399: Moving the entire building sector towards low CO_2 emissions

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Abstract
This paper is based on a report commissioned by the Spanish Housing Ministry entitled 'On a strategy to direct the building sector towards efficiency in greenhouse gas (GHG) emissions'. The report investigated how the building sector in Spain could rise to the global challenge of reducing GHG emissions, by adding strategies to current policies which consist in making the use of new buildings more efficient and progressively improving the efficiency of existing ones.
The study considered all emissions associated with the creation (construction of buildings) and maintenance (use of buildings) of habitability, which is the service that buildings must supply. Thus, in 2005, the emissions associated with the building sector were equivalent to 33% of total emissions in Spain, having increased by 112% between 1990 and 2005.
The main conclusions are that the building sector has an important role to play in reducing the greenhouse gas emissions attributable to Spain. It must not only improve its energy efficiency but also implement widespread and long-term changes. The strategies suggested involve a thorough transformation of the sector with regard to the way that it is developing and the way that it understands habitability.

Keywords: building sector, greenhouse gas emissions

1. Introduction

According to the Fourth Assessment Report by the Intergovernmental Panel on Climate Change, there is very high confidence that human activities since 1750 have been responsible for the current trend in global warming [1]. According to the report, the increase in anthropogenic greenhouse gases (GHG) emissions into the atmosphere is the cause of the observed change in climate.

In 2005, atmospheric concentrations of GHG, specifically CO_2, far exceeded the natural range over the last 650,000 years. The global increase in CO_2 concentrations in the atmosphere is due primarily to the burning of fossil fuels. The industrial production system and economic development rely heavily on fossil fuels. This system extracts carbon from reserves in the lithosphere and uses the energy produced during its combustion, without taking into account the effects of the resulting carbon emissions that remain in the atmosphere and leave the carbon cycle open.

Climate change is a major global issue; it threatens the biosphere on which humankind depends. However, to address the problem, major adjustments must be made to the current unsustainable production system. If the effects of climate change are to be minimised, not only must existing technologies be improved—current industrial systems and social models must also be reconsidered, especially in developed countries.

In 1994, the first international treaty regarding climate change, the United Nations Framework Convention on Climate Change (UNFCCC), came into force. Its main objective was to stabilise GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system [2]. In 2005, an addition to the UNFCCC treaty, the Kyoto Protocol, came into force. This is a legally binding international agreement to reduce GHG emissions worldwide. Specifically, the agreement requires industrialised countries to collectively reduce their GHG emissions by 5.2% for the period 2008-2012 as compared to their 1990 emissions [3].

The Kyoto Protocol is the first step in an attempt to mitigate the effects of climate change, but it is not enough to achieve the UNFCCC objective. Therefore, in the near future, requirements to reduce GHG emissions will become increasingly demanding. One step in this direction occurred on 23 January 2008 when the European Union committed to reducing its overall emissions by at least 20% compared to 1990 levels by 2020. Another example was when the last United Nations Climate Change Conference established the bases for post-Kyoto agreements. Citing the Fourth Assessment Report of the IPCC, the final document of the conference declared that, in order to avoid a temperature increase of more than 2.4ºC, emissions would have to be reduced by 50 to 85% by 2050 compared to 2000 levels.

Considering this context, in this paper we raise the challenge of reducing CO_2 emissions from the Spanish building sector.

2. Building sector emissions

2.1 Definition of the building sector

This study considers all emissions associated with habitability, which is defined as all services that a building is required to provide. Generally speaking, habitability is a building's ability to provide shelter and accessibility to services that people need in order to carry out their activities.

It is important to consider all emissions necessary to achieve habitability, such as those associated with the embodied energy of the materials required to build a building and those produced during the maintenance of habitability. This refers to emissions associated with the use of the building to maintain the services and level of comfort required for people to live, work and perform other activities.

The building sector deals with all kind of buildings, from residential dwellings to service sector buildings (e.g. offices, hospitals, hotels, commercial space, schools and sports facilities).

2.2 Emissions associated with the use of buildings

Mainly, the sources of emissions associated with the use of a building are heating and cooling, hot water, lighting, cooking, electrical appliances and other specific appliances depending on the type of building. Table 1 shows an example of the emissions related to the use of a conventional dwelling occupied by four people in the Barcelona metropolitan area [4].

Table 1: Energy and emissions associated with the use of a conventional dwelling in Barcelona

	kWh / year	kg CO_2 / year
Heating and cooling	4940	993
Hot water	3150	633
Cooking	1050	211
Electrical appliances	2080	942
Lighting	617	280
Total	11837	3059

Table 2 shows the energy consumption and emissions associated with the use of various types of buildings in Spain [5]. In this table, to convert energy consumption into CO_2 emissions, the following factors were applied:

- Gas: 1 kWh = 204 g CO_2
- Electricity (Spain, 2005) [6]: 1 kWh = 501 g CO_2

These factors show that gas is 2.5 times more efficient than electricity for a given quantity of energy consumed.

Table 2: Energy consumption and CO_2 emissions associated with the use of different types of buildings in Spain

Building type	Electricity (%)	Fuel (%)	kWh / m^2	kg CO_2 / m^2
Multi-storey residence	25	75	107	30
Detached house	25	75	43	12
Office	86	14	145	67
Hospital	50	50	251	88
Commercial space	100	0	327	164
Hotel	52	48	403	144
School	31	69	43	13
Sports centre	20	80	303	80
Sports centre with swimming pool	45	55	31	10

2.3 Emissions associated with the construction of buildings

The manufacture of the materials required for the construction of buildings uses energy and, consequently, emits CO_2. In this study, we considered the emissions associated with embodied energy. The embodied energy values depend on the intensity of the manufacturing process required for each material. For example, traditional materials, i.e. stone and wood, require less than 5 MJ of energy per kg of material manufactured. The materials adopted by the building sector during the industrial revolution, such as cement and steel, require up to 50 MJ/kg for manufacturing. The most recent technological advances have led to the widespread use of plastics and metals, which require up to 215 MJ/kg. [7]

Table 3 shows the aggregate emissions of a conventional building built using the most common construction system in Spain [8]. It consists of a reinforced concrete structure, two-layer exterior walls with insulation, inverted roofing and plastered interior partitions.

Table 3: Aggregate emissions of a conventional building in Spain

	kg CO_2 / m^2	%
Foundation	93.67	16.9
Structures	168.88	30.4
Exterior walls and roofs	102.99	18.5
Interior walls	25.54	4.6
Exterior cladding	9.84	1.8
Interior cladding	35.94	6.5
Doors and windows	58.40	10.5
Services	56.92	10.2
Other	3.20	0.6

3. Analysis of all emissions from the building sector

This section presents a top-down analysis of emissions from the Spanish building sector from 1990 to 2005 and compares them to the total national emissions set out in the Kyoto Protocol.

3.1 Analysis of Spanish emissions

The Kyoto Protocol states that Spain's GHG emissions must not increase by more than 15% with respect to 1990 levels during the 2008-2012 commitment period.

Spanish emissions exceeded the limits in 1997 and continue to increase. In 2005, the last year for which data is available, emissions were over 52% higher than in 1990 and Spain became one of the least successful countries in achieving the objectives of the Kyoto Protocol.

Figure 1 shows the percentage of emissions per sector in 2004 based on the 2008-2012 National Allocation Plan, the GHG inventory of the European Environment Agency and Eurostat statistics, but considers emissions produced by the electricity industry as attributable to the sector that finally consumes the electricity. The graph shows that the emissions attributable to the use of buildings account for 21% of the total Spanish emissions: 7% are direct emissions, i.e. those produced through combustion in buildings, and 14% are indirect emissions resulting from electricity use. If both direct and indirect sources are considered, the building sector is particularly relevant in the evaluation of GHG emissions in Spain.

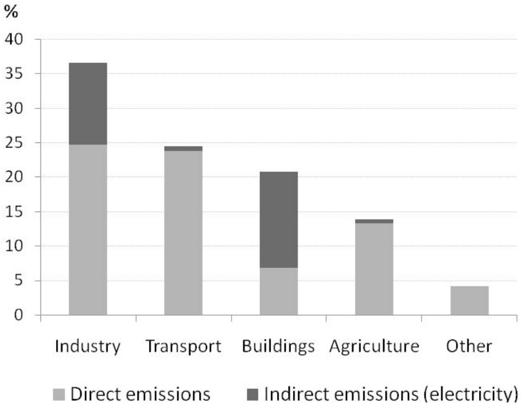

Fig 1. Breakdown of Spanish emissions by sector (%) (2004)

3.2 Analysis of emissions from the use of buildings

The previous section showed that in 2004 the emissions produced by the use of buildings accounted for 21% of total national emissions. Fourteen years earlier, this figure was 16%. This means that, although national emissions increased by 52% from 1990 to 2005, the growth rate of emissions attributable to building use was twice as high, at 101% (Figure 2).

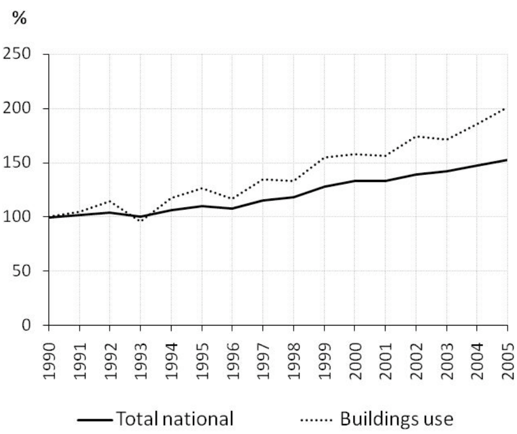

Fig 2. Variation in total national emissions and emissions attributable to the use of buildings (%)

Figure 3 shows, in absolute terms (Gg of CO_2), the changes in these emissions by building use and energy source. The emissions associated with the domestic sector increased by 77% in fifteen years, while the emissions associated with the service sector increased by 144%. This means that the percentage of emissions produced by the service sector has increased. Specifically, in 2005 the overall emissions level of the service sector was just 22% smaller than that of the domestic sector. It is also noteworthy that the emissions produced by electricity consumption are significant throughout the whole period. Furthermore, these increases were considerable in both sectors, but especially in the service sector.

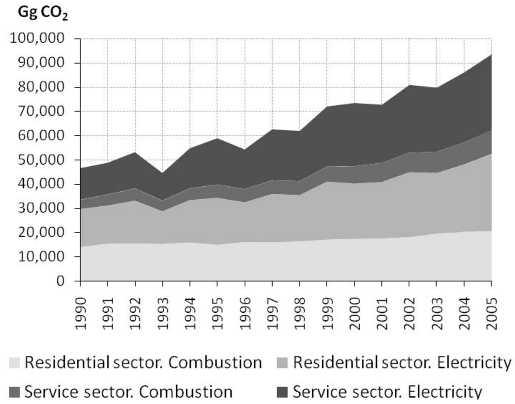

Fig 3. Changes in emissions associated with the use of buildings (Gg of CO_2)

Figure 4 shows the changes in emissions per square meter of existing building stock. The emissions in the domestic sector are much lower than those in the service sector. Moreover, emissions per square metre in the domestic sector were almost constant, whereas emissions in the service sector greatly increased per square metre. This was mainly due to electricity use.

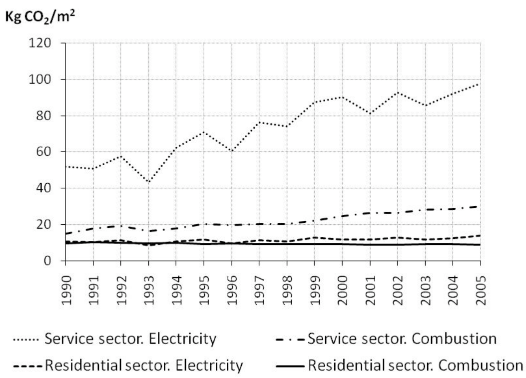

Fig 4. Changes in emissions attributable to the use of buildings per unit area (Gg CO_2/m^2)

3.3 Analysis of emissions from construction in the building sector

Under the accounting system of the Kyoto Protocol, emissions associated with the construction of buildings are not necessarily attributed to Spain. The Kyoto Protocol attributes such emissions to the country where they are physically produced, rather than the country that imports the final product. Thus, the emissions associated with manufacturing the materials used to build a building in Spain are attributed to all the countries where those materials were manufactured. However, in this paper we do not use this accounting system and have considered these emissions as part of the final product or service because this is the reason for the building's existence. That is, the final products are the buildings and the service is habitability.

Emissions associated with the construction of buildings are directly proportional to the number of new and restored buildings. Figure 5 shows the amount of newly built areas, restored areas and demolished areas over fifteen years in Spain. It is clear that restoration and demolition are insignificant compared to newly constructed buildings.

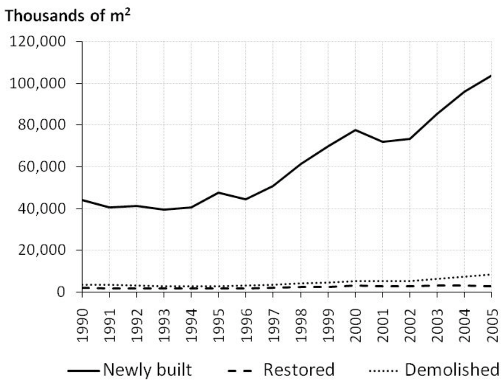

Fig 5. The evolution of newly built, restored and demolished areas in Spain (in thousands of m^2)

This trend has resulted in an increase in building stock: in 2005 there were 51% more newly built areas than in 1990. This increase was mainly due to the domestic sector, which, during the study period, accounted for between 85 and 88% of the total newly built areas.

The total built area grew at a much higher rate than the national population, which for the same period grew by only 11%. Thus, in 1990, residential dwellings (main homes, second homes and unoccupied dwellings) occupied an area of 36 m^2 per person, while in 2005 this figure was 51 m^2.

By applying an approximate emissions coefficient per new square meter built using the conventional construction system in Spain, 500 kg CO_2 / m2 [6], we obtained an estimate of the emissions associated with the creation of habitability.

Figure 6 shows the variation in the percentage of the total national emissions and the emissions resulting from the manufacturing of building materials. For the fifteen-year study period, the emissions associated with the manufacturing of building materials increased by 133%, which is more than double that of total national emissions (52%). In 1990, the emissions from building-sector manufacturing were equivalent to 8% of national emissions, while in 2005 they were equivalent to 12%.

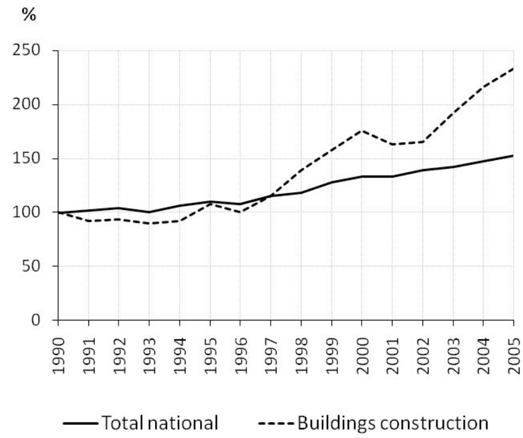

Fig 6. Variation in total national emissions and emissions due to construction in the building sector (%)

3.4 Analysis of overall emissions from the building sector

Emissions associated with the use of buildings increased by 101% from 1990 to 2005, while emissions associated with the manufacturing of building materials increased by 133% in the same period. Therefore, considering the emissions of the entire building sector, including activities related to the creation and maintenance of habitability, there has been an overall increase of 112%, as shown in Figure 7. This means that the sector as a whole has hugely exceeded the proportion of emissions allocated to Spain by the Kyoto Protocol, which is an increase of 15% with respect to 1990 levels. From the perspective of the building sector, this represents a double problem. First, the building sector is a huge contributor to the increase in national emissions, and second, this sector will lose competitiveness as new restrictions are enforced.

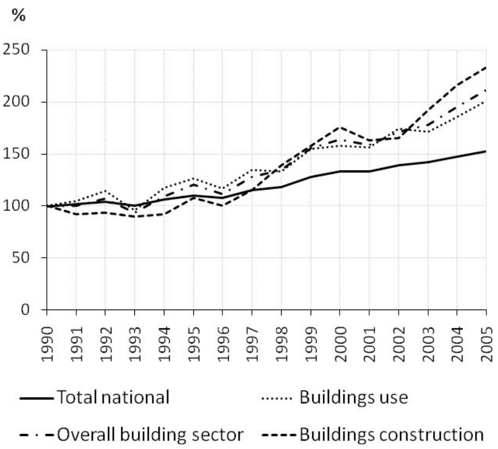

Fig 7. Variation in total national emissions and emissions associated with the building sector (%)

Figure 8 shows the changes in the total national emissions and the emissions associated with the building sector. In 1990, emissions from the building sector as a whole were equivalent to 24% of national emissions; by 2005, this figure had increased to 33%. Therefore, this sector is particularly significant in relation to national emissions and, moreover, its importance is growing.

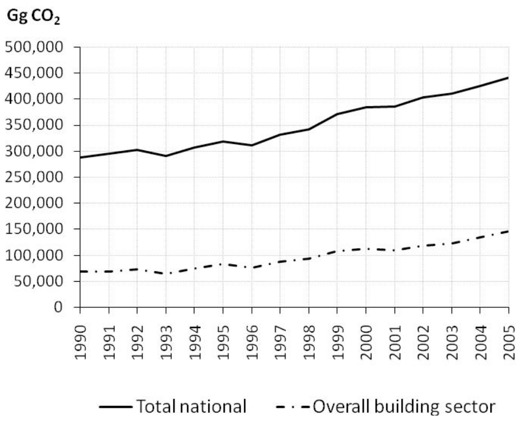

Fig 8. Changes in total national emissions and emissions attributable to the building sector (Gg of CO_2)

4. Strategies

GHG emissions from the building sector result mainly from the energy required to achieve habitability. There are several implemented strategies for reducing these emissions.

In the European Union, for example, there are some activities related to the manufacturing of construction materials in which emissions are limited. These activities are located in Europe and are listed in Directive 2003/87/EC [9]. If a building in Europe uses an imported construction material manufactured in a country without such regulations, emission restrictions do not apply to this product.

Many countries are improving energy efficiency on different scales, from energy-efficient light bulbs and electrical household appliances to the production and distribution of electricity. Most developed countries are replacing most CO_2-emitting fuels, such as coal, with natural gas, which can produce the same amount of energy but emits 40% less CO_2. These countries are also introducing renewable energies (solar power, wind power, hydropower, geothermal power, biomass etc.), which do not emit GHG emissions. Finally, carbon capture and storage (CCS), a technology which is beginning to be implemented, reduces atmospheric CO_2 emissions by capturing and storing the emissions of the largest producers.

Although these efforts help to achieve the objectives of the Kyoto Protocol, they are not enough to achieve the most optimistic scenarios of minimising the effects of climate change. Thus, efficiency in reducing GHG emissions will be a continuous requirement in every sector of society and represent a factor of competitiveness that is essential to maintaining economic growth.

From the perspective of the building sector as a whole, the only way to address this challenge is with innovative strategies that aim to reduce the CO_2 emissions not of a particular building but of the entire sector. The following sections describe some of the options.

4.1 Reducing emissions of the existing building stock

As seen in Section 3.2, the emissions associated with the use of residential buildings per unit area has been relatively constant from 1990 to 2005. Thus, the 101% increase in the emissions associated with the use of buildings is mainly attributed to the construction of new buildings.

The only easy way to reduce such emissions involves restoring existing buildings instead of developing new efficient buildings, which would increase the sector's overall emissions (even if the new buildings are very efficient during its use, they can only reduce expected increases; nevertheless, they still emit GHG).

The current strategies implemented in Spain address both issues: they improve the performance of existing buildings and enforce an energy reduction of 30% in new buildings with respect to the energy consumption in conventional buildings [5]. However, considering the changes in emissions from the building sector from 1990 to 2005, much stronger interventions in the existing building stock are necessary to change the current trend.

The existing building stock must be constantly transformed towards improved efficiency in terms of CO_2 emissions.

4.2 Transformation of the building sector towards a zero-emissions sector

The continued growth of the building stock requires increased emissions based on the manufacturing of construction materials. This translates into 35-45% of the total emissions attributable to the building sector and around 30% of emissions from the complete life cycle of a particular building. All of these emissions must be compensated in order to prevent overall increases in the sector as a whole. This can be achieved by improving the efficiency of existing buildings during their use.

New buildings and the restoration of existing ones must consider the concept of maximum efficiency in terms of GHG emissions. Management strategies must take advantage of the opportunities to produce energy without emissions. Another option is to opt for materials that facilitate emission fixing. Only a building sector with zero emissions could lead to the free generation of habitability.

4.3 Redefining habitability

Habitability should be the objective of the building sector. All activities which are necessary for the creation, distribution and maintenance of habitability constitute this sector. Therefore, to redefine habitability and achieve maximum environmental efficiency, which in this case requires minimal CO_2 emissions, coordination within the sector is essential.

Currently, habitability is established without concern for the resources used to create and maintain it. Not only is there a lack of control in sourcing resources, but current building regulations do not allow the reproduction of existing buildings that have achieved a socially acceptable status of habitability using a small amount of resources.

Assuming that CO_2 limits will be stricter in the near future, the building sector has to change its trends and search for ways to achieve maximum CO_2 efficiency in relation to habitability. This implies a change in the sector's normal operations. A new approach should only consider the resources available (or emissions available) and from there attempt to achieve the maximum habitability. To achieve this, a reconsideration of the main purpose and utility of the buildings, i.e. habitability, is necessary.

Habitability, in a residential sense, is currently defined based on inflexible building models. Generally, this model considers a 'typical' family home, but this is not representative of the wide variety of existing homes in society. A new habitability model, consisting of different levels of habitability, should be designed based on the requirements of society. It should be based on services, and accessibility to them, as a demand but not as characteristics of rigid spaces.

In conclusion, habitability needs to become coherent with the new situation posed by climate change. A new definition of habitability must be adaptable in two aspects: satisfying the social demand and adhering to new restrictions on CO_2 emissions. The more efficient the building sector is in adhering to these restrictions, the more habitability will be possible to create.

5. Conclusions

In Spain, emissions from the building sector as a whole make up a significant portion of total national emissions. Although national emissions already exceed the Kyoto Protocol limits, the emissions of the building sector have followed a faster rate of increase.

The main causes of this increase have been the rapid growth in the number of new residential buildings and the intensification per unit area of electricity in service sector buildings.

New restrictions on CO_2 emissions will soon become increasingly demanding, which will affect all sectors of society. In the case of the building sector, it is important to realise that the buildings built today will be in use when this new situation comes about.

To address this challenge, the building sector must adopt a pro-active strategy that reduces its emissions and promotes effective adaptation to new requirements. Such a strategy must be based on the following three points:

- A reduction in the emissions of the existing building stock, considering that the only way to reduce emissions within the building sector is to improve its efficiency by renovating the existing building stock.
- A transformation of the building sector towards a zero-emissions profile. This implies that new buildings cannot produce any emissions in the construction process or in their use.
- A new definition of habitability. Habitability, the main objective of the building sector, must be defined on the basis of CO_2 efficiency.

6. Acknowledgements

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