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Assessing the relationship between urban planning options and carbon emissions at the use stage of new urbanized areas: A case study in a warm climate location

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ABSTRACT

The trend in urban population growth marks the sustainable development of cities as a critical challenge on the path towards the efficient use of resources and the mitigation of the environmental impact of human activity. Scientific studies have generally focused on the quantification of the environmental impact derived from the usage/operational stage of buildings. This study also includes the impact associated with the use of public facilities and services in cities.

The aim of this paper is to study the CO_2 emissions from the use stage of buildings and public facilities through different urban planning solutions. Six development scenarios have been evaluated, considering the most common residential building typologies with a common construction surface, which includes: single- family units (detached and semi-detached) and apartment blocks of different building heights. The main finding is the relevant contribution of the use of urban facilities and public services to the overall environmental impact of an urbanized area during its lifespan. The impact of urban planning on the total carbon emissions in cities is shown in the results.

The outcome of this research will guide relevant stakeholders in urban development to promote sustainability criteria in urban design guidelines and their inclusion in the policy arena. The results will also help city managers to better understand the role of public services in the overall environmental impact of urbanized areas.

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1. Introduction

Climate change is a common concern for the entire international community. At the recent Paris Climate Change Conference, the first equitable global agreement to deal with global warming was adopted and the target of limiting the increase in temperatures to 2 °C by the year 2100 was agreed to. According to the speech by Laurent Fabius in the aforementioned conference, “a global climate agreement is a universal necessity that should be answered by all countries, promoting climate solidarity and supporting the mobilization of financing and technologies” [1].

Human activity in urban areas is the primary source of anthropogenic CO_2 emissions, the major contribution to climate change [2]. Urbanized areas consume more than 60% of the world’s energy [3] and cities produce more than 70% of global carbon emissions [4].

The world’s population is migrating from rural to urban areas. The phenomenon is noticeably more intense in developing countries, posing a social, economic and technical challenge to the leaders of cities [5]. If this migration trend continues and considering the predicted growth of the world’s population, by 2015 the urban population will have increased by 2.5 billion people [5].

In this context, two main issues arise: i) lack of information on and uncertainty about growth trends of future urban zones; ii) the opportunity for the development of new urban areas based on sustainable design. The fast growing urban agglomeration in cities has a ripple environmental effect: i) more Green House Gas (GHG) emissions [6]; ii) increase of the heat island effect [7]; iii) more consumption of land and natural resources. Moreover, increasingly demanding comfort standards are predicted, which will significantly contribute to household energy demand and the rise of carbon emission contributions in cities [8]. Urbanization, energy

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consumption and carbon emissions are co-integrated and their relationship varies depending on the income level of the country and the degree of development [9]. As well as the previously mentioned environmental impacts, population concentration in new residential zones leads to other additional effects, such as changes in local governance and policy [10].

On the other hand, cities are the main contributors to economic development in developing countries. City administrators and governments are in the difficult situation of promoting economic development while facing the need to ensure living conditions and the supply of resources for the new urbanized areas [6], all in strict accordance with the existing sustainable development targets [11].

Worldwide initiatives under the umbrella of the sustainable development of growing cities are increasingly influencing the policy arena. Among those initiatives, urban planning and spatial optimization are playing an important role in the mitigation of CO_2 emissions at an urban level [12]. The study of measures to mitigate the environmental impact of cities entails a multi-disciplinary and multi-sector effort. An integrated approach is necessary to evaluate emission patterns associated with the use stage of cities.

This paper aims to examine the relationship between urban planning options and CO_2 emissions at the usage/operational stage of buildings and urban facilities. Earlier stages of this research examined the effect of urban planning on carbon emissions and waste estimation at the construction stage [13,14]. A quantification of carbon emissions during the usage/operational stage of urbanized areas is given, considering the energy consumed by: a) use of buildings; b) use of urban infrastructures and municipal facilities. Diverse urban planning scenarios are established to compare results depending on the building type. The contribution of each energy use is estimated.

Six development scenarios are evaluated, considering the most common residential building typologies in Spain. For each scenario, the energy consumption of buildings and public supply networks during the phase of occupation/use is evaluated. Then, the carbon emissions associated with each end use are estimated. The results obtained, together with the findings of the previously mentioned study on CO_2 emissions and waste generation at the construction stage [13,14], offer a comprehensive analysis of the environmental impact of different urban planning options.

The paper is organized as follows. First, a short literature review on the study of urban form and GHG emissions is given. Section 3 briefly describes the urban solutions studied. Section 4 focuses on methods, presenting the calculation procedure to obtain the associated energy consumption of the urban solutions considered. Results are set out in Section 5 and the discussion is conducted in section 6. Finally, in section 7 the conclusions are summarized.

2. Urban form and greenhouse gas emissions

This section provides an overview of the latest studies on urban development and environmental impact. First, we focus on the literature that examines the relationship between urban morphology and GHG emissions. Then, we examine the role of public and urban facilities on the assessment of the environmental impact of cities and the existing literature.

Generally, the literature which aims to quantify the impact of urban morphology on CO_2 emissions uses a limited number of variables, which highlights the difficulty of the matter [6,12,15]. Traditionally, studies that assess the environmental impact of urban morphology had focused on GHG emissions caused by the usage/operational stage of: a) buildings [15]; b) urban transport [16–19]; c) both [20,21].

In this context, Burgalassi et al. examined the relationship between urban spatial structure and carbon emissions and found a positive correlation between urban sprawl and emissions from residential heating and private transport on a city scale [20]. Urban sprawl has been identified as a catalyst for CO_2 emissions associated with the development of urban areas [6]. The authors estimated carbon emission evolution according to the urban form of 30 capital cities, parameterizing urban form as a set of landscape indicators. The results indicated that CO_2 emissions increased as the urban landscape showed more complex and irregular spatial patterns. Previous studies also confirmed that compact urban form significantly reduces energy consumption and CO_2 emissions in the household sector [21].

Wang et al. analyzed the carbon footprints of different urban developments that corresponded to three historical ages, making a distinction between building, household and transportation [8]. Ishii et al. evaluated the impact of implementing GHG mitigation technologies in building energy consumption in three different urban forms: high density centralized form, medium density average form and low density de-centralized form [15]. Results show that the maximum reduction in energy consumption and GHG emissions was found for the medium-density form, projecting an energy saving of 67.6% by 2050. There is also an increasing amount of literature that takes a more comprehensive approach, considering the contribution of the urban heat island effect as a result of urban morphology [22–24].

Urban facilities and municipal services are essential for human well-being and economic development, and their environmental impact is not negligible [25]. Although it is known that urban morphology also affects the design and operation of urban facilities over their long lifespan, little literature can be found on this topic. The work of Wang et al. should be mentioned, as it includes facilities and public services (among others indicators) to categorize urban development intensity and its relationship with CO_2 emissions [12]. Results show that both factors exert a positive influence on CO_2 emissions.

The responsibility of local municipalities in the energy management sector is increasing [26]. Besides efficient use of resources in public infrastructure, for effective operation, the scale of engineered infrastructure must match that of local authorities [25]. A deeper understanding of the role of urban facilities is essential for moving from data to action for urban sustainability and could help local governments in the design of energy projects, and economic investment for mitigating the environmental impact of urban areas [25,26].

On a city scale, while extensive technical and legislative efforts are made elsewhere to increase energy efficiency in residential buildings, very little literature focuses on the role of public facilities and infrastructure necessary for urbanizing a plot of land. Rossi et al. developed a study on the urban heat island effect on the carbon footprint of outdoor lighting systems [22]. In particular, they quantified the increase of the urban carbon footprint associated with public lighting as a function of the outside temperature increase. Results claimed that, even for a high-efficiency LED lighting system, it is estimated that an increase of 3.3 °C in urban temperature is responsible for an 800 ton CO_2 eq/year increase. Other pieces of work applied life cycle assessment methodology to evaluate the environmental impact of two streetlight technologies [27]. The results highlighted the crucial role of battery recycling in the environmental performance of public stand-alone PV-powered lights, compared to grid-powered lights. Local support is vital for developing energy efficient plans in cities and attracting economic investment, both public and private. In this context, Redulovic et al. analyzed the economic investment in energy efficient public lighting projects on a city scale, claiming that energy efficiency projects at a city level can be both environmentally friendly and feasible [26].

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