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Rethinking social housing in terms of environmental sustainability: An empirical analysis

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Research Paper

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Rethinking social housing in terms of environmental sustainability: An empirical analysis

Environmental problems are being increasingly recognised as critical strategies for attaining sustainability in social housing, given the persistent demand for social housing in urban areas. However, to remain inexpensive, housing built for low-income groups requires greater environmental compromises. The main objective of this study is to examine social housing projects from an environmental sustainability standpoint and determine whether they have a low environmental impact. This study also aims to inform policymakers about the environmental sustainability of social housing projects and provide an opportunity to review housing policies in terms of environmental sustainability. Six social housing projects were selected under the same climatic conditions from Spain and Turkey, with distinct economic classifications and housing policies. The findings indicate that although social housing built in Spain has a smaller carbon footprint than Turkey throughout the manufacturing (A1–A3) and building (A4–A5) phases, social housing projects in both countries cannot be classified as low-impact housing projects.

Key words:

housing policy, social housing, environmental sustainability, low environmental impact housing, CO_2 emissions

Prethodno priopćenje

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Preispitivanje socijalnog stanovanja s gledišta ekološke održivosti: empirijska analiza

Ekološki problemi sve češće predstavljaju važne strategije za postizanje održivosti u socijalnom stanovanju, s obzirom na stalnu potražnju za socijalnim stambenim objektima u urbanim sredinama. Međutim, kako bi ostali jeftini, stanovi izgrađeni za osobe s niskim primanjima zahtijevaju veće ekološke kompromise. Glavni je cilj ovog istraživanja ispitati projekte socijalnog stanovanja sa stajališta ekološke održivosti i utvrditi imaju li mali utjecaj na okoliš. Tim se istraživanjem nastoji informirati tvorce politika o ekološkoj održivosti projekata socijalnog stanovanja i pružiti priliku za preispitivanje stambenih politika u smislu ekološke održivosti. Odabrano je šest projekata socijalnog stanovanja u istim klimatskim uvjetima u Španjolskoj i Turskoj, s različitim ekonomskim klasifikacijama i stambenim politikama. Istraživanje pokazuje da, iako socijalni stanovi izgrađeni u Španjolskoj imaju manji ugljični otisak od stanova u Turskoj tijekom faza proizvodnje (A1–A3) i izgradnje (A4–A5), projekti socijalnog stanovanja u obje zemlje ne mogu se klasificirati kao projekti stambenog zbrinjavanja s malim utjecajem na okoliš.

Ključne riječi:

stambena politika, socijalno stanovanje, ekološka održivost, stambeni objekti s malim utjecajem na okoliš, emisije CO_2

1. Introduction

Globally, approximately 1.47 billion people are considered poor, as measured by the international poverty threshold of $ 1.90 per day [1]. The disruption caused by the COVID-19 pandemic has amplified the forces of conflict and climate change that had already impeded the progress of poverty reduction in 2020, causing severe global poverty to rise for the first time in more than 20 years. As a result of the pandemic, additional 120 million people are now living in poverty, with the number predicted to grow to 150 million by the end of 2021 [2], despite efforts under the Sustainable Development Goal to minimise the population of the urban poor [3]. Several social housing initiatives have been developed in cities to accommodate the socially disadvantaged populations. During the period 2000–2020, slum improvement programmes claim to have helped almost 300 million individuals in slum areas, demonstrating the relevance of housing programmes, and this trend is projected to continue in future decades [4].

Similarly, it is critical to design methods aimed at reducing not only poverty but also the cost of estimating CO_2 emitted over the life cycle of buildings. According to a report released in 2019 by the United Nations Environment Program and International Energy Agency, building and construction sector accounted for 39 % of the global energy-related CO_2 emissions. Most nations have included buildings in their intended nationally determined contribution, a voluntary CO_2 emission reduction target, to minimise CO_2 emissions from the building sector [5]. Among all building types, residential buildings account for 27 % of the global energy consumption and generate 17 % of the global CO_2 emissions [6]. With regard to social housing, environmental issues are being increasingly acknowledged as key policy targets for achieving sustainability in low-cost housing, given the detrimental effects of climate change and natural resource decline [7]. Environmental sustainability in social housing has been stressed since the mid-1990s, in tandem with the promotion of sustainable human settlement development, as declared in the Istanbul Habitat Agenda II in 1995 [8]. Given the significant number of dwellings in the market sector, considerable deterioration in environmental quality and inefficient resource usage may be expected if the housing design is not environmentally sound. Consequently, sustainable architecture has been promoted and embraced, particularly in developed nations, resulting in better living environments for low-income people [9, 10]. However, owing to concerns of being inexpensive, housing constructed for low-income groups makes greater sacrifices to address environmental concerns. Given the building lifecycle, the reduction in greenhouse gas emissions has recently become an environmental priority with regard to social housing development to achieve sustainability [11]. However, there is a lack of clarity within and between housing producers and policymakers on how to jointly address these critical challenges in housing policy, which is exacerbated by a lack of systematic research on theory, practice, and metrics for integrating environmental sustainability and low housing cost. The argument over the costs and advantages of environmentally-enhanced housing, as well as the implications for housing costs, has primarily been presented as a trade-off between the two competing goals, namely, cost and environmental performance. Therefore, the primary goal of this study is to analyse social housing constructed for disadvantaged populations from an environmental sustainability perspective and to seek an answer to the question of whether social housing also has a low environmental impact. Furthermore, given the ongoing need for social housing in urban regions, current policies on low-cost public housing are worth investigating. This study is designed to enlighten policymakers on the environmental sustainability of social housing developments and to provide an opportunity to review housing policies in terms of environmental sustainability. It analyses social housing projects under the same climatic conditions in Turkey and Spain, where diverse housing policies exist. The OERCO2 program was used because of its open-source structure and user-friendly interfaces.

2. Understanding social housing for low-income groups

As industrialisation and urbanisation progressed, individuals moved from rural hinterlands to city centres to find work and improve their standard of living. Governments in many developed and developing nations have been dedicated to providing low-cost dwellings that are appropriate, cheap, and of acceptable quality as a fundamental social necessity for low-income groups. Many regions worldwide have dominated the construction of new residential stocks during the past few decades [12]. However, the use of sustainable construction methods to alleviate the social housing crisis is relatively uncommon [13]. Nevertheless, it is imperative for sustainable intervention in the building environment to survive because of the large financial and natural resources and significant waste streams created by the building sector [14]. The Brundtland report describes sustainability as a development that addresses the demands of today and does not compromise the ability of the future generations to satisfy their own needs [15]. The World Commission on Environment and Development further contends that this idea is the framework for environmental policy integration and development strategies. This definition identifies two essential concepts. The first is the belief that the needs of the poor are met, and the second is the capacity of future generations to respond [16]. Based on both principles, the social housing requirements of the low-income group should be properly addressed, while addressing environmental restrictions, and both should be handled at the present and future levels in terms of development techniques and social components [17]. However, economic means are required to offer social service or to reflect non-profit motivation in making it available to beneficiaries and considering environmental protection in choosing the construction of social housing. Sustainability concerns arise if suitable measures for the provision of social housing are not appropriately and effectively integrated [17]. Energy efficiency measures often have significant initial costs, but the benefits are spread over a long period. With such high discount rates, customers are frequently unable to save for the future or have access to cash for investment [18]. Most of the time, because quantity is more essential than quality in social housing, the focus is devoted to the economically effective use of resources, and, environmental harm is frequently neglected.

3. What is low environmental impact housing?

Low environmental impact buildings, also known as green buildings, generally encompass both building methods and uses that are environmentally friendly and resource efficient over the entire building lifespan [19]. According to the Royal Institute of British Architects, six important principles for low-IE design have been proposed:
- an integrative approach for use of energy corresponding to building type
- use of building shape and fabric to reduce energy demand
- focus on isolation and tightness of air
- implementation of highly efficient services with low-carbon fuel
- implementation of low-carbon operations in buildings
- incorporation of renewable energy [20].

This clearly highlights the significance of early planning and design phases in building production processes, such as building orientation [21], material selection [22], and bioclimatic features [23, 24], for developing buildings with low environmental impact. Although there is no precise definition of low environmental impact housing, some nations have attempted to define it by setting energy consumption limits. For example, in the Danish building code, the energy frameworks in residential buildings are split into two energy consumption levels: low-energy class 1 (35 kWh/m^2) and low-energy class 2 (50 kWh/m^2) [25]. According to González and Navarro [19], the CO_2/m^2 production of low-impact environmental housing is 196.028 kg CO_2/m^2, whereas that of conventional housing is 269.572 kg CO_2/m^2. According to the European Commission, buildings with carbon footprint (tCO_2eq/m^2) less than 0.5 tCO_2eq/m^2 can be classed as having a low environmental effect [26].

4. Efforts in social housing

In developing nations, both the official and informal sectors play a critical role in housing supply [27], whereas housing provision is mostly based on the official sector in developed countries. Low-income housing is referred to by several names, including social, public, affordable, and community-based housing [28]. Each concept relates to the various players involved in housing development and has been developed in response to housing policies that have changed over the previous 50–60 years. Housing policies have undergone substantial transformations in three periods. Beginning in the 1960s, the public housing method was implemented, followed by the establishment of the self-help approach in the mid-1970s and the enabling approach in the mid-1980s [8, 29]. In most cases, public housing is owned and maintained by government organisations, which are in charge of providing housing that includes accommodations as well as essential infrastructure and services. The primary limitations of the first method are the inability to satisfy the immense demand for low-income housing and the inability of the poor to afford housing owing to the high cost of housing units [27]. Due to rising concerns about resource depletion and the detrimental effects of climate change, environmental issues and climate sensitivity among low-income households have received increasing attention in recent years.

4.1. Turkey

In Turkey, social housing has been for a topic of discussion for years as low-income groups are unable to obtain adequate housing owing to a shortage of legal and comprehensive alternatives. However, most of approaches addressed this issue from the standpoint of "household shortage"; the short-term populist policies and ignorance of the complexity of the situation have only contributed to the intricacy of the issue [30]. The concept of social housing remained a peripheral issue until the early 2000s because of a gradual decrease in state intervention in the early years. Until 2000, neither the private sector nor state entities or instruments were able to arrive at a complete answer [31]. Turkey's rapid urbanisation and the size of new structures call for urgent changes in the legislative and operational framework. Government policy measures are frequently required to address the housing requirements of the population without undue costs [32]. In 2002, the government emphasised upon neoliberal policies and pursued a national economic strategy based largely on large-scale construction projects. Because the Government policy was based on the idea thatsafe and cheap housing was no longer available in the market and that low-income people had inadequate living circumstances, the Government began to prioritise housing for people with low incomes [33]. Consequently, the government had to intervene in the market and build as much housing as possible to resolve the situation in the shortest possible time.

Bond-based financial arrangements have evolved in several OECD nations, providing affordable housing providers with low-cost, long-term loans to promote an affordable housing supply [34]. However, in Turkey, only efforts by The Housing Development Administration (HDA) have addressed the affordable housing the problem.

Since the private sector is not obligated to provide social housing because of financial concerns, it avoids constructing social housing. The HDA is Turkey's sole authority for building houses for low-income people. Therefore, the efficacy of the HDA operations that predominate in this sector must be discussed. The objective of this study is to call into question the long-term efficacy of houses produced by the HDA, the sole supplier of social housing in Turkey, in terms of affordability.

The HDA prioritised social housing over the last 20 years [33]. The HDA, founded in 1984 and run on a non-profit basis, has grown to become the principal government body in charge of national housing development [35]. In the Turkish housing sector, the HDA has taken important measures to alleviate housing deficits. The HDA claims that 5–10 % of Turkish housing requirements are met, resulting in approximately 50,000 dwelling units annually. A total of 837,572 dwelling units have been built by TOKI since 1983 [36]. In terms of the allocation of HDA housing projects, 15 % are "Fund raising by method of revenue sharing" projects, while the remaining 85 % are "Social Housing" projects [37]. However, the absence of design flexibility leads to uniformity resulting from fast production, without consideration of regional and climatic differences. Consequently, each region is executed in a standard manner with little modification. Building materials are of the same type across the country. In other words, The HDA generally produces a certain type of standard apartment buildings with flat façades and repetitive designs [38]. The social housing program of the HDA is aimed at the poor, low-income, and middle-income individuals who:

- cannot afford to purchase a home under current market conditions and whose maximum income does not exceed 6500 Turkish lira (277,03 EUR)
- possess a "Green Card",
- "receive salary within the Law No. 2022205",
- "benefit from the Social Aid and Solidarity Encouragement Fund within Law No. 3294206",
- "are not dependent on any one of the social security institutions" [39].

However, sustainability has not been addressed as a key concern in the planning or architectural practices of most social housing developments. While enhancing the quality and speed of social housing projects, it is critical to consider sustainability and reduce conflicts between housing needs and profitability.

4.2. Spain

Housing in Spain is dominated by owner-occupied sector [40], with only a small socially leased sector; government spending on housing policy accounts for less than 1 % of the GDP, which is significantly less in comparison to other developed countries [41]. Due to past governmental policies, housing and real estate have remained significant components of Spain's economy even after the end of the dictatorship, and homeownership has consequently emerged as a pillar of the Spanish political economy. As the most important connection between government policies and the growth of forms of reproduction that benefit the most disadvantaged, housing in Spain is also the most important relationship between government policies and the development of the construction and finance industry [42]. The Franco government encouraged the building industry by providing direct subsidies to builders to foster economic development rather than to achieve social objectives, as was the case under the previous administration [43]. Following the Civil War, a succession of rent regulations were implemented to encourage rental housing while penalising new private investments in rental housing, resulting in the degradation of existing structures. Furthermore, the Spanish housing market has allocated limited resources to the construction of new public housing for rent. Before the 1960s, laws were in place to develop socially leased housing areas owned by the government. As part of the Housing Plan of 1961–1976, the Francoist administration reversed a prior policy that encouraged the construction of state-subsidised housing in which new projects may be privately held [44]. While social housing programmes in the rest of Europe at the time were linked to rent, these policies integrated state housing into private markets. As a consequence of these policies, there has been a widespread public perception that renting is a waste of money, leading to political resistance to fiscal reforms that can benefit the general population [41]. A robust real estate market emerged from the policies of the 1960s; and when combined with the scarcity of social housing, the working class found themselves at the mercy of real estate capitalists. Due to Spain's high homeownership rate and large mortgage debt, the global financial crisis of 2007 revealed fundamental inconsistencies in the housing sector, which had barely increased productivity during the preceding decade [45]. Prior to the financial crisis, 87 % of Spain's housing stock was privately held, and the country had one of the highest homeownership rates in the European Union, with a rate of 76.2 % in 2019, far above the European average of 69.80 % [46]. In contrast to the rest of Europe, where socially rented housing dominates the social housing infrastructure, Spanish housing policy prioritises homeownership, with only 2.5 % of the total housing stock being rented [40]. In the context of "social housing", historically, two distinct alternatives have been utilised to enable housing supply under the label Vivienda de Proteccio´n Oficial, often known as subsidised housing, as well as housing for rent. In the first case, subsidies are provided to both the supply and demand sides of the housing market; in the second case, housing for rent is provided to both the supply and demand sides of the market, with developers qualifying for a subsidy and families benefiting from rents below market rates [47].

In regards to public social housing, circumstances are unique because inhabitants lack both the knowledge and financial means to make significant investments in building retrofitting and energy-efficient equipment replacements. Furthermore, they are often not the owners of the homes and thus do not have the authority to make any significant modifications to the facilities, which makes any investment effort difficult [48].

However, there have been long-standing concerns about evaluating the environmental effects of housing in Spain. First, the European Directive 2006/12/EC was effectively implemented [49]. The construction sector was extremely busy during the first decade of the 21st century, and large amounts of building materials ended up in uncontrolled landfills. However, in 2008, Spain enacted the Royal Decree 105/2008 to encourage prevention, reuse, recycling, and other types of recovery, as well as to ensure that disposal operations are properly treated and contribute to sustainable construction activities [50].

5. Methodology

The OERCO2 tool was used to calculate the carbon footprints of several selected social buildings, which proved to be a helpful method. It is possible to assess the carbon footprint of a residential building project before construction using the OERCO2 tool, which is an online application [51]. The OERCO2 project received funding from the European Union in 2016. The primary objectives of the project are as follows.

- It focuses on the European methodology to calculate CO_2 emissions during the construction process and throughout the life cycle of materials.
- It Implements a standardised European curriculum to enhance the understanding of climate change and disseminates information regarding the emissions associated with various components.
- It creates an open educational resource focused on disseminating information on CO_2 emissions in construction processes [52].

To perform embodied energy assessment, the tool employs a cradle-to-site life-cycle assessment, which is divided into A1, A2, A3, A4, and A5 life-cycle stages, which correspond to manufacturing (A1–A3) and construction (A4–A5) phases [53], Figure 1.

The assessment approach for determining the carbon footprint associated with the construction of residential buildings relies on the analysis of the bill of quantities of the project and the classification system of the construction work. This system facilitates the breakdown of information pertaining to material, labour, and machinery requirements. The OERCO2 software obtains environmental data from the Ecoinvent database using the SimaPro program, chosen because it covers all materials typically used in the construction of buildings [55], Figure 2.

The data derived from the bill of quantities for each project are organised in accordance with the Construction Information Classification System [57] and are presented in units per square metre of construction (u/m^2). The mean quantity of each activity (Qi) is determined using statistical methods for each construction category, as outlined in the model for evaluating building construction [58]. The aforementioned average quantities are converted into inputs, such as materials, manpower, and machinery. The quantities of different resources are assessed using the carbon footprint methodology to determine the CO_2 emissions resulting from all construction procedures. The study of the carbon footprint of residential buildings involves the implementation and construction stages of the building life cycle

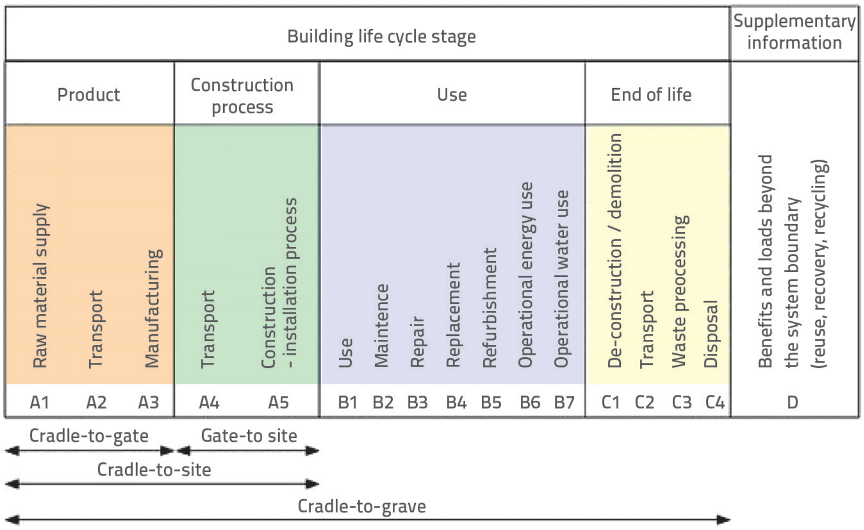

Figure 1. Stages in the life cycle of a building [54]

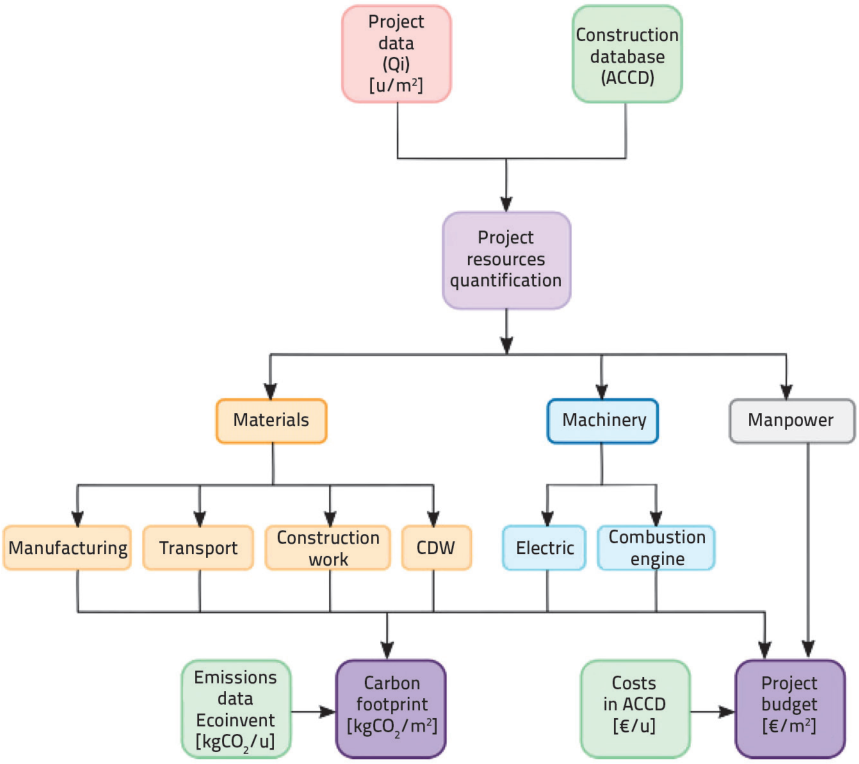

Figure 2. OERCO2 methodology [56]

(A1–A5); Research into the other two phases of the building life cycle (B1–C4), namely, the periods of use and demolition, does not form a part of this analysis.

6. Case study

Six social housing projects in Spain and Turkey under similar climatic conditions were selected. Social buildings with reinforced concrete structures in Turkey (Antalya) and Spain (Andalusia) were compared. Andalusia is geographically located within the latitudinal range of 36°–38° N, whereas the Antalya Province is situated between the latitudes of 36°–30° N. The Mediterranean climate prevails over both cities. The region under consideration shows a climatic pattern characterised by arid summers and humid winters, wherein summer temperatures vary from warm to hot, whereas winter temperatures tend to be relatively mild. Despite exhibiting similar climatic conditions, the economic classifications and housing policies of these regions differ. This study may provide valuable input for determining the potential influence of housing policies and the economic conditions of a nation on the environmental consequences associated with social housing.

A multi-family residential building with different numbers of stories below and above ground was selected as the construction type in both countries. The constructive methods utilised in the selected structures are most commonly used in both countries [38, 56]. In addition, a case study was selected from the social housing built over the last 15 years (2008–2023) to better reflect the impact of policies in the country. Thus, the study findings may be useful for analysing the countrywide housing sector.

Table 1 summarises the most important characteristics of the analysed projects, including the type of dwelling, built-up surface, number of aboveground and underground floors, and structural and architectural solutions used for the foundations, structure, and roof.

Table 1. Case study characteristics

	Turkey (Antalya)			**Spain (Andalusia)**		
Types	**A**	**B**	**C**	**D**	**E**	**F**
Year	2008	2009	2014	2012	2008	2010
Built-up surface [m^2]	6232.32	7678.93	11526.3	7772.08	4440.34	12210.97
Floors above ground	5	5	12	5	3	12
Underground floors	1	2	1	2	1	1
Footings	isolated	concrete slab	concrete slab	slab	Isolated	Isolated
Roof	sloping	sloping	sloping	sloping	flat	flat
Formwork systems	metallic	metallic	metallic	metallic	metallic	metallic
Floor slabs	concrete slab	concrete slab	concrete slab	ceramic hollow blocks	ceramic hollow blocks	ceramic hollow blocks
Walls	reinforced concrete	brick walls	reinforced concrete	brick walls	brick walls	brick walls
Wall finishes	gypsum plaster	gypsum plaster	gypsum plaster	gypsum plaster	gypsum plaster	gypsum plaster
Flooring	laminated wood	laminated wood	laminated wood	terrazzo	terrazzo	terrazzo
Ceilings	plaster	plaster	plaster	plaster	plaster	plaster
Insulation	polystyrene	polystyrene	polystyrene	polystyrene	polystyrene	polystyrene
Claddings	plastic paint	plastic paint	plastic paint	stone	stone	stone
Window frame	aluminium	aluminium	aluminium	aluminium	aluminium	aluminium
Glazing	thermal-acoustic glazing	thermal-acoustic glazing	thermal-acoustic glazing	thermal-acoustic glazing	thermal-acoustic glazing	thermal-acoustic glazing
Door	wooden	wooden	wooden	wooden	wooden	wooden
Hot water	electric heater	electric heater	electric heater	solar energy system supported by an electric heater	solar energy system supported by an electric heater	solar energy system supported by an electric heater
Air-conditioning system	-	-	-	heat pump	heat pump	heat pump
Water pipes	Galvanized steel	Galvanized steel	Galvanized steel	copper	copper	copper
Sewer pipes	reinforced PVC	reinforced PVC	reinforced PVC	reinforced PVC	reinforced PVC	reinforced PVC
Earth transport	mechanical	mechanical	mechanical	mechanical	mechanical	mechanical
Lifts	yes	yes	yes	yes	yes	yes

7. Finding and results

The study using the OERCO2 tool was conducted in six social housing projects chosen from two different countries (Table 1); as depicted in Figure 3, the findings are described in terms of the carbon footprint, expressed as carbon dioxide equivalents per square metre of land area (tCO_2eq/m^2).

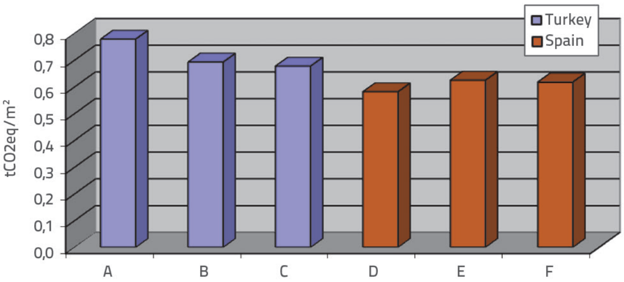

Figure 3. Carbon footprint (tCO_2eq/m^2) analysis of social housing projects

No statistically significant differences are observed between the two countries in terms of the typology. However, compared to the social housing projects constructed in Spain, social housing projects constructed in Turkey have a greater carbon impact during the manufacturing (A1–A3) and construction (A4–A5) phases.

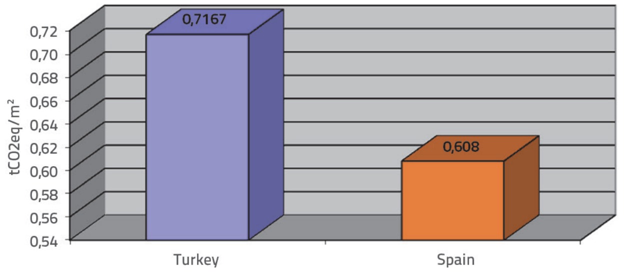

Figure 4. Average carbon footprint (tCO_2eq/m^2)

Building materials have a greater impact (90–95 %) on the assessment of the carbon footprint than machinery (5–10 %). The results reveal that the following variables are the most significant in the carbon footprint calculation: building materials (44 %), labour (35 %), and on-site electricity usage (18 %). Mobility, machinery, and direct land consumption are the least important factors.

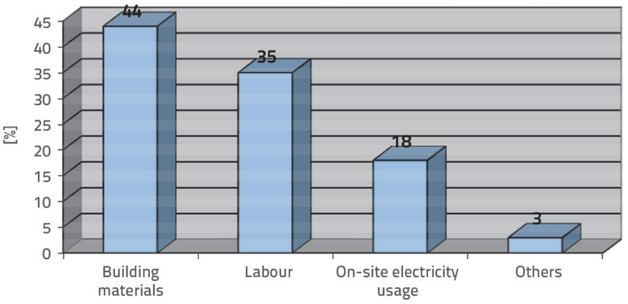

Figure 5. Effects of variables on building carbon footprint (percent)

According to research conducted on residential buildings, reinforced concrete [59] and structural steel [60] have the greatest effect on the environment. Concrete, steel, ceramics, polystyrene, and PVC account for 87 % of the overall carbon footprint in both countries.

An inverse relationship exists between tCO_2eq/m^2 and the total number of stories in a certain block of buildings. An experimental A'-type building with attributes comparable to those of the A-type block was created to facilitate a better comprehension of the relationship between the number of storeys and environmental impact. Type A' has precisely the same functions as type A and is organised into a total of six floors with one basement. The findings are summarised in Figure 6.

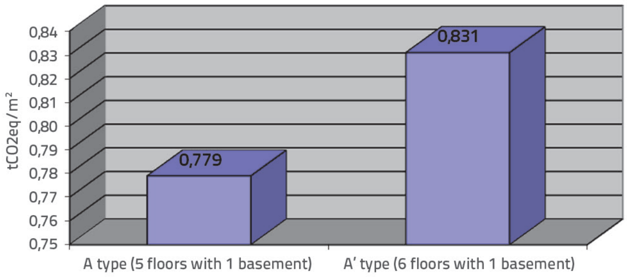

Figure 6. Comparison of A type and experimental A type (tCO_2eq/m^2)

Structures with a greater net floor area owing to the greater number of storeys have a lower tCO_2eq/m^2 than those with a smaller net floor area. This finding is interpreted as follows: the effect of the roof and basement components remains constant even when the number of storeys is increased, resulting in a reduction in tCO_2eq/m^2.

The differences between the typologies with and without underground floors are noteworthy from this perspective.

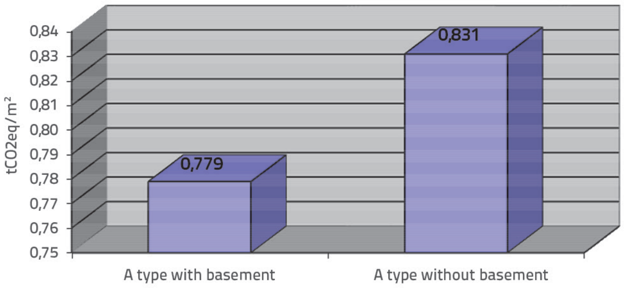

Figure 7. Effect of the basement on environmental impact (tCO_2eq/m^2)

The absence of a basement in a building with the same surface area constitutes an additional 7 % of the total environmental impact of the building. Underground floors are included in the calculation of the results per square metre; Nevertheless, the presence of finishes is significantly less than that on aboveground levels. This relatively reduces the economic and environmental impact per m² and can compensate for the result of having a basement.

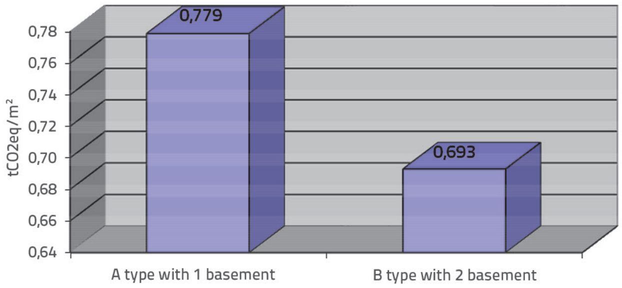

Figure 8. **Effect of basement on environmental impact (Turkey) (tCO_2eq/m^2)**

For example, Typology B (five storeys above the ground and one underground) has a lesser environmental effect than Typology A (five floors above the ground and two underground). The same can be said for typologies D and E in Spain. Type D (five floors above the ground and two underground) has a less negative effect on the environment than type E (three floors above the ground and one underground).

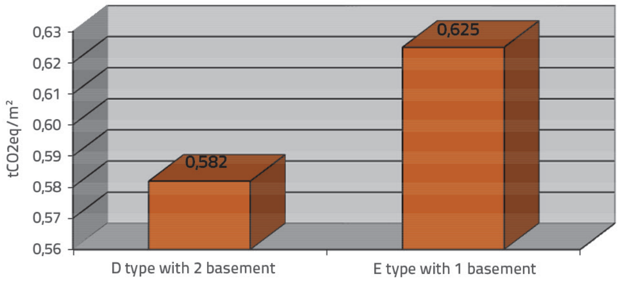

Figure 9. **Effect of basement on environmental impact (Spain) (tCO_2eq/m^2)**

Additionally, there is no discernible variation in the environmental impacts of the different types of foundations, structures (all reinforced concrete), and roof types (flat or inclined).

8. Recommendations

Six social housing projects in Spain and Turkey, both of which have distinct economic categorisations and approaches to housing policy but share the same climatic conditions, were chosen. Although social housing constructed in Spain has a lower carbon footprint than that in Turkey throughout the manufacturing (A1–A3) and construction (A4–A5) stages, neither country's social housing projects can be classified as low-impact housing. However, as a consequence of this comparison, recommendations that can ensure a reduced effect on the environment have been identified. The evaluation was conducted based only on the influence on the environment, and the recommendations are constructed based on the findings obtained above (Section 7).

Building materials have a significant impact on carbon footprint. The manufacture of building materials and their transportation, construction, operation, maintenance, and eventual demolition require a significant amount of energy, which results in the emission of a considerable proportion of carbon. Table 2 illustrates the proportional contribution of each building material to the total weight, as well as the total amount of carbon emissions.

Table 2. Carbon footprints of materials [55]

Material	**Carbon footprint** [tCO_2eg/t]
Soil	0.007
Wood	-0.0992
Concrete	0.112
Asphalt	0.21
Ceramic	0.22
Aggregates and stones	0.004
Metals	1.50
Plastics	3.25
Glass	0.669
Plaster and pastes	0.002

This process presents with is an opportunity to reduce carbon emissions while simultaneously increasing the energy efficiency of buildings and avoiding major increases in investment costs. Building materials must have minimal carbon emissions and high energy efficiency from the beginning of the planning and design processes. The use of alternative construction materials should be encouraged.

The carbon footprint is significantly affected by the total number of storeys in a building. A structure is more beneficial to the surrounding environment in terms of eco-friendliness when it has more floors. Reducing the number of levels is not financially feasible when considering the overall floor space per lot. Nevertheless, studies have shown that this benefit is no longer present above 20 levels [61].

The presence of a basement in a building with the same surface area minimises the economic and environmental effects per square metre. It is important to remember that finishes on the aboveground levels must be able to compensate for the basement. Otherwise, including underground floors in the result per square metre calculation may have a negative impact on the carbon footprint of the building.

9. Conclusion

The main objective of this study was to examine social housing built for low-income groups from an environmental sustainability viewpoint to determine whether low-cost housing has a low environmental effect. Six social housing projects with the same climatic circumstances were selected from Spain and Turkey, with different economic classifications and housing policies. The OERCO2 program was used to determine the carbon footprints of various social buildings selected for the study.

No statistically significant difference is observed between the two countries in terms of the typology of the buildings inside their own borders. This is because in Turkey, there is a lack of design flexibility and homogeneity as a consequence of mass production [38], whereas in Spain, the design of social housing is governed by a dense set of regulations that tightly regulate the form and usage of the domestic space [62].

Although neither country's social housing projects can be classified as "low-impact" in terms of the carbon footprint, social housing constructed in Turkey has a higher carbon footprint than social housing constructed in Spain throughout the manufacturing (A1–A3) and construction (A4–A5) stages. However, solar panels a requirement for new housing in Spain since 2006, have a significant effect on the carbon footprint per square metre of houses during the installation period. The installation of a solar panel increases the carbon footprint per square metre by approximately 2 %. Although this appears to have a negative effect during the construction phase, when the long-term environmental impact of the building is assessed, buildings with solar panels are found to have a lower carbon footprint than those without solar panels [63].

The limited financial resources for social housing is an important consideration when selecting building materials for housing construction. The use of low-cost materials with poor energy efficiency is particularly common in housing projects. However, the materials used in construction have a greater influence on the calculation of carbon footprint. Strategies to reduce the carbon footprint of residential buildings include the use of recycled concrete and steel, reused ceramics, and low-energy insulation. In Spain, there has been a growing concern about the assessment of construction and demolition waste in housing policy for more than a decade, whereas in Turkey, there is no such policy in place. The study results may provide important feedback to policymakers and architects, as well as an opportunity to evaluate housing policies in the future in terms of environmental sustainability.

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