by various entities, consultancies, and architecture firms, among others. These LCAs have been performed using different calculation software, data sources, and methodological options (e. g., regarding the life cycle modules included).
- **Synthetic cases:** These are based on digital models of buildings that represent typical residential and office buildings designed in Spain.

Table 3 - Real cases VS Synthetic cases.

	Real cases	Synthetic cases
Number of cases	53	126
Main data source	Main data source	BIM models of buildings
Environmental data	Various sources	Ecoinvent v 3.10/ DAPs
Life cycle modules included	Vary by case	A1-A5 B1-B7 C1-C4 D
Building lifespan	50 or 60 years, depending on the case.	50 years

Table 3 compares some of the main aspects of the two types of data that make up this study, highlighting some of the key differences.

The data collected from real cases and generated in synthetic cases aim to be representative of the expected carbon emissions over the life cycle of buildings constructed throughout Spain. The data collection template is developed based on previous studies [40], adapted to the specificities of this project, and the same data template is used for both real and synthetic cases.

Real cases

53 real cases have been collected, representative as much as possible of the wide variety of situations defined. The selection of these cases is based on a mapping of existing LCA data of new residential buildings constructed in Spain and developed by data providers that have collaborated with INDICATE-ES. From the cases collected, the diversity of the software used and the LCA data providers is prioritised to cover all climatic zones (the most densely populated, now and in the future) and seismic and no seismic zones in Spain. Extensive information has been collected on real cases to identify the variables that most influence the variability of the results.

Synthetic Cases

For conducting the LCAs of the synthetic cases, a methodology was specifically developed for this project, co-created with the collaborators involved in the validation of INDICATE-ES and aligned with the EN 15879 standard [4] (and the Level(s) of the European sustainability assessment framework [41]. The method of defining archetypes used here has been applied in similar studies [42].

A detailed description of the methodology and the calculation assumptions is included in the document (see technical annexes and documentation in the web data repository linked at the beginning of this report).

For each of the seven types of buildings analysed, 18 possible variations were considered, **giving rise to the 126 synthetic cases**. These building configurations aim to represent the possible variations across Spain. Each subtype was dimensioned according to three criteria:

- **Three construction types:** designed to reflect low impact environmental values, modal values (i.e., the most frequent), and maximum impact values.
- **Three levels of thermal resistance** for the building envelope (low, medium, and high).
- **Two levels of mechanical resistance** (medium and high), characteristic of different regions of Spain.

Calculation of Carbon Emissions for Synthetic Cases

Figure 4 shows the workflow to obtain the LCA results and their analysis. This process allowed for the simplification of data acquisition and organisation, minimising potential errors and optimising processes. Furthermore, by using a systematic structure for building information organisation and material extraction, based on Level(s) framework, the methodology emphasises controlling factors that can significantly influence LCA results: building inventory, methodological options, calculation assumptions, and environmental data.

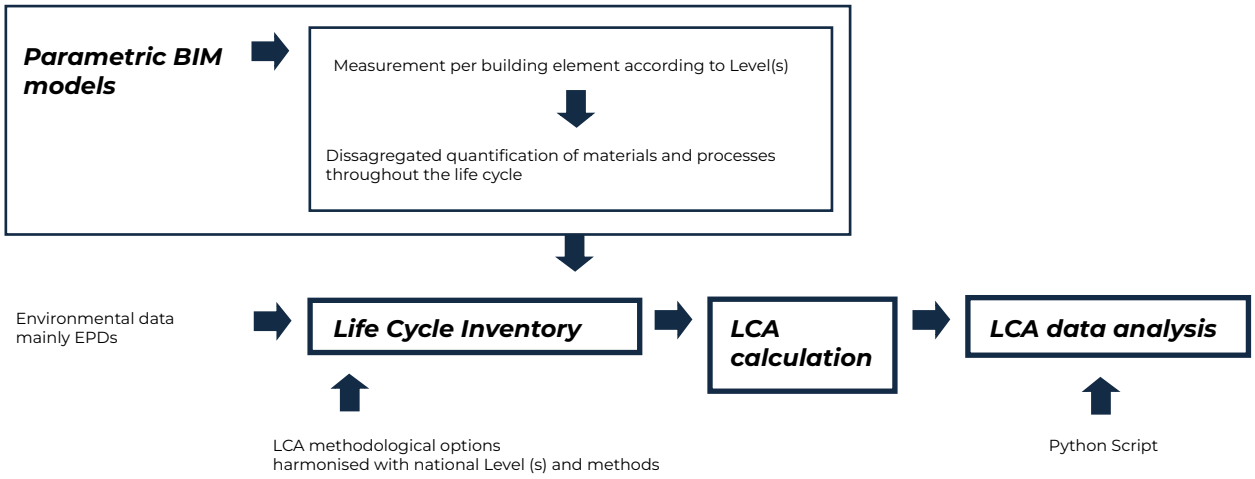

Figure 4 - Workflow stages diagram of INDICATE-Spain.

Stage 1. Parametric BIM models

These models are created based on the selected case study buildings, varying construction types (e.g., flat roof type) to more accurately estimate material quantities per element. The systematic breakdown of elements follows the Level(s) framework. These data are extracted from the BIM models and automatically linked to a data structure that parametrically enriches these data and provides quantities of materials, products, and components involved throughout the building's life cycle.

Stage 2. LCA Inventory

In addition to data on the quantities of materials, products and components that make up the building, different types of environmental data were used in the analysis: 1) Specific data from EPD of products preferably manufactured in Spain or the region and 2) generic data from Ecoinvent v 3.10 [43]. To apply these data to the established archetype structure, three categories were defined. For each group of archetypes, different calculations were made for the environmental data associated with the materials:

- **Minimum impact archetypes**: Calculated using the lowest possible data extracted from the EPDs. If no EPD data were available, generic data was used without further adjustments.
- **Typical impact archetypes**: Calculated using the INIES method, with specific data increasing according to the number of available EPDs for each product. If specific data were unavailable, the INIES method recommends using generic data increased by 30% x (1,3) (see the Annex Data INIES method).
- **Maximum impact archetypes**: Calculated using generic data increased by 30% (x1,3).

Regarding biogenic carbon, the -1/+1 approach was adopted, as it is used in many of the EPDs included in the study. The -1/+1 approach counts biogenic carbon as -1 for the carbon captured by wood during the extraction of raw material and as +1 for the biogenic carbon released at the end of the life cycle (EN 15804).

Stage 3. LCA Calculation

A specific tool was developed, based on custom Excel sheets, adapted from the tool developed within the UpfrontCO2 project 'Construct Innovate/IGBC/University of Galway WLC Calculator (UpfrontCO2 project) - v2.2', provided by GBC Ireland. This tool incorporates the predefined and agreed methodological

options, the calculation assumptions, and the environmental data. Additionally, the tool facilitates the adaptation and optimisation of the data flow, automatically linking it to the next stage.

Stage 4. LCA data analysis

At this stage, the previously organised and systematised data from Stage 3 is further refined. A summary results sheet is finalised, which will include all LCAs conducted in the project (including those for archetypes, real buildings, and LCA data contributed by collaborators). For data analysis, previous developments [40], are used, focussing on processing, organising, systematising, and visualising the LCA results of buildings.

Methodological Options and Calculation Assumptions for Synthetic Cases

Depending on the life cycle module, various criteria were established to determine the calculation assumptions and methodological options for performing the LCA. Table 4 details the main assumptions and data sources used for the LCAs, organised according to the information modules described in the EN 15978 standard [4].

Table 4 - Calculation assumptions and data sources for LCAs of syntetic cases.

Module	Description	Assumption	Data source
A1	Raw material extraction	Environmental data defined based on the type of archetype (maximum, modal, and minimum impact archetypes).	Ecoinvent 3.10 [43], or EPDs
A2	Transport to factory		
A3	Manufacturing		
A4	Transport to building site	For bulk materials, a distance of 250 km is considered. For other types of materials, an average distance is calculated using modeling in QGIS (600 km). For imported materials, a distance of 22,000 km by sea is taken into account.	INDICATE Spain
A5	Construction	Estimated electricity and fuel consumption per m^3 of materials, factoring in future emission evaluations.	Kellenberger et al., (2007) [44]
B1	Use	2% assumed annual leakage rate for refrigerants. Carbonation capture considered for concrete products.	CIBSE TM65 [45] EN 16757:2023 [46]
B2	Maintenance	Estimated electricity and fuel consumption per m^3 of materials, factoring in future emission evaluations.	Kellenberger et al., (2007) [44]
B3	Repair	Estimated electricity and fuel consumption per m^3 of materials, factoring in future emission evaluations.	Kellenberger et al., (2007) [44]
B4	Replacement	Impacts of the replaced element in the product phase (A1-A3), including impacts of A4, A5, B2, B3, C1, C2, C3, C4 from installation. Service life of building elements adjusted to INDICATE-ES framework.	Level(s) manual [41] adjusted to Spain
B5	Refurbishment	Estimated electricity and fuel consumption per m^3 of materials, factoring into future emission evaluations.	Kellenberger et al., (2007) [44]
B6	Operational energy	Limit values established by the Spanish Technical Building Code, including future decarbonisation projections based on official sources (PNIEC).	CTE [47] PNIEC [20]

B7	Operational water	Emissions related to the water cycle and associated impacts. Based on Level(s) framework to estimate water consumption, multiplied by emission factors.	Level(s) [41]
C1	Deconstruction	Average electricity and fuel consumption per m^3 of demolition.	Kellenberger et al., (2007) [44]
C2	Waste transport	Average distance to landfill and treatmnet plants of 50 km by truck (16-32 tons).	INDICATE España
C3	Waste treatment	General data published by INE on "Waste collection and treatment statistics."	INE (Instituto Nacional de Estadística (Spain), 2024) [48]
C4	Final disposal	General data published by INE on "Waste collection and treatment statistics."	INE (Instituto Nacional de Estadística (Spain), 2024) [48]
D1	Reuse	Data are included if specified by the product's EPD.	EPDs
D2	Exported energy	Not considered in this analysis. Although exported solar energy could significantly reduce net energy consumption, its exclusion is due to predetermined reasons in the study methodology. Reducing the impact of energy production can lead to an increase in the embedded impact of related facilities.	n/a

3.3 Results and Interpretation

Whole life cycle carbon emissions per functional equivalent (unit of building area) of the building typologies (synthetic and real cases)

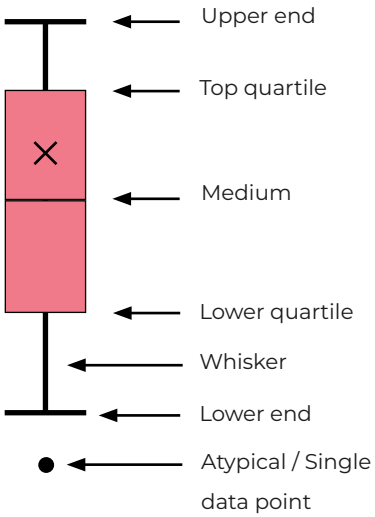

Figure 5 - Explanation of box-and-whisker plots.

The figures presented in this section are box plot charts, representing the following key values:

- Upper and lower quartiles: These indicate that 25% of the cases fall above and below the box, respectively. They define the boundaries of the box, which contains 50% of the cases within the middle range.
- The median: This is the central value, meaning that there are an equal number of cases above and below it.
- The mean value (the X in Figure 5): This is the statistical average of the dataset.
- Outliers: These correspond to data points that are significantly far from the main dataset.

Based on the results obtained, Figures 6 and 7 were created, showing the emission ranges over the full life cycle of the analysed buildings, in Kg CO_2eq per functional equivalent (square metre of gross floor area, GFA), for both residential and non-residential buildings, and for synthetic and real cases. The data is presented here per unit of gross floor area to allow comparison with real data and other studies [40].

Overall results for residential and non-residential typologies.

Synthetic cases

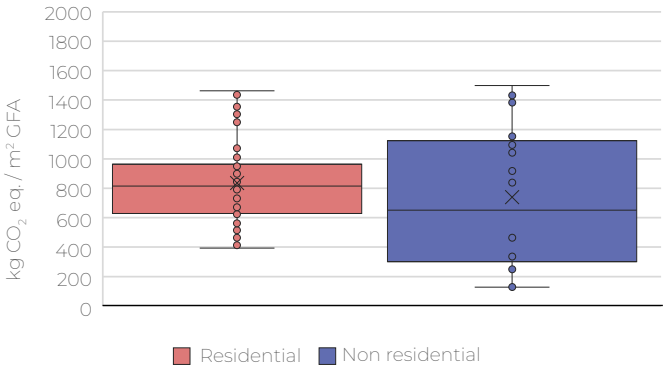

Figura 6 - Synthetic cases. LCA (stages A – B – C) kg CO2eq./m² of Built Area (GFA), residential and non-residential.

Real cases

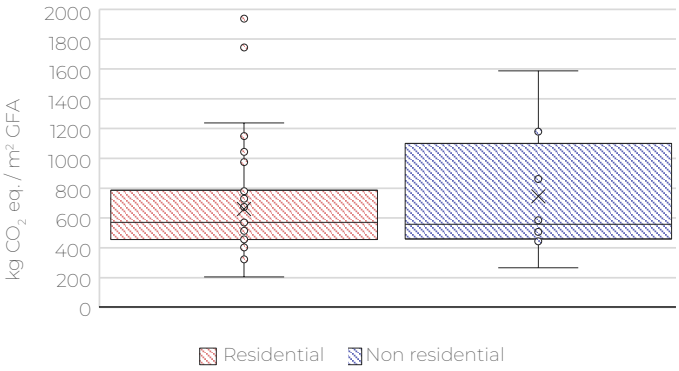

Figura 7 - Real cases. LCA (stages A – B – C) kg CO2eq./m² of Built Area (GFA), residential and non-residential.

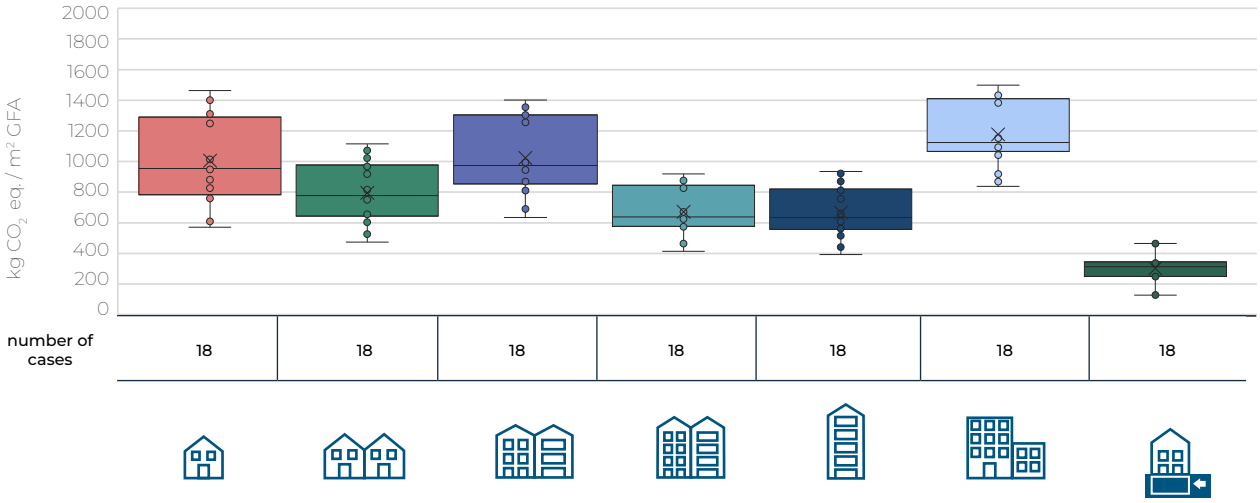

Figure 8 - Synthetic cases. LCA (stages A – B – C) kg CO2eq./m² of Built Area (GFA), by typology.

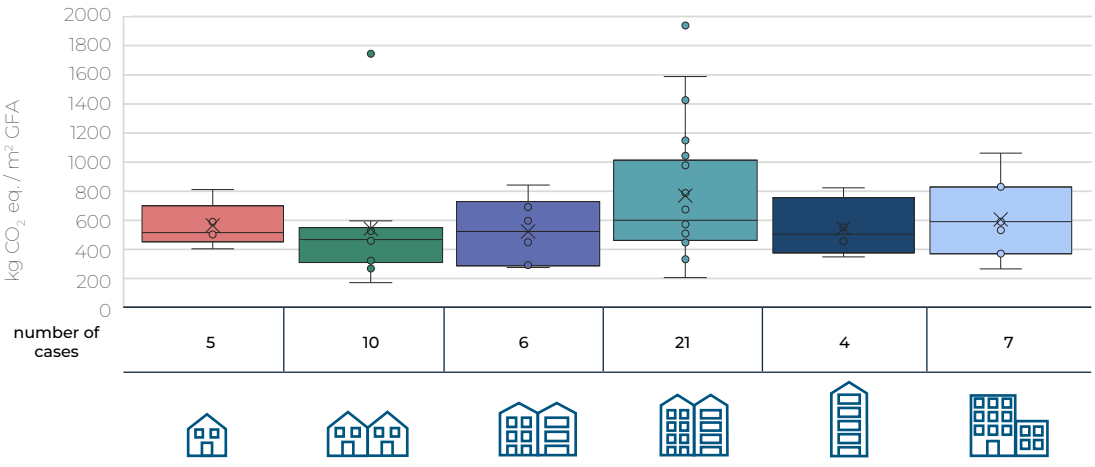

Figure 9 - Real cases. LCA (stages A – B – C) kg CO2eq./m² of Built Area (GFA), by typology.

Table 5 - Summary of values obtained by typology and type of case (synthetic or real).

Kg CO_2 eq/ m² of GFA		Single-family detached house	Single-family row house	Multifamily houses < 3 floors	Multifamily houses > 3 floors	Multifamily tower houses > 3 floors	Office	Parking	Total LCAs
Synthetic Cases	Range min-max.	570- 1.463	473- 1.114	634- 1.402	413- 919	393- 935	874- 1.499	128-464	
	Average value	1.005	794	1024	672	666	1.177	334	
	n° of cases	18	18	18	18	18	18	18	126
	n° of storeys	2	2	3	6	10	3	2	
Real cases	Range min-max.	402-811	171-596	290-842	205-1.587	348-822	266-1.061	-	
	Average value	564	542	523	769	544	605	-	-
	n° of cases	5	10	6	21	4	7	-	53

The 126 theoretical or synthetic archetypes do not reflect statistical behaviour; rather, they were deliberately selected to cover the spectrum of construction possibilities in Spain, ensuring that any LCA (Life Cycle Assessment) conducted using the same assumptions and methodology falls within these ranges. In Figure 9, the following can be observed:

- Modal archetypes are situated in the middle range, representing the most common construction solutions, with medium thermal resistance, both possibilities for seismic acceleration, and default generic data (according to the INIES methodology, see the Annex Data).
- Maximum archetypes are above this middle range, corresponding to higher-impact construction solutions, high thermal resistance, located in seismic zones, and with increased generic data from Ecoinvent v3.10 [4].
- Minimum archetypes fall in the lower quartiles, corresponding to low-impact construction solutions, minimum thermal resistance, in non-seismic zones, and developed with specific data from Environmental Product Declarations (EPDs).

Regarding synthetic results (Figure 8), the typologies included in this study do not account for underground parking, which has been analysed as an independent typology. For the real cases, the impacts generated by parking facilities have been included in some of the total results, which may be one of the causes of the variability observed in the results. Of the real cases, 36% did not include parking in their total results.

For the real cases (Figure 9), preliminary results reveal a wide range of carbon emissions generated throughout the life cycles of the buildings, ranging from 205 kg CO_2eq per m² to more than 1587 kg CO_2eq per m² GFA. This broad range highlights the significant variability in the results provided by different data suppliers and the number of cases considered per typology, as shown in Figure 5.

Figure 9 presents the general results of the typologies analysed from the 53 real cases. The average values range between 523 and 769 kg CO_2eq per m² GFA, across all building typologies (residential and non-residential).

Some of the sample comes from newly constructed buildings within certain certification schemes, so their results may not be fully representative of typical Spanish construction practices. Differences in the construction lifetime configurations were detected depending on the evaluation scheme for which the data was prepared. The results have been harmonised to a 50-year lifespan.

Key Findings from Data Analysis by Building Type:

- **In the case of Spain, and due to the lack of harmonization among real cases, the synthetic cases are considered more reliable when it comes to obtaining emission ranges. Real cases have been useful for comparing and validating the partial results of the synthetic cases.**

- Synthetic case results: The influence of construction characteristics, thermal resistance, and seismic acceleration on synthetic results is confirmed. By varying these aspects, a range of carbon emissions values has been established for the life cycle of buildings in Spain, with average values similar across all building types:
666 and 1177 kg CO_2eq./m² GFA.

- Real case results: The variation in results is proportional to the number of cases considered. The variation in data is not directly related to building type, but with the number of cases. The average values for all the typologies range from 523 to 769 **kg CO_2eq./m² GFA.**

- Comparability of real vs. synthetic cases: In future developments, it would be of interest to conduct the LCA of real cases using the INDICATE methodology to explore the origin of the dispersion. Both data sources, synthetic and real, will likely converge once an official harmonised method is established and adopted by both. The source of real cases should go beyond the sustainability field and cover all types of buildings for greater representativeness. This would allow for a whisker plot based on real cases aligned with the synthetic data, eventually making the synthetic data unnecessary.

WLC emissions per other functional equivalents for synthetic cases

a) Comparison of emissions by type of floor area. Gross Floor Area (GFA), Usable Floor Area (UFA) and Heated Floor Area (HFA)

Considering different floor area definitions and metrics, figure 13 shows the relationship between the gross, usable, and heated areas for the different typologies. It is important to clearly define what is included in each of them (see Annex Definition of surfaces).

These figures correspond to synthetic data generated from digital models of actual buildings, with only one case per typology, so more data would need to be collected to establish statistical percentages that reflect reality. In any case, the current analysis provides an approximate picture. The values obtained for detached and terraced houses show similar variation percentages. In the case of multi-family housing, a variation is observed between the usable and heated areas, due to common areas and service spaces.

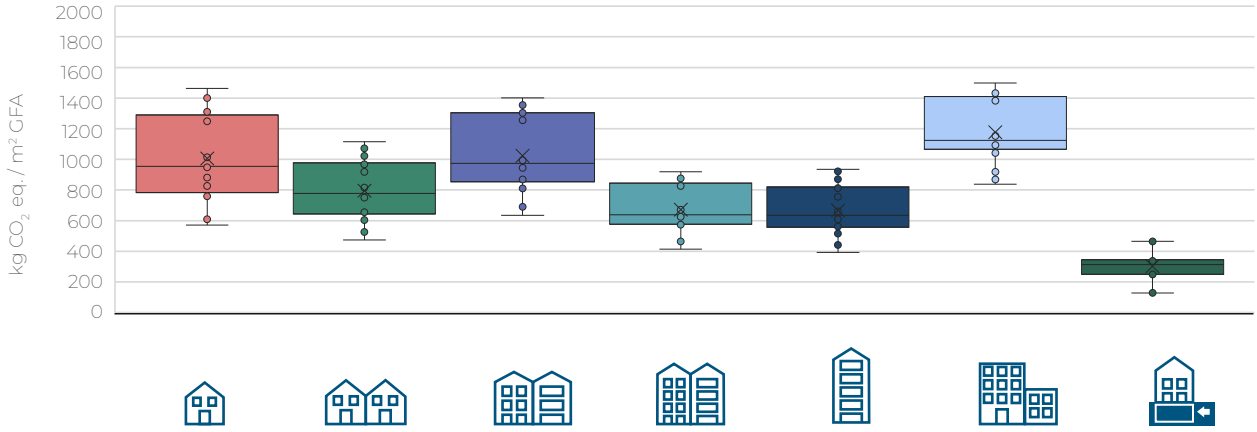

Figure 10 - Same as Fig. 8 – Synthetic cases. LCA (stages A – B – C) kg CO2eq./m² of Built Area (GFA), by typology.

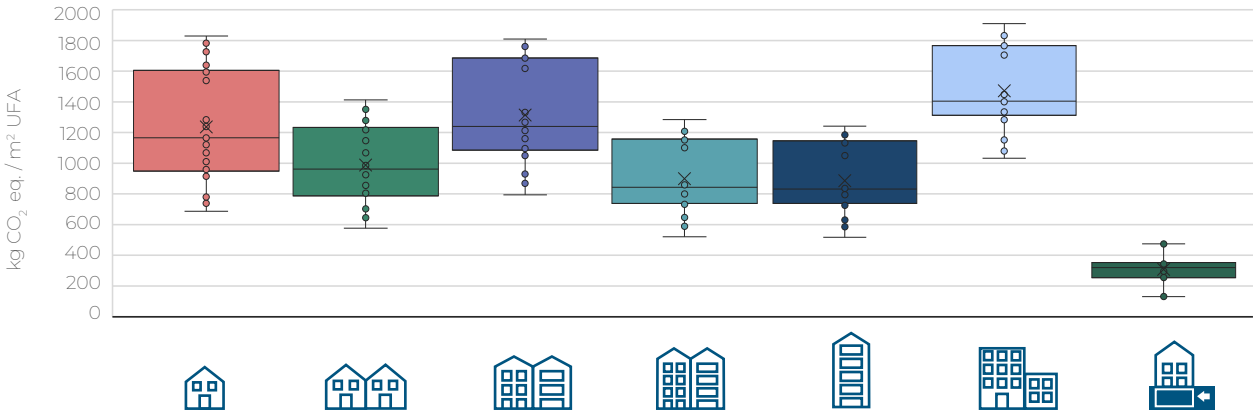

Figure 11 - Synthetic cases. LCA (stages A – B – C) kg CO2 eq./m² of Usable Floor Area (UFA), by typology.

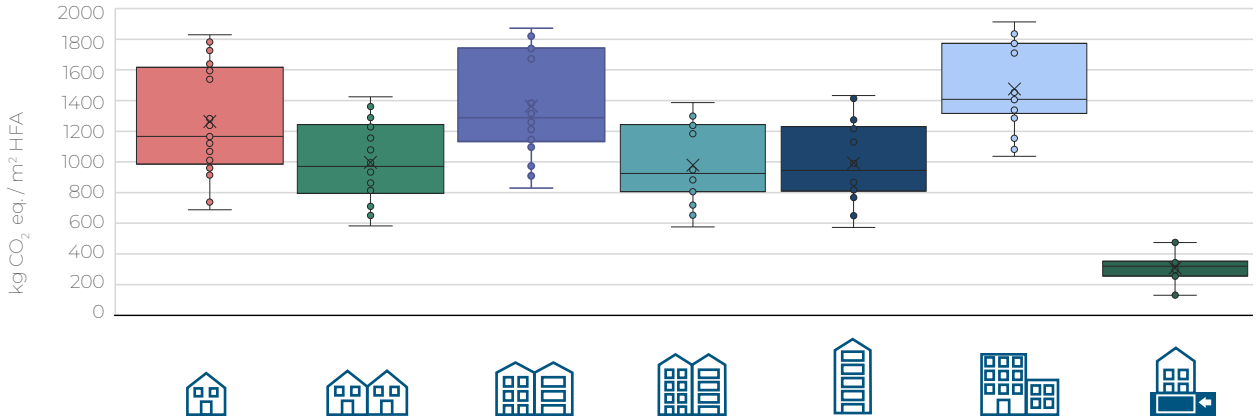

Figure 12 - Synthetic cases. LCA (stages A – B – C) kg CO2 eq./m² of Heated Floor Area (HFA), by typology.

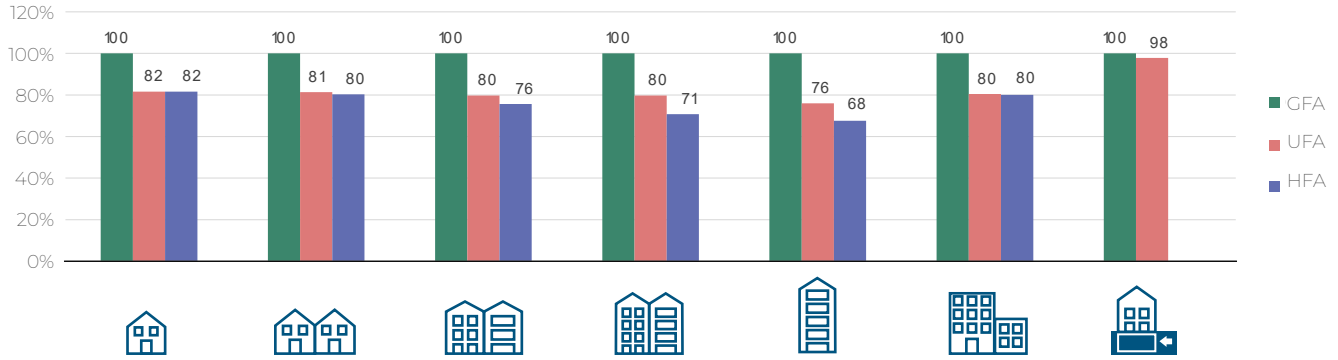

Figure 13 - Synthetic cases. Relationship between Built Area (GFA), Usable Floor Area (UFA), and Heated Floor Area (HFA), by typology.

b) Indicators that account for the use intensity

An indicator based on the functional equivalent per capita is introduced due to the trend of increasing living space for the same number of occupants. Reducing impact per unit of surface would be useless if houses continued to grow. Having a per capita indicator allows for an absolute metric without needing to know or influence the total surface area of the houses.

To calculate the number of occupants, the same criteria used in similar studies [40] were applied. The adopted criterion for residential buildings assumes one occupant per available bed in the houses. For office buildings, the number of occupants was estimated at 0,1 people per square metre of building, while for parking buildings, it was estimated based on the number of available parking spaces.

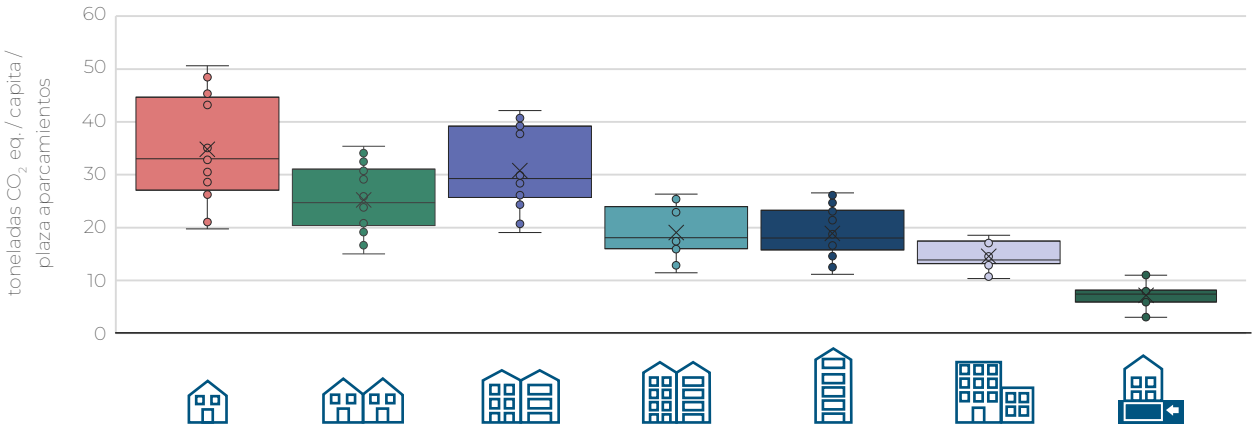

Figure 14 - Synthetic cases. LCA (stages A-B-C) tonnes CO2eq./per capita or parking space, by typology.

Key findings from the comparative analysis between different functional equivalents:

- The variation that exists when considering different surface areas is shown, which, depending on the type considered, helps to understand its characteristics and where potential reduction ranges are located.
- The importance of including results using these three ratios is confirmed, as they are relevant for evaluating each type of building (Gross floor or usable area / heated area / per capita).
- It is important that the definition of surface areas is clearly established, as the variation in the ratio can range from 20-30% between the gross floor and heated areas.
- The inclusion of the heated area ratio allows consideration of the impact of common areas and enables a fairer comparison between typologies.

Whole life cycle Carbon emissions per life cycle information modules and building elements (synthetic and real cases)

a) Carbon emissions by life cycle stage (Mean values archetypes of synthetic cases)

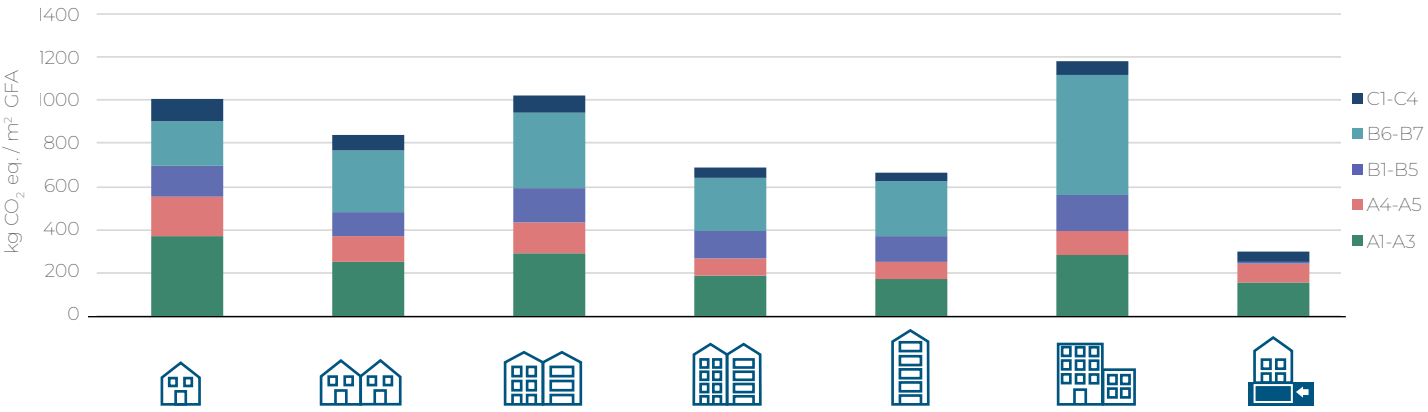

Figura 15 - Synthetic cases. Contribution to LCA from the life cycle modules in kg CO2eq./m² of Built Area (GFA), non-seismic modal archetypes.

Carbon emissions by life cycle stage (%)

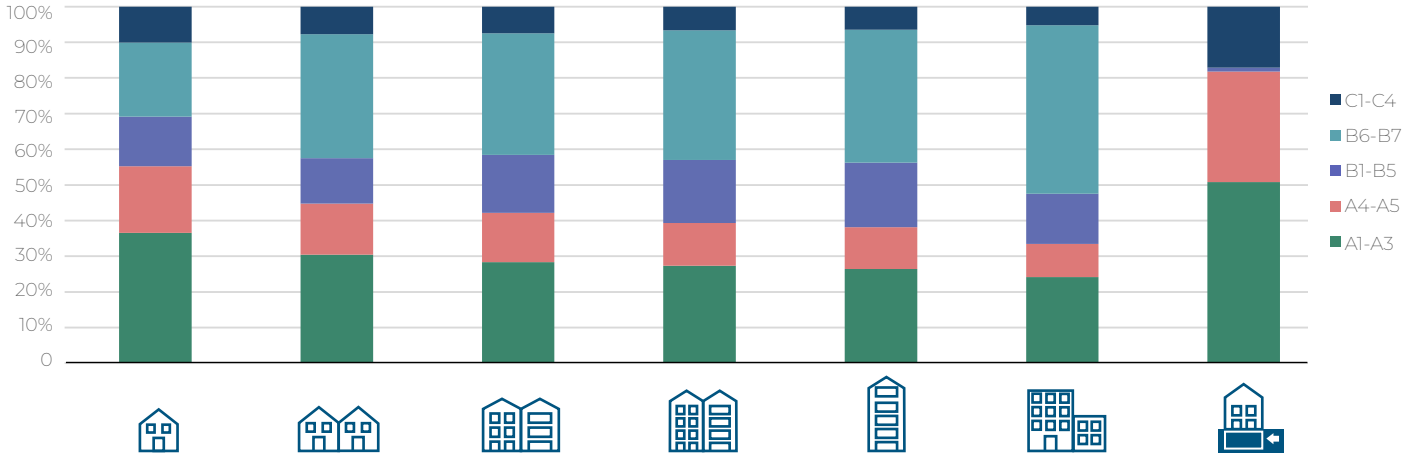

Figure 16 - Synthetic cases. Contribution to LCA from life cycle modules in percentage, non-seismic modal archetypes, relative to GFA.

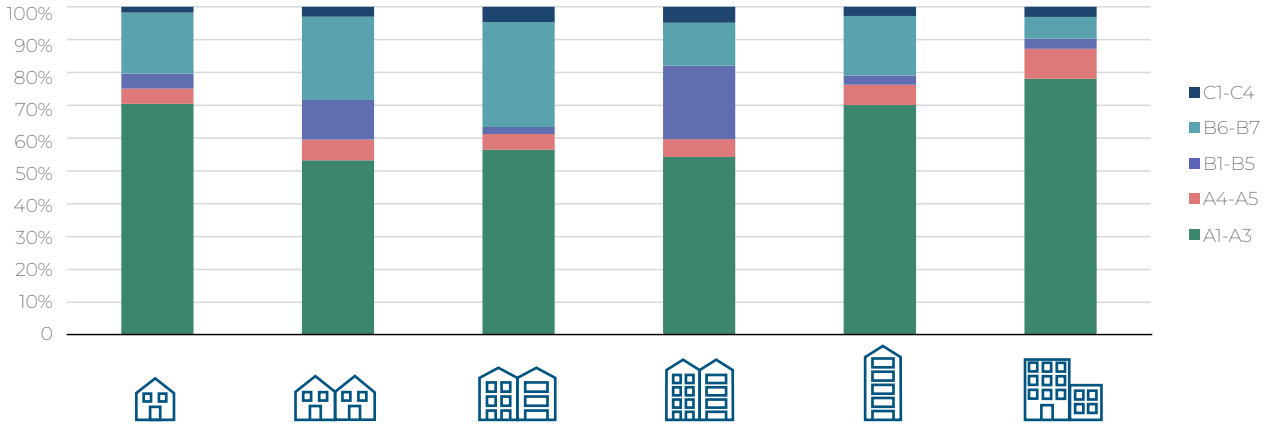

Figure 17 - Real cases. Contribution to LCA in percentage from life cycle modules, average values, relative to GFA.

Table 6 - Percentage of inclusion of impacts data by life cycle stages in the real cases.

	A1-A3	A4-A5	B1-B5	B6-B7	C1-C4
Percentage of data inclusion	100%	100%	68%	60%	68%

Figures 15 to 17 show the distribution of impacts according to the life cycle information modules of the buildings analysed. The results show the differences in the scope of the system boundaries consider in synthetic and real cases. Table 5 shows that the existing data sources in the Spanish context allow the calculation of at least modules A1-A3, A4 and A5. The reasons for not including the rest of the modules may be due to the lack of sufficient data or calculation assumptions to facilitate it. Modules A1-A5 have not been included simultaneously in all cases; that is, certain cases have included modules A1-A3 and A4, while others have included modules A1-A3 and A5. In the Annex data, in real cases, the negative values in modules B1-2-3-4-5 are due to carbon capture by carbonation of cement-based products and carbon capture by biogenic materials. In these cases, it is observed that carbon capture in the product phase has sometimes not been compensated by emissions in the final phase of the life cycle, as defined by the EN 15804 standard [5] (see Annex Data).

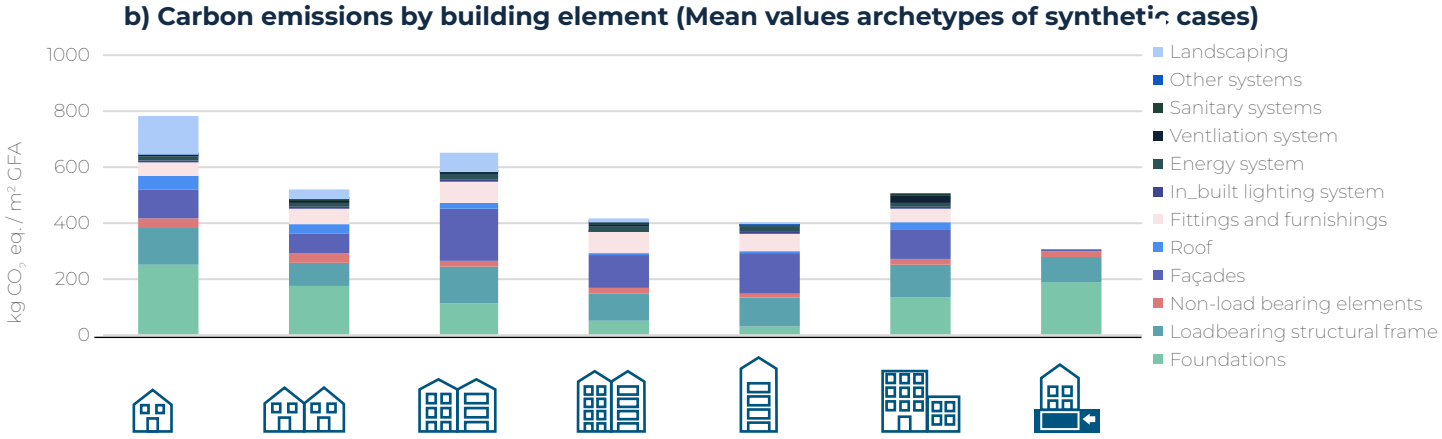

Figure 18 - Synthetic cases. Contribution to LCA from elements according to Level(s) in kg CO2eq./m² of Built Area (GFA), non-seismic modal archetypes.

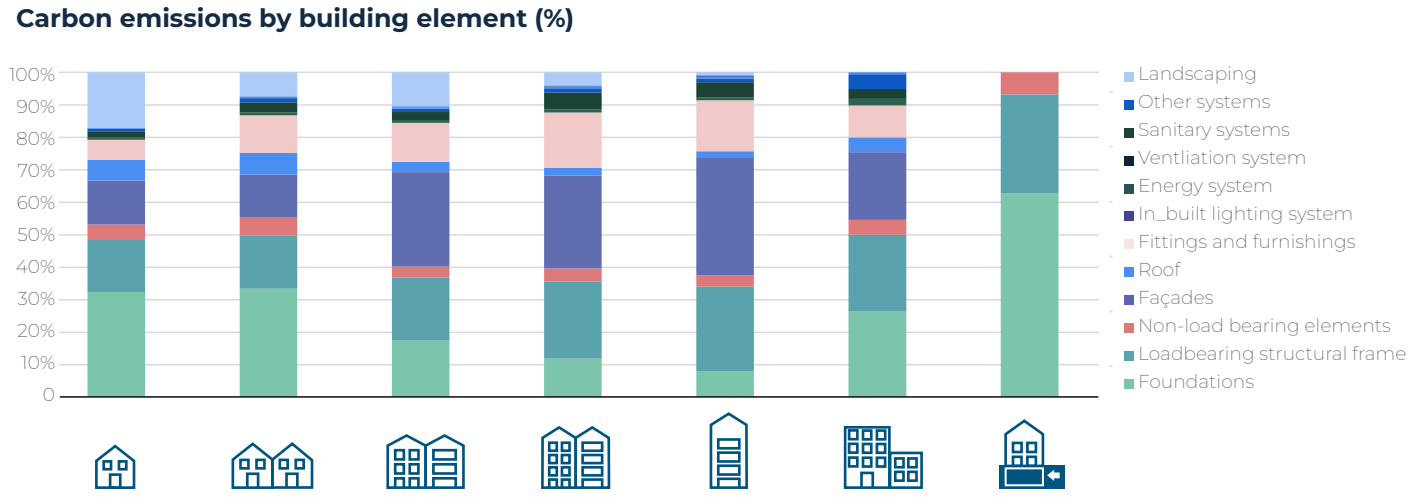

Figure 19 - Synthetic cases. Percentage contribution of elements according to Level(s) in non-seismic modal archetypes, relative to GFA.

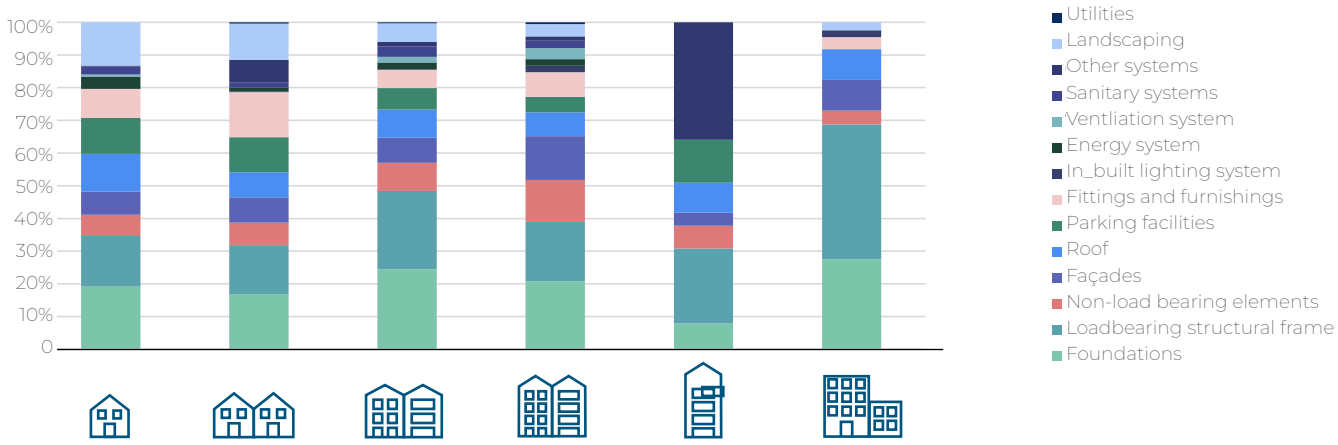

Figure 20 - Real cases. Percentage contribution to LCA from elements according to Level(s), average values, relative to GFA.

Figures 18 to 20 show the average values for the building elements included in the LCA. In the case of the synthetic cases the values correspond to the archetypes of mean values, in case of real cases the values correspond to the average of the total number of cases considered.

For synthetic cases (figures 18 and 19) results show that the same group of building elements are considered, the variation of the results depends on the material intensity and the associated embodied impacts of each solution. For the real cases (figure 20) results show differences in the building elements included in the LCA and some of the values obtained for some groups of materials have given values close to zero. For example, for the tower typology, the results for fittings and furnishings are near zero, which probably indicates that chosen materials have very low impact or have not been included in the LCA. Both synthetic and real cases show that the systems or group of elements that generally produces the highest impacts are the foundations and the structure.

Key Findings from the Analysis of Data by Stages and Systems:

- In both the synthetic and the real cases, the data behave similarly, and the modules with the highest and lowest values are comparable in both cases.
- In both real and synthetic cases, the foundation, structure, and building envelope have a significant influence on the embodied impacts.
- The greatest impacts occur in the product phase A1-A3, B4, and B6.
- The common practice in Spain includes the product and construction stages (A1-A5), which represent the initial peak of carbon emissions and have the greatest impact.
- The disaggregation and granularity of the information allow for the comparison of results from real and synthetic cases by comparable fragments.

Results of the analysis of the behaviour of design variables

An analysis was carried out on the behaviour of the variables that define the upper and lower ranges: three possible thermal resistances of the building envelope (low, medium and high); two mechanical resistances (medium and high), characteristics in Spanish territory due to seismicity; and three types of data sources, ranging from specific data for minimum impact archetypes to generic data used for maximum impact archetypes (see Annex Detailed analysis of the results).

Key findings of the analysis of the behaviour of design variables:

- The influence of construction, thermal resistance, and structural characteristics, and the data quality on the whole life cycle carbon values obtained for the synthetic results is demonstrated.
- It is shown how, by using variations in these aspects, it has been possible to construct a range of life cycle carbon values for buildings in Spain.
- Comparison of the impacts of the embodied envelope reveals that the impacts of similar building solutions do not show much variation when the thicknesses of the insulation of the building envelope are modified.
- The most influential factors are the construction characteristics and the mechanical resistance. The impact of minumun impact construction solutions without seismicity can be up to 80% lower compared to those with maximun impact and in seismic zones.

3.4 Summary of Key Findings

- Importance of having a harmonised method and improving the comparability of results.
- Values obtained by typology, by life cycle stage, and by element (see Table 5).
- Maximum impact combinations can be three times higher than minimum impact combinations (synthetic cases).
- The influence of typology and volumetry and common areas.
- Need to use different functional units to assess each typology.
- Importance of using specific data (EPDs).
- The type of construction solution has a significant impact on the total results.
- The influence of seismic zones on the quantification of the materials that make up the structure and on environmental impacts is significant.
- The variation of the thermal resistance of the envelope to adapt to different climate zones has a low influence. However, climate adaptation also refers to the inertia of the construction solution, which is indeed significant.
- The impact of underground parking is significant.
- High impact of replacements (B4) and their related impacts on the total results.
- Importance of modules A1-A3 and their direct implication in the calculation of A4, A5, B4, C3, C4.
- The structure and foundations are generally the building systems that have the highest impact on the total embodied impact results.

4. Stakeholder Engagement

4.1 Key stakeholders and engagement goals

INDICATE-ES is a participatory project, where the co-creation methodology facilitates the acceptance of results and promotes subsequent dissemination.

At the beginning of INDICATE-ES (early 2023), the political agenda was quite different from the current one (end-2024), with the EPBD already approved and a European roadmap established. The implementation of life cycle carbon measurement was still distant, so it was decided to include advanced agents in the building-level LCA methodology, generally identified through GBCE's network of contacts. Today, with a focus on 2028, the new INDICATE LIFE projects will be in a different position, and it may be interesting to also include manufacturers and experts in product-level LCA.

The collaborators form a **leading group of professionals** and change agents, each emphasising different aspects, enriching the process and methodology, and consolidating a multifaceted approach. The selection includes:

- Entities with decision-making capacity in policy development: at the national level (IETcc-CSIC, responsible for the Spanish building code) or at the regional or metropolitan level.
- Local Administration pioneers or those closely related, to demonstrate the public sector's ability to act through Green Public Procurement.
- Building-level LCA experts to support the development and validation of the methodology: generally, all collaborators in the validation task, but especially consultancies, construction institutes, and software owners.
- Communication agents capable of reaching the sector and raising awareness, such as Construction Institutes or associations from academia or professional realms.
- Data providers to ensure access:
  - Consultancies
  - LCA software owners
- Central Administration technicians (MIVAU) as observers.

In many cases, these collboratiors are driving initiatives to reduce the environmental impact of buildings, initiatives that are potentially replicable and scalable or that stand out for their sectoral outreach and awareness-raising capacity (see Annex about Initiatives).

4.2 Stakeholders' Interest

The interests of the collaborators in the obtained results are varied:

- General need for benchmarks that allow for the assessment of results obtained in an LCA and show the decarbonisation potential.
- Interest in obtaining reference values that can be incorporated into their respective activities. For

example, GBCE will assess the possible inclusion of the INDICATE results, or its future developments, in the GBCE (VERDE) label to evaluate the results of the LCA criterion.

- Keeping up to date with methodological decisions that may affect the reference values of this first approach to a baseline.
- Ability to contribute their experience and viewpoint.
- Dissemination of results among their members, collaborators, or stakeholders.
- Potential future application of a possible INDICATE development in Green Public Procurement.
- Interest in the development of the process as a potential starting point for the development of an official methodology (in the case of IETcc).

4.3 Type of commitment proposed

Two types of participation were proposed, depending on the task carried out. Economic compensation for the tasks allowed for greater involvement and commitment from all parties.

- **Task 1: Participation in co-creation and methodology validation**
  Involved participation in multiple follow-up meetings, bilateral meetings for clarification, review of shared documents, and completion of two surveys. Collaborator follow-up in Task 1 was a success, enabling the creation of a solid working group. The project has served as a link between participants and with entities such as MIVAU or the JRC, creating a communication channel.
- **Task 2: Contribution of pre-existing LCA data from real cases**
  The data has been provided confidentially and always in compliance with the current data protection laws. It has been limited to eight cases per collaborating entity to encourage the greatest number of possible sources and an equitable distribution of the available budget, while also allowing for the amortisation of the learning curve involved in completing a form for each building, based on the KU Leuven form. The budget limitation has allowed for the collection of 53 cases; however, the existing potential to gather more LCA information is very high, with many more cases identified among current collaborators or from certification schemes. In any case, both synthetic and real data have enabled the achievement of a critical mass of information, which we hope will have a “snowball effect” to attract more data in the future.
- **Overlap of both tasks**
  Some collaborators assumed both tasks simultaneously, acting as a key data source.

4.4 Social sustainability of the project

Beyond the direct project partners (University of Seville and GBCE), the broad participation of paid collaborations allowed INDICATE funds to be distributed among more than 20 entities. In this sense, the project is a success regarding its social sustainability.

Gathering such an active group of collaborators, engaged in their own decarbonisation initiatives, is likely to generate future synergies and foster collective intelligence that could be very helpful. To this end, the most interesting initiatives from the collaborators are being published (see Annex of Initiatives).

INDICATE itself has boosted the implementation of life cycle carbon measurement and LCA methodologies, thanks to the interest generated among participants and the expected impact of its dissemination.

4.5 Key stakeholder concerns

Task 1: Co-creation and methodology validation

- Decarbonisation as a cause of durability loss due to the reduced quality of products in a poorly understood decarbonisation process.
- Achieving excessively low results due to a limited building inventory.
- The initial sample of 50 cases was considered insufficient. This led to the creation of 126 synthetic or theoretical cases, compared with a non-harmonised sample of 53 real cases provided by the collaborators.

Task 2: Contribution of pre-existing LCA data from real cases

- Difficulty in filling out the form that collects results from pre-existing LCAs. The structure of disaggregated data for comparison posed a challenge.
- Difficulty in filling in surface areas.

4.6 Addressing the challenges

INDICATE-ES has demonstrated the importance of recognising legitimate stakeholder concerns and developing an open, transparent, and inclusive process, accessible to all types of stakeholders, to develop the INDICATE-ES methodology. This fosters a spirit of collaboration, essential to reaching consensus on life cycle carbon measurement. The academic and non-profit nature of the project partners has contributed to an atmosphere of trust. INDICATE's characteristics have helped address the challenges:

- **Based on co-creation.** Everyone has been able to express their opinions and be heard, influencing the methodology. Their opinions have been recorded in the two surveys conducted and in the meetings throughout the project. Co-creation facilitates the acceptance of the results as they have been part of the decision-making process.
- **Open and improvable**: Part of an iterative process of continuous improvement, starting with what we have and building upon it.
- **Transparent and traceable**: Allows tracking and building upon previous work.
- **Automated**: Any change can be updated quickly because it's a system of interconnected files.

The Ministry's (MIVAU) presence as an observer ensures that the process is heard by policymakers and may be useful.

4.7 Data source for real cases

The involvement of key collaborators in Task 1 validation, especially consultancies and LCA software owners, has been crucial in gaining access to some of the cases. The data providers for real cases in INDICATE-ES are:

- **VERDE Auditors (EA VERDE-GBCE):** 12 buildings from 4 EA VERDE. Not all buildings are certified with VERDE, as an EA-VERDE can also audit other certification schemes.

- **Developers and designers:** nine buildings come from one developer. Two project teams that provided data were suggested by two software owners.
- **Sustainability Consultancies** working with multiple certifications: 13 buildings from 2 consultancies. Working with multiple consultancies ensures coverage of all tools.
- **Software Owners**, who directly or indirectly contributed a varied sample of common tools in Spain: 12 buildings from 2 software owners that provided client data

4.8 Main challenges identified in data collection

Challenges Related to Obtaining Synthetic Data

The main challenge was generating the maximum amount of representative data using minimal resources. The established method, which evolved with input from collaborators, efficiently defines theoretical ranges from 126 cases, categorised into 7 types with 18 variations each, resulting from the combination of 3 levels of impact for the construction solution, 3 thermal resistances, and 2 mechanical resistances.

One of the project's priorities was to ensure acceptance of the results by the large group of expert collaborators. To achieve this, consensus was sought, particularly on four key aspects that influence the calculation:

- Environmental data used in the calculation.
- Composition of construction elements.
- Assumptions for stages beyond the product stage.
- Selection of solutions considered to have minimal, maximal, and modal impact.

This consensus was achieved through continuous project follow-up with the collaborators in frequent meetings. The result is considered by all to be a valid starting point, understanding it as part of an iterative process of continuous improvement. The positioning of the collaborators during the survey in the final phase of the project can be found in the annex 'Survey Results'.

Challenges for real cases

The main challenge was finding representative data on LCA practices in Spain, ensuring a variety of tools were used while also representing the same case categories defined for synthetic cases (building types, climate, and seismic zones). Additionally, the selected cases needed to be as complete as possible regarding the stages and components considered and needed to maintain records of their calculations to fill out a spreadsheet based on KU Leuven's template.

The success of the process was due to including potential data providers, or contacts that facilitated access to them, in the group of collaborators who co-created the methodology. The process involved identifying real data providers and the type of data they held via a form, which allowed selecting the most representative cases according to various tools, climate, and seismic zones, and building types. Each provider was limited to eight cases for greater representation. The number of identified cases far exceeded those finally selected. Continuous follow-up was then necessary for effective communication regarding the required data, how to compile it, and meeting deadlines.

5. Benefits of life cycle carbon measurement and benchmark values

5.1 Life cycle carbon measurement as an opportunity to unleash innovation and competitiveness

The European Green Deal promotes green growth for Europe, based on competitiveness and sustainable innovation. The systemic changes brought about by the EPBD (Energy Performance of Buildings Directive) may provide a competitive advantage for those who adapt first to the new reality.

- Professionals trained in BIM (Building Information Modelling) and LCA (Life Cycle Assessment)
- Technical teams that prioritise sustainability with a life cycle approach in their projects
- Builders who understand the scope of the change and can adapt to the decarbonised model
- Developers who are the first to declare the life cycle carbon of their developments linked to their Energy Performance Certificate (EPC)
- Manufacturers who are the first to produce their Environmental Product Declarations (EPDs), as specific data reduce the impact calculation results and will be prioritised in technical specifications
- Manufacturers whose products are focused on decarbonisation

5.2 Benefits of having reference values

Having a baseline reference allows us to understand where we are and where we could potentially reach. INDICATE has laid the first stone towards defining it.

Policymakers

- Anticipate the impact of the construction sector given its growth forecasts and assess to what extent emission limits may be necessary.
- Stimulate renovation by comparing its impact with that of new construction.
- Formulate decarbonisation policies and identify those measures with the greatest potential. Given that INDICATE is a flexible calculation framework, a later development could serve as a tool to simulate the impact of different policies.

Public and Private Developers

- Incorporate sustainability as a market positioning strategy.
- Support for non-financial reporting and taxonomy.
- Reduction of scope 3 emissions from their activities.

- In Green Public Procurement, having a baseline facilitates the application of requirements beyond those needed for the private sector. This can help generate demand for decarbonised products and buildings, stimulate the market, and serve as an example.

LCA Practitioners (consultants, designers, etc.)

- Benchmarks and reference values to assess the project's carbon footprint against industry standards and identify opportunities for emission reduction and improvement
- Support for project decision-making

Manufacturers

- Evaluation of the influence of their products on benchmark values
- Boost to the decarbonisation of their products
- Incentive to improve data quality and produce EPDs

Financial Institutions

- Provide investment references for banks and investment funds
- Development of financial products for low environmental impact projects, such as green mortgages

Sector Training Providers

- Internalisation of an order of magnitude that can be communicated to the sector
- It allows for an open and transparent methodology that can be used as an educational resource

6. Recommendations

All stakeholders in the value chain must act, and they must do so through collaboration, assuming responsibility as a sector to address the dual challenge of providing affordable housing within planetary boundaries, while achieving decarbonisation of the sector.

6.1 Recommendations for Policymakers in Spain

Preliminary Considerations

As outlined before, the Ministry of Housing and Urban Agenda (MIVAU) proposes to implement a Life Cycle Assessment (LCA) methodology by 2026. This methodology may potentially include mandatory reporting for A1-A3 (product stage) and B4 (replacement) for certain building elements, with default values, or a voluntary declaration for the rest of the modules and elements. Work is also underway to develop an initial list of default generic data, which will be published during 2025. This initial approach effectively addresses several needs:

- **A harmonised methodology is necessary to improve comparability and demonstrate decarbonisation potential**. While it is possible to decarbonise buildings even without an official LCA method, such as by comparing with other LCAs conducted using the same methodology, analysing progress in relation to previous buildings, or comparing with a reference building or sustainability certification values, **only an official harmonised methodology ensures comparability**. Different methodologies with varying scopes and levels of thoroughness hinder LCA comparability and create disparities, **discouraging rigour and generating distrust in the LCA methodology**. The INDICATE methodology for synthetic cases offers a comparative framework in the absence of an official method and highlights aspects that the official methodology will need to define, providing a viable proposal. As an open and improvable method, it can be adapted to a future official methodology and automatically recalculate its results.
- **A balance is required in defining the scope of the LCA.** Only a cradle-to-cradle methodology prevents the hidden displacement of burdens between stages and allows for the strengths of each construction system to be highlighted, reflected in different life cycle modules. This facilitates flexible decarbonisation that includes the entire industry. By making it mandatory to calculate only the product stage (A1-A3) and its replacements (B4), with default values for the remaining modules, the more mature and straightforward aspects of the methodology can be included without losing the full life cycle perspective. At the same time, this allows for the temporal value of the initial carbon peak in A1-A3 to be considered. The same applies to the building components. By making it mandatory to calculate those with the greatest impact and including default values for the others, the difficulty of implementing building carbon footprint measurement is reduced.
- **Flexible decarbonisation**. There is no silver bullet in construction—a single solution, system, or product that alone can meet the decarbonisation goal. The entire construction industry must be involved to achieve the objectives with flexibility. Many manufacturers are implementing decarbonisation measures driven by climate law and the European agenda. Only a cradle-to-cradle LCA methodology avoids hidden burden shifts between stages and highlights the strengths of all decarbonisation strategies, which are reflected in different stages and modules of the life cycle:

- Low embodied energy in manufacturing and/or construction
- Carbon storage capacity
- Reusability or recyclability (building as a material bank)
- Durability, both within the system's limits (fewer replacements) and beyond
- Low maintenance requirements
- Degradability and low emissions upon decomposition

- **Reducing the upfront carbon spike is crucial due to its temporal value.** In the product stage (A1-A3), a carbon peak occurs even before the building is occupied (Fig 14). Temporal value implies that carbon avoided today is more valuable than that avoided in the future. Reducing its impact buys time to implement mitigation and adaptation policies. Additionally, A1-A3 creates less uncertainty because it relies on manufacturer data, rather than assumptions. Moreover, more data is available since these stages are mandatory in the preparation of Environmental Product Declarations (EPDs).
- **Focusing on the building elements with the greatest impact is key.** The MIVAU approach will include mandatory declarations for certain elements, with default values introduced for the others the foundation, structure, and facades carry significant weight. Finishes are also important, mainly due to replacements in B4 (Figures 18 and 19).
- **A database or list of default generic environmental data is essential** because:
  - Many product categories lack EPDs. The process of drafting the necessary harmonised standards for EPDs for all products could take many years, posing greater challenges for more innovative products.
  - During the initial stages of a project, generic data is always useful to allow quick comparisons between different solutions.
  - Even if EPDs exist for A1-A3 data, the rest of the modules must be completed to conduct a cradle-to-cradle LCA. It is important to note that version A1 of the EN 15804 standard for the preparation of EPDs required the declaration of only A1-A3, while the current version A2 mandates, with some exceptions, the declaration of A1-A3, C1-C4, and D. MIVAU will publish a list of default generic environmental data by 2025, with support from the University of Seville.
- **Capacicty building.** Dissemination is key to generating demand for LCA training. The central administration needs to raise awareness throughout the sector about the upcoming mandatory carbon footprint measurement.
  In this regard, MIVAU has presented the project **'ARCE 2050, Zero Emissions Architecture'** to accelerate the decarbonisation of the Spanish real estate sector and provide information on the entire process. It will be accessible from: https://www.mivau.gob.es/arquitectura-edificacion. In addition to this initial MIVAU proposal, already in development, the following recommendations are suggested for advancing life cycle carbon accounting to effectively drive decarbonisation.

Recommendations for the definition of the LCA Methodology

Priorities to Address:

- Develop a communication and dissemination strategy for regulatory actions regarding decarbonisation of the construction sector.
- Design and publish the official harmonised cradle-to-cradle LCA methodology, allowing the strengths of construction products regarding decarbonisation to be highlighted.
- Encourage policies that emphasise the temporal value of carbon in the product stage.
- Promote policies that maintain the value of resources used, in line with circular economy principles.
- Develop a default generic data list and ensure its ongoing maintenance, review, and expansion, enabling API connectivity with available tools.
- Consolidate a working group to progressively define the methodology and set boundaries.

Long-term:

- Establish a data infrastructure to store and monitor the lifecycle carbon data of buildings, facilitating tracking of the decarbonisation process.
- Develop a national roadmap for the decarbonisation of the building sector in Spain, aligned with the mandate of the EPBD, through a co-creation process with stakeholders. The European project BUILDING LIFE, in which GBCE is a partner, is working precisely in this direction. Available at: https://gbce.es/proyectos/building-life/

1. Definition and dissemination of an official methodology to incentivise and clearly assess resource value retention, a priority of the circular economy.

As shown by the high impact at the product stage (Fig. 15 and 16), maintaining the value of resources already used in building components and the building itself is a key strategy for decarbonisation and is one of the fundamental principles of the circular economy.

a) **Value retention within the building system: Durability.** As expressed by contributors throughout the process (section 4.5), decarbonisation must not be an excuse for compromising the quality and durability of buildings. An official methodology must clearly consider the advantages of durability:

- Components with a lifespan of less than 50 years: Improving their durability means fewer replacements in B4 (substitution).
- Components with a lifespan greater than 50 years: they should be properly valued, as established in the EN 15978 standard or its upcoming revision expected for mid-2025.

b) **Value retention beyond the system: Building as Material Banks.** Buildings are designed to be dismantled, with their components reused, remanufactured, or recycled in other buildings, prioritising maximum value retention. Functional or aesthetic obsolescence often occurs

before physical obsolescence. Disassembly facilitates a life beyond the system and reduces the impact of renovations. Adaptability reduces functional obsolescence. The absence of toxins and maintaining the identity of materials make recirculation easier. An official methodology must consider the benefits of the building as a material bank.

- Benefits in the original building result in negative emissions in D, beyond the system.
- Benefits in the receiving building result in emissions avoided in A1-A3.
- Necessary treatments for recovery are accounted for as positive emissions in D, which coincide with emissions in A1 of the receiving building (processing of secondary materials).
- To avoid double counting, module D should always be reported separately.

2. Inclusion of multiple indicators in regulations, based on different Functional Units, for a better understanding of building performance.

Identifying the appropriate functional unit is crucial. The standard defining the surface area must be clearly indicated, and it will need to be decided which indicator(s) will apply future limits.

a) Relative indicator per unit of surface area (gross floor or usable) – $KgCO_2eq/m^2$ – facilitates comparison between construction systems and allows the impact of the entire building to be understood, based on its total surface area. However, it complicates the comparison between typologies, requiring the proportional allocation of shared spaces to compare different housing types. The variation in impact per unit of gross floor and usable surface area can range from 20-30% depending on the typology (Fig. 8 and Fig. 10). To select the main surface indicator, gross floor or usable, references from other international studies (Ramboll [38], CO_2mpare [49], etc.) can be considered, and the guidelines from Level(s) on whether the IPMS standard will be adapted in the communicated results should be monitored. In any case, the EPBD uses usable surface area (greater than 1.000 m^2) as the reference for mandatory reporting from 2028.

b) Relative impact indicator per heated floor area – $KgCO_2eq/m^2$ HFA, as in the energy performance certificate (HFA in Fig. 11) allows for easier comparison of the impact between different types of housing by allocating the impact of shared indoor spaces over the dwelling's surface area.

c) Indicators per capita. Given the trend towards larger houses with more surface area per occupant, a relative indicator to surface area may be insufficient, hindering effective decarbonisation. A per capita indicator – $KgCO_2eq$/per capita (Fig. 14) – can drive efficiency in space usage and include an absolute indicator without needing to affect total dwelling size.

d) Specific indicators for high-impact areas. Underground parking facilities have a significant impact (Fig. 8). Paved outdoor areas have a very high impact due to replacements (Fig. 18 and 19), and large developers tend to increase these spaces. Therefore, the introduction of specific indicators for these areas is recommended:

- **Outdoor areas** – $KgCO_2eq/m^2$ outdoor surface – since the impact of these areas decreases with landscaping, an irrigation water consumption indicator should be included alongside.
- **Parking areas** – $KgCO_2eq/m^2$ parking – limiting this could incentivise lower-impact designs and promote sustainable mobility, reducing reliance on private cars. Reporting it separately also facilitates comparison between typologies.

3. Introduction of alerts on the consistency of the results. Use of Artificial Intelligence (AI).
The use of alerts based on consistency of results and the proportionality and symmetry between the different modules can serve as a quality control mechanism and support for LCA practitioners. AI and the introduction of advanced mathematics to relate variables are effective tools for analysing the accuracy and coherence of results and open new fields of study, already being applied in INDICATE-ES. For example, symmetry between:

a) A5 (construction) and C1 (deconstruction);

b) Construction transport (A4) and waste transport (C2);

c) Product stage (A1-A3) and waste treatment and disposal (C3-C4);

d) Biogenic carbon consideration in A1-A3 and in C3.

4. Need to create a building-level data repository.
In Spain, LCA data management at the building level is proposed at the regional level alongside the Energy Performance Certificate (EPC), but mechanisms and agreements between administrations are needed to complete a repository with LCA data at the building level. The geoportal that currently collects EPC data could also help gather lifecycle carbon data. The data collected will allow better understanding of building behaviour to:

a) Refine default values for non-mandatory stages and components in the carbon reporting of the new DB-SA of the CTE from 2026.

b) Adjust the baseline of reference values defining the performance of the existing building stock and complete the data from INDICATE or other parallel projects, helping to define the roadmap for future limits.

c) Detect and complete LCA consistency alerts.

5. Maintenance, updating, and expansion of the default generic data list.
It is urgent to have a default generic data list to begin measuring as soon as possible, but also to ensure that default values are properly assessed. Although in the short-term internal consistency will be more important than data accuracy, it will be necessary to refine the data progressively. This will be possible as more building LCAs and product EPDs become available. Additionally, the most innovative products, which might face greater challenges in developing their EPDs, should be represented in this generic database.

An eventual continuation of INDICATE- ES could contribute to the development and analysis of new data to refine the default values. Furthermore, the research could be extended to other geographical areas, different typologies or partial analyses of the systems that make up the building, among other aspects. INDICATE- ES makes available the hypothesis used in the project, facilitating their integration in new developments. This would allow, for example, to channel the development of specific aspects through doctoral programmes.

6. Improving information on elements and systems with the greatest impact.
As shown in Fig 18 and 19, the impact of installations is relevant, but there is little information available on this, so it is recommended to promote improvement of these data.

7. Programme of use for the early application of the EPBD.
The goal of starting measurements in 2026 is to gather data to establish a roadmap that incorporates progressive limitations starting from 2030. According to the directive, these limitations will apply to all new buildings, beginning in 2028 for those larger than 1,000 m^2 of usable space. We recommend a gradual implementation of the directive, taking advantage of its early adoption in Spain in 2026 to apply slightly higher limits during the preceding period, allowing for a progressive upskilling of the sector. Regarding renovations, it is recommended to initiate an analysis process similar to the one carried out in INDICATE

8. Progressive and announced inclusion of other impact indicators.
Starting with carbon accounting simplifies the initial implementation of LCA methodology, especially given the difficulty in creating default generic environmental data. However, it is recommended to:

- **Communicate** early on the intention to gradually introduce other indicators, raising awareness of their importance to encourage sector engagement.
- **Prevent** manufacturers from hiding impacts through their decarbonisation efforts. For example, incineration of waste as a decarbonisation strategy can generate toxic emissions depending on the type of waste incinerated.
- **Prioritise** introducing indicators that report water consumption and pollution throughout its lifecycle, and even limit water consumption during the operational phase, given Spain's high risk of desertification (74% of the territory).

9. Launching a co-creation process to define a roadmap including progressive limit values.
It is recommended that, when the time comes, decisions be made through a consensual co-creation process, similar to the one followed with INDICATE-ES. The consolidation of a group of collaborators established during the current process is considered one of the project's main achievements. In later stages, it would be beneficial to include other stakeholders, especially manufacturers, financial institutions, developers, etc.

Recommendations to policymakers for the decarbonisation of the sector

Priorities to Address

Short term

- Analyse the availability of Environmental Product Declarations (EPDs) by product type and support the creation and updating of EPDs through subsidy programmes, funding, or tax incentives.
- Encourage innovation and especially support SMEs developing innovative decarbonised products.
- Promote building renovation as a key decarbonisation strategy.

Short term

- Review urban planning from a decarbonisation perspective.
- Promote sustainable mobility that reduces reliance on private cars, thus decreasing the need for parking in buildings.
- Support and encourage innovation in biological-based construction products, derived from rural by-products, to foster the development of the primary sector in depopulated Spain.

1) Support for the development of product-level data (EPDs) and innovation.
One of the basic strategies to reduce the carbon footprint of buildings is the use of higher quality data. Therefore, having an EPD will already provide a competitive advantage for manufacturers. However, It's not just an accounting reduction; better data leads to more effective decarbonisation.

- Obtaining a clearer picture of the impact of the building stock can make the implementation of decarbonisation policies and strategies more effective.
- The creation of EPDs will help manufacturers progressively decarbonise their products and offer a competitive edge to those with lower carbon footprints.

It is important that governments provide support through subsidy programmes, funding, or tax incentives for the creation and updating of EPDs. Special priority should be given to manufacturers developing innovative products and systems that reduce the impact of construction, particularly SMEs. Innovation addresses new challenges, in this case, the challenge of decarbonisation.

INDICATE-ES has used 133 EPDs, but it has been noted that most of them are for finishes. It would be beneficial to identify product families with the greatest deficiency in EPDs and implement specific support programmes, for example, sawn wood, waterproof membranes, and others.

2) Design regulations and political instruments to incentivise the reduction of initial carbon peaks in the product phase (A1-A3).
It is recommended to incentivise low-carbon footprint products, supporting manufacturers and researchers in developing innovative products through support mechanisms such as:

- Developing and promoting existing product decarbonisation roadmaps.
- Innovating in bio- and geo-based products, circular economy, digitalisation, industrialisation, etc.

3) Support for bio-based products to promote rural support and territorial cohesion in a circular economy.
Biological-based construction products made from by-products of agricultural or livestock activities are an example of the innovation that can drive the review of the EPBD. These products offer low-energy manufacturing solutions and generate co-benefits. Within a circular economy framework, which does not compete with food security but reinforces it, these products add value to depopulated rural Spain, offering an opportunity for territorial cohesion and rural development. Sub-products like sheep wool derivatives, rice or other cereal straw, or wood chips from forest cleaning or agricultural pruning can help create employment in rural areas.

Moreover, halting rural depopulation helps reduce the geographical mismatch of unoccupied housing and alleviates the housing availability crisis in Spain.

4) Prioritise building renovation and retaining the value of existing structures.
The climate emergency and housing needs necessitate a shift in mindset towards retaining the value of already built structures and making use of the carbon investment in the existing stock.

- The emissions avoided from the product and construction phases, and new buildings, are very high, and have a high temporal value, encouraging the prioritisation of renovation. An LCA will objectively assess the benefit of impact reduction in A1-A5 compared to the impact of renovation (B5) (see Fig. 15 and 16).
- Improving the durability of components and construction solutions, along with the good condition of structures, will enhance renovation potential. It is advisable to encourage these aspects in regulations wherever possible.
- Designing for adaptability and disassembly minimises functional obsolescence, a common reason for demolishing buildings before the end of their useful life. Including this in the Spanish Technical Building Code (CTE) would help retain value (Level(s) framework indicators 2.3 and 2.4).

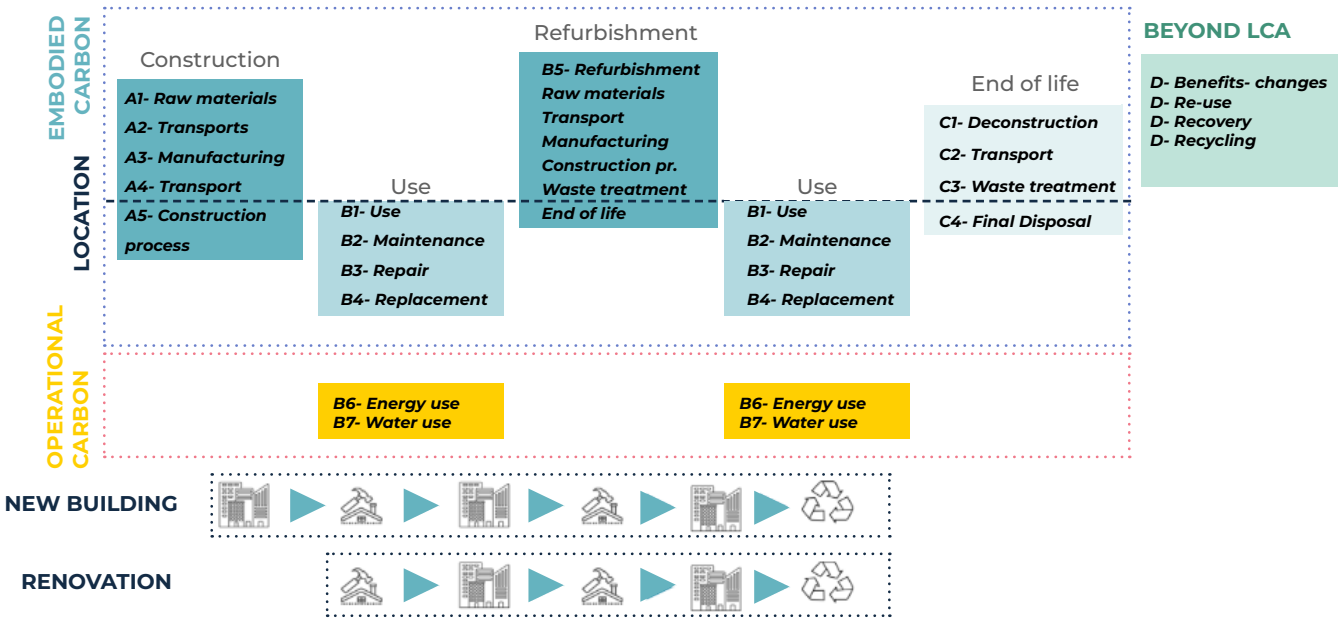

Figure 21 - Representation of life cycle carbon for new construction and existing buildings. Source: Building Life, based on UNE-EN 15978.

5) Review urban planning and mobility from a decarbonisation perspective.
Urban planning greatly impacts the decarbonisation of buildings, as shown by the variability of results for different typologies per floor area (Fig. 10, 11, and 12) and per capita (Fig. 14).

- For single-family houses, terraced houses have a lower impact per m² than detached ones. For multi-family buildings, taller buildings have a lower relative impact than shorter ones. When considering per capita impact, detached single-family houses have a higher impact than multi-family ones. Urban planning should take these factors into account.

- Basement parking, which are prevalent in our car-dependent cities, have a high impact (Fig. 8). Alternatives must be reconsidered. Urban development oriented towards public transport and sustainable mobility reduces dependence on private vehicles and the need for on-site parking. In any case, it is recommended to rethink the configuration of the car parks and relocate them on the ground floor or semi-basements. The profitability of land is a barrier to these decisions, so urban planning regulations may need to enforce this change. Additionally, setting lifecycle carbon limits for buildings could drive this configuration change by defining limit values that affect parking.

6) Highlight the value of Green Infrastructure and Nature-based Solutions (NbS).
Landscaped outdoor spaces reduce the impact of paving and its replacements (Fig. 18 and 19). Connecting these green spaces through green infrastructure offers co-benefits for health and resilience that go beyond decarbonisation. It is important to remember that biodiversity and healthy soils act as carbon sinks, and fighting climate change depends not only on reducing emissions but also on protecting natural sinks.

6.2 Recommendations for designers and LCA practitioners

Priorities to Address

Short term

- Training in Life Cycle Assessment (LCA).
- Gradually incorporate LCA methodology from the preliminary design stage.
- Internalise an order of magnitude and reference values for decarbonised solutions.
- Familiarise with sufficiency strategies, which have greater potential to reduce the carbon footprint

Long term

- Incorporate the life cycle approach and LCA as an integrated tool in project development, with a full cradle-to-cradle scope.
- Identify decarbonised solutions and products as an additional requirement in the project specifications.

1. It is necessary to integrate the life cycle approach and LCA methodology as a **design tool from the first steps**, not just as a final report.

2. **Digitalisation** and the use of Building Information Modelling (BIM) will improve information management and facilitate the implementation of LCA methodology.

3. **Prioritise sufficiency strategies**. The carbon footprint depends on the quantity of materials incorporated into a building. Optimising spaces and volumes, with decisions relating to building configuration and form, reduces the absolute impact and not just the relative one per unit of surface area (Fig 13). The references obtained in INDICATE regarding typologies help in decision-making at this stage.

4. Once the quantity of necessary materials is reduced, **prioritise low carbon footprint solutions with a life cycle approach**. Prioritise low-impact products and solutions, whether due to their low embodied energy from manufacturing or by incorporating secondary materials (reused, remanufactured, or recycled). For products with a higher footprint in the product stage, optimise them as much as possible and aim to reduce their impact in other stages, whether through their durability (fewer replacements in B4 or benefits beyond the system in D) or their ability to be recirculated in other buildings (benefits beyond the system in D).

5. **Focus on the aspects that generate the greatest impact**. For embodied carbon, focus on reducing the product stage and the number of replacements. Focus on the structure and envelope. **Avoid subterranean volumes where possible**, due to the impact of retaining structures (Fig 8 and 16). For operational carbon, analyse its reduction with a life cycle approach that considers the embodied carbon of both passive and active measures implemented.

6. **Prioritise maximum value retention**. Assess the possibility of renovating existing buildings before opting for new construction. Conduct a comparative LCA to analyse the impact of both options. If renovation is not possible, consider reusing some elements.

7. **Design for disassembly** to facilitate the retention of product value for as long as possible, whether in the same building (durability) or as a material bank for other buildings.

8. **Design for adaptability** to avoid functional obsolescence, extending the building's useful life and enhancing its future renovation potential.

9. **Incorporate Nature-based Solutions (NbS)** for their lower carbon footprint and co-benefits for health and climate resilience, such as outdoor landscaped areas instead of paved ones (high impact from their replacements).

10. Request Environmental Product Declarations (EPDs) from manufacturers and **prioritise the use of products with EPDs** in project specifications to achieve better results and promote product decarbonisation. Bear in mind that comparing individual product EPDs is insufficient; **complete construction solutions should always be compared**, with performance described in equal functional units (thermal, acoustic, mechanical, fire performance, etc.) and considering their assembly, which affects durability and potential for future recovery.

6.3 Recommendations for public and private developers

Priorities to Address

Short term

- Training in Life Cycle Assessment (LCA) for technical teams.
- Incorporate life cycle carbon measurement into the technical specifications of tender documents.
- Prioritise the use of products with Environmental Product Declarations (EPDs).

Long term

- Progressive decarbonisation of construction solutions by identifying and applying the products and systems that contribute most to this.
- Incorporation of a material passport that maintains the identity of materials and helps turn the building into a future material bank.

1. Make data-driven decarbonisation a competitive advantage and market strategy.

2. Incorporate life cycle carbon measurement into the **technical specifications of private (large developers) and public (Green Public Procurement) tenders**. Consider the educational impact these tenders have on many professionals.

3. Reconsider the **configuration and programme of the building, prioritising decarbonisation**. Where possible, and considering the impacts of different typologies and basements, reconsider the building's configuration and volumetry. Incorporate LCA methodology into the initial feasibility calculations of developments. Optimising for decarbonisation linked to sufficiency strategies implies cost optimisation by reducing the material and energy resources mobilised without losing performance. This is about avoiding waste, which can even result in savings.

4. **Consider introducing Nature-based Solutions (NbS)** in the outdoor spaces of developments, valued for leisure and health, but with a real impact on decarbonisation and other co-benefits that may add value. For example, non-paved green spaces reduce urban heat islands, regulate runoff, reduce pollution, improve biodiversity, etc.

5. Use life cycle carbon measurement in **Corporate Sustainability Reporting (CSRD)** and explore the possibilities of sustainable financing linked to taxonomy.

6.4 Recommendations for the Industry

For manufacturers

1. Generate Environmental Product Declarations (EPDs) for their products according to the EN 15804-A2 version, as it provides a competitive advantage by offering key information to specifiers and designers.

2. Promote the decarbonisation of their products with the help of EPDs. Innovative construction product manufacturers that add low-carbon accounting to their features will benefit from market demands:

    - Concrete and steel with lower carbon footprints than traditional ones.
    - Local products with low embodied energy and mineral-based, such as compacted earth, lime, clay, etc. (geo-materials).

- Local low-impact, bio-based products like wood, plant fibres, mycelium, bamboo, cork, sheep wool, natural linoleum, etc., which temporarily sequester carbon (bio-based materials).
- Resource-efficient construction systems that reduce the carbon footprint: prefabricated, industrial, modular, parametric, etc.
- More durable products and construction solutions, requiring fewer replacements or extending the building's life beyond the 50-year study period.
- Solutions and products supporting the circular building model as a material bank.
- Construction solutions and products that support intersectoral circularity, such as by-products from the textile, agriculture, or livestock sectors.

For builders and contractors

1. Industrialisation: Adoption of more resource-efficient construction systems that reduce the carbon footprint, such as prefabricated, industrial, modular, parametric systems, etc.
2. Adoption of circular economy principles to retain the maximum value of the resources used.
3. Digitalisation for better information management to support the circular economy.

For Owners of LCA Calculation Software

1. Monitoring and adoption of the publication of the official methodology and the publication of the list of generic environmental data by default to access the data via API.
2. Facilitate the incorporation of DAPs from the new EN 15804-A2 version.

For certification schemes

1. Assess the introduction of the LCA methodology from the preliminary design phase.
2. The reference values obtained in INDICATE can serve as scoring references.

6.5 Recommendations for Financial Institutions

1. Implementation of financial models that monetise decarbonisation, such as energy savings.
2. Consider sustainable investment according to the European Taxonomy.
3. Explore the development of carbon markets as they can affect buildings.

6.6 Recommendations for those responsible for training plans

1. Include the life cycle approach in university and vocational (blue-collar and white-collar) training programmes.

6.7 Recommendations for policymakers in Europe

1. **Common Framework:** Although each country may establish different conditions in terms of speed or partial goals, the final goal of climate neutrality by 2050 for all of Europe requires that European comparability be guaranteed at least through:

    - A harmonised European method (from the Delegated Act to be published before 2026).
    - Level(s) as the methodological framework, for example, in the definition of surface area.
    - Definition of information granularity, allowing similar aspects to be compared.

2. **Regional Particularities:** From 2030, the life cycle carbon of buildings will begin to be limited, taking climate zones into account, as determined by the EPBD. However, other aspects besides climate must be considered:

    - The seismic acceleration of site has an important influence.
    - The construction traditions of each area, derived from climate strategies.
    - Local material availability.

    The results obtained by INDICATE-ES are not transferable to other regions in northern Europe, where thermal insulation strategies prevail. Southern European countries, where temperatures are within the comfort zone for much of the year, use heavier materials with greater thermal inertia to protect from summer heat. Inertia dampens and delays the thermal wave entering the building and combines with ventilation during cooler hours to achieve thermal comfort. Although envelope insulation has little impact on the carbon footprint the impact of the solution's inertia is very high. Although there are solutions with low-impact thermal inertia, a progressive implementation of limits is necessary to allow for a realistic adaptation of the industry.

3. **The Need for a Prior Comparative Study**: Based on collected data, to help characterise systems by region and apply different limitations, collaboration between Member States will be needed, with research initiatives already underway, such as INDICATE data [6], CO2mpare [49], or the reports by Ramboll [38], as well as through the systematic collection of building-level LCA data.

4. **Different Risks:** Member States have different environmental and social urgencies. In the case of Spain and other southern European countries, including indicators related to water consumption and its potential contamination is of great interest. It is up to each State to analyse these and establish the indicators and the speed at which they will be included in their roadmaps.

5. **Further Development of LCA Methodology**: Some aspects of Level(s) need revision and clarification.

    - Due to its impact, embodied carbon from replacements (B4) is particularly important and has been considered excessive by INDICATE-ES collaborators, as well as the end-of-life assumptions, which vary significantly between States.

- The rules for renovation need to be clearly defined, including aspects such as penalties for replacements when the product's lifespan has not yet been reached.

6. The inclusion of **future limits should consider module D** to support circularity strategies and others. For example, an increase in emissions may occur in the product stage due to the inclusion of photovoltaic systems with grid feed-in, which is accounted for in D. Additionally, it is recommended to **introduce a second limitation related to the product and construction stages**, to account for the temporal value of carbon. It would also be possible to introduce a single limitation in D, but by applying a dynamic approach to give more weight to the impacts produced in A, allowing for the temporal value of carbon to be taken into account. In any case, the application of limits at the European level must be progressive, with the speed of implementation adapted to the construction reality of each Member State, regardless of their final convergence.

7. Next steps

7.1 Capacity building and the need for raising awareness

The entire sector must integrate the life cycle approach into its working philosophy. Training is essential, but raising awareness and **sparking interest** to generate demand for education is also necessary.

This responsibility should be shared across various stakeholders: academia, vocational training, professional ssociations, construction institutes, NGOs, and even public (Green Public Procurement - GPP) and private developers through the specifications of their tenders. In any case, the MIVAU initiative to centralise the related information on the ARCE 2050 website will be very helpful in raising the sector's interest.

INDICATE-ES collaborators lead several related initiatives (see Annex Initiatives).

Actions aimed at raising awareness and communicating a sense of scale:

- Statistical data related to building permits.
- Dissemination of research projects through conferences and seminars.
- Workshops and working groups in professional associations.
- Construction awards.
- Development of project tools that promote the life cycle approach.
- Through technical specifications in tender documents for public (GPP) or private bids from large developers.

We invite other administrations and interest groups to take up these initiatives of INDICATE-Spain partners, and all international INDICATE projects to collect and disseminate initiatives of interest.

7.2 Refinement of the method

INDICATE is an open methodology that automatically recalculates results with future adjustments.

Base methodology

- Adaptation to the revisions of the Spanish Technical Building Code (new DB-SA), the EN 15978 standard, and Level(s).

Optimisation of Tools and Processes:

- B4: Replacements. Detailed studies are needed to analyse replacements more realistically.
- Improve generic data applied to A5, B2, B3, B5, and C1, based on studies by Kellenberger, and update it with Spanish values with the support of collaborators who have already offered to provide data for future studies.
- Improve assumptions regarding recycling (C2) and landfilling (C3).
- Inclusion of buildings with different geometries for each typology. The 18 variations of the 7 typologies, up to a total of 126 synthetic cases, are based on a single geometric model for each typology. It is necessary to simulate other geometries to consider factors such as compactness and to blur the particularities of the design of the projects analysed here, which are based on real buildings provided by the collaborators, and whose basic characteristics can be consulted in the annex and the web repository.
- Incorporate module D as soon as more data becomes available.

Expansion of Underlying Data:

- Increase the number of Environmental Product Declarations (EPDs) of construction products.
- Include EPDs for some product families, such as sawn wood, waterproofing membranes, and others.
- Update EPDs from the previous version of the EN 15804-A1 standard to the new A2 version.
- Improve data on installations.

7.3 Preparation of the progressive limit values of the roadmap

The values obtained from the synthetic cases in INDICATE are a reference framework upon which real data can be superimposed, and they will converge once a harmonised method exists.

Values defining the third quartile could serve as a key reference for a progressive roadmap (Fig. 8), where the 25% of solutions with the highest impact would be outside what is acceptable. As building impacts decrease, this value will diminish, allowing it to always serve as a progressive target.

- It should be noted that the box and whisker chart values in INDICATE-ES are not statistical but rather reflect possible ranges. Limiting quartiles restricts solution types, not a statistical sample. A statistical analysis would be needed to identify what percentage of Spanish buildings would be affected by limitations based on quartiles. Other countries, such as Denmark, have also used quartiles to define their roadmap. However, in their case, the data is based on real cases.

- We recommend analysing the suitability of using different limit values depending on the location, according to mechanical requirements (seismic zone, soil resistance, etc.) and thermal requirements. For example, by applying coefficients to base common limit values across the territory.
- We recommend that the ratio used in limit values consider not only the building's constructed or usable area but also the heated area, which corresponds to that of dwellings and provides a more accurate and fairer image by allocating the impact of common areas to the houses.
- As mentioned in the recommendations to European policymakers, we recommend a double limitation: on one hand, including module D to promote circularity, and on the other hand, focusing solely on stage A to reduce the initial carbon peak that will allow us to delay a climate tipping point of no return. It would also be possible to apply a single limit in D with a dynamic approach, giving more weight to the impacts produced in A.

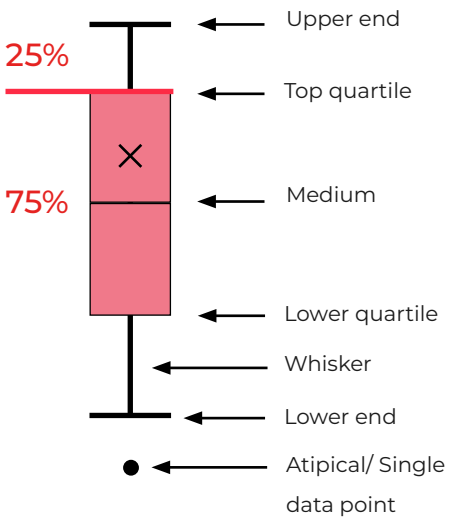

Figure 22 - Example of emission limitation based on the upper quartile of the sample.

In any case, while INDICATE provides an initial idea of building behaviour and what the reduction framework could be, the desired process would be as follows:

1. Approval of an official life cycle carbon measurement methodology (pre-consultation period) and a default generic data list.
2. Recalculation of INDICATE results based on the official methodology and progressive refinement of results, including the solutions defining maximums, minimums, and modes.
3. Collection of real data carried out using the official harmonised methodology.
4. Convergence of results from real and synthetic cases and the establishment of a data framework, confirmed by statistical data.
5. Establishment of the roadmap, based on the third statistical and harmonised quartile.
6. Progressively, the box and whisker chart shifts towards lower values, making the third quartile limitation (25% of buildings) more demanding and requiring a review of limits over time.

To define the limit values and roadmap, we recommend following a co-creation process like the one used by INDICATE-ES, involving all stakeholders, which will facilitate acceptance of the decisions. The working group established in INDICATE could be a starting point, which should be expanded to include construction product manufacturers, developers, financial institutions, and educators.

7.4 INDICATE as a testing tool for decarbonisation policies

INDICATE-ES is not just a set of reference values but also a a flexible calculation framework and a potential tool for policymakers, as it can serve to test decarbonisation policies. The automated system used to develop synthetic data can model new scenarios arising from different decarbonisation policies and strategies. This helps in determining which policies are the most cost-effective. For example: accelerating the decarbonisation of the energy mix, increasing the use of renewables, feeding energy back into the grid, implementing district heating and cooling (DHC) networks, supporting a circular economy model, or promoting the decarbonisation of various materials.

The current development of INDICATE-ES is a first step in an iterative process of continuous improvement. There is still work to be done, not only to refine the results and allow for the modelling of all possible decarbonisation and environmental footprint reduction policies, but also to include renovation projects and other types of buildings. At present, it provides a snapshot of the current situation, but it could evolve into a set of snapshots of parallel scenarios. It is also a system that can be replicated in other regions.

7.5 Enabling framework and supportive policies

The political will of Spanish government to implement the Energy Performance of Buildings Directive (EPBD) at an early stage provides a favourable framework for the usefulness of INDICATE-ES results. The involvement of the IETcc-CSIC as collaborators in INDICATE and MIVAU as observers, along with the support of the University of Seville in developing the default generic data, enhances the method's utility as a starting point.

The co-creation approach fosters the acceptance of INDICATE-ES results and their subsequent dissemination by the collaborators themselves. The transparency of the process encourages potential future developments by third parties, building on the work already done and pooling efforts.

7.6 Limits to the use of INDICATE-ES results

The results obtained through INDICATE should be considered as a **preliminary approximation to a baseline range of reference values within a research project** that has created a highly useful initial reference framework and consolidated a reflection group around the methodology.

Any use of the data/methodology outside the project context should be analysed based on the specific objective. The use of ratios for regulatory applications or in public tenders would require further refinement, clarification, and adjustment of certain aspects. This is particularly important not only to ensure proper implementation, acceptance, and confidence from the sector but also to avoid potential inconsistencies with applicable regulations or standards.

8. Key messages

1. The need for data at both product and building levels: Specific data (EPDs) are required to achieve better results and to drive the decarbonisation of products; generic data are needed for early project stages and to fill information gaps, as well as building-level LCA data based on an official harmonised method, which will provide a statistical framework for setting a roadmap with progressive limits.

2. The need for an official harmonised LCA methodology: A cradle-to-cradle methodology that highlights the strengths of all products and project strategies. This methodology should have a holistic view, covering all stages and all impacts, but it is essential to start gradually, based on some certainties.

3. The need to report absolute indicators (per occupant), not only relative ones (per m^2), to accurately reflect the decarbonisation of the built environment, given the trend towards building larger houses with more space per occupant.

4. The influence of seismic zones in the application of life cycle carbon limits.

5. Reducing the impact of outdoor areas through landscaped zones, considering additional co-benefits (health and resilience).

6. The importance of incorporating LCA as a tool in the early stages of the project, to make high-impact decisions, such as building typology, volumetry, or the incorporation of underground parking, aspects that affect the percentage of common areas, envelope surface, or containment structures.

7. The importance of focusing on the life cycle elements and modules that generate the most embodied carbon, specifically the product stage and the structure.

8. Considering the temporal value of carbon due to the climate emergency and prioritising the reduction of the initial carbon peak by selecting low-impact products. It is essential to support innovation in decarbonised products and systems and to promote renovation to offset the carbon already invested in the existing building stock.

9. The importance of the circular economy, which enables the maximum retention of resource value, either during the building's life (durability) or beyond it (building as a material bank).

10. The urgency of raising awareness and training the sector in life cycle and LCA approaches.

11. Collaboration across the entire value chain is necessary for building decarbonisation.

12. Decarbonisation is an opportunity to unleash innovation and improve the sector's competitiveness, with multiple co-benefits for development.

13. Decarbonisation applies at all scales, from product and building to urban and territorial.

14. Public sector leadership through Green Public Procurement plays a crucial role due to its exemplary value, which can help develop the market.

15. Decarbonisation is the only way to respond to the need for affordable housing within the planetary boundaries.

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