Environmental Changes Produced by Household Consumption

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Abstract: This paper analyzes the impact of the fall in household consumption after an economic crisis in Spain on greenhouse gas emissions. To this end, household consumption is differentiated by the age of the main provider by using a conversion matrix that relates consumption groups to activity sectors. A multisectoral model was used to quantify and compare the environmental impact caused by the consumption of each age group, indicating that the older the age of the main household provider, the smaller the reduction in GHG emissions associated with their consumption. The results facilitate an analysis of how the greenhouse gas emissions of the different sectors of the Spanish economy, associated with the population under study, varied before and after the 2008 crisis, and confirm that the sectors with the greatest reduction in emissions were, in this order, extractive industries, construction, manufacturing industry, wholesale and retail trade and transport and storage. This is relevant for decision making in the field of environmental policies in crises, akin to the one the world is currently experiencing.

Keywords: household; greenhouse gas emissions; input–output analysis; economic crisis

1. Introduction and Literature Review

1.1. Introduction

According to the European Environment Agency [1], the increase in spending on the consumption of goods and services in Europe caused an environmental impact on production and consumption on a global scale. Thus, it is necessary to modify consumption patterns and reduce greenhouse gas (GHG) emissions through new production processes and greater innovation in technology to mitigate global warming. Among the main production sectors responsible for air pollution and GHG emissions is electricity, because when it is generated in thermal power plants, fossil fuels, such as coal, oil, or gas are burned. According to the report prepared by the European Parliament on the basis of the United Nations Framework Convention on Climate Change (UNFCCC), 80.7% of total emissions are produced by energy generation, 10.1% by agriculture, 8.72% by industrial processes, and 2.75% by waste management [2].

Transportation is responsible for more than a quarter of polluting emissions due to diesel or gasoline combustion engines that vehicles need to move, whether they are cars, trucks, buses, or ships. It is important to note that the ratio of emissions per passenger is very high in air transport, corresponding to 2% of global pollution emissions according to the International Air Transport Association (IATA). The gradual return of tourism and increase in air travel after the pandemic will once again contribute to global warming, as air transport demand is expected to triple in the period 2020–2050. The percentage of the world’s population that traveled by air was 11% in 2018, with a maximum of 4% corresponding to international flights [3].

Another polluting sector highlighted, in addition to water consumption and chemical use, is the fashion sector, which also produces significant GHG emissions. In fact, the latest UN Conference on Trade and Development [4] mentioned that the fashion industry is the second most polluting industry in the world. Finally, another sector with very high
emissions is the food sector, the activities of which are derived from agricultural production, livestock, forestry, and fishing, which have increased by 200% in the past five decades with a growth forecast of 30% more by 2050, according to the Food and Agriculture Organization of the United Nations (FAO).

To reduce emissions caused by transportation, new technologies are being developed and have been analyzed by different authors. For example, the promotion of policies related to the use of biofuels contributes to a green economy by reducing carbon emissions, as shown by a study conducted in the Yunnan region of China [5]. Biomass energy-driven systems are essential for the mitigation of the use of fossil energy and the reduction in CO₂ emissions, as shown by the combined cooling, heating, and power (CCHP) system at the micro-scale for domestic use [6]. Mohan, Yang, Raman, Sivasankaralingam, and Chou [7] conducted a study using renewable biodiesel to optimize stationary diesel engines generating power in domestic and commercial applications, thereby reducing emissions. In addition, local policy strategies aimed at mitigating climate change reduce the carbon footprint of household consumption, as shown by Ottelin, Heinonen, and Junnila [8] in a study conducted in the Helsinki metropolitan area. The reduction in carbon emissions was more than 7% from 2006 to 2012, despite the 1% increase in expenditure.

The success of European industries in recent years in reducing environmental pressures and carbon emissions and in increasing energy efficiency is due to changes in production systems, international trade, and consumption patterns. The evolution of industrial CO₂ emissions was very similar in all countries, but it was better in industrial production than it was in household consumption after the economic crisis [9]. Therefore, studies such as this are important, which are focused on analyzing emissions caused by households’ consumption.

Regarding the Spanish economy, the crisis of 2008 brought about changes in food consumption patterns in Spanish households, which reduced the carbon footprint [10]. Moreover, household consumption of imported goods and services (international trade) is very uneven according to income, given that prior to the crisis, households with greater income imported 30% of their total consumption, which dropped to 20% during the crisis. Households with less income imported only 20% of consumption, and this remained steady during the crisis [11]. Thus, an in-depth analysis must be performed on these changes in consumption patterns after economic crises in order to properly direct the energy policies aimed at households.

In Spain, the action plans of the agencies of the Ministry for Ecological Transition and Demographic Challenge [12] are directed toward a commitment to the fight against climate change and support for international agreements in this regard. In 2005, the Renewable Energy Plan for Spain 2005–2010 [13] promoted a transition to a low-carbon energy model through a series of investments in future years. A commitment was made to persevere with renewable energies to achieve sustainable development, mitigate climate change, and to obtain a greater supply of energy consumption from local energy sources.

This plan contributed decisively to the reduction in GHG emission levels that is part of Spain’s international obligations, particularly those from the Kyoto Protocol, because renewable energy sources were included as a tool essential for the reduction in CO₂ emissions. Subsequently, the European Commission presented Directive 2009/28/EC, a comprehensive directive on the use of renewable energy sources, which contained criteria and provisions to ensure sustainable production and use of bioenergy. Spain assumed the 20-20-20 energy goals set by the European Union and included them in the Renewable Energy Plan 2011–2020 [14].

Currently, the European Commission, through the European Green Pact, set the goal of improving GHG emission reductions by 2030 to at least 55% over the corresponding numbers in 1990. This year, 2021, will see the submission of legislative proposals to meet the policy objectives for the EU on climate and energy for the period 2021–2030. These include an increase in the share of renewable energies by 32% and an improvement in energy efficiency by 32.5%. The EU will report on progress made by adopting a series of
standards aimed at fulfilling its international commitment under the Paris Agreement [15]. Spain will submit to the European Commission the National Integrated Energy and Climate Plan 2021–2030 [16], which sets out to reduce GHG emissions by 23% when compared with 1990 numbers. It also commits to complying with Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018, on the governance of the Union Energy Union and Climate Action.

1.2. Literature Review

The following notable studies that use the same methodology applied in this research study, the input–output method, address the effects of household consumption on GHG emissions, both domestically and internationally.

The work of Ma, Chen, Guan, Meng, and Zhang [17] aimed to associate China’s history of CH₄ emissions from 2005 to 2012 with socioeconomic factors by combining input–output models with analysis, using structural decomposition based on consumption and income data. The resulting papers showed that household consumption and income changes were the main drivers of CH₄ emission growth in China, while the most important factor offsetting these CH₄ emissions remained changes in efficiency during the same period. After 2007, emissions from exports plummeted due to the global financial crisis and economic stimulus programs, but those from capital formation increased rapidly.

Liu, Wu, Wang, and Wei [18] used the input–output model in order to determine how China’s increasing household consumption impacted carbon emissions, and to compare urban areas to rural areas, which account for greater than 40% of all carbon emissions in the period from 1992 to 2007. They concluded that household consumption is a significant contributor to CO₂ emissions, but the rise in emissions due to increasing consumption could be mitigated by changing the composition of goods and services consumed by households and by shifting household consumption patterns to less carbon-intensive products.

The aim of the study by Kopidou and Diakoulaki [9] was to investigate how changes in the production and consumption of industrial products in four European countries affect the CO₂ emissions. This was carried out over 2000–2011, and they divided the period into two subperiods, 2000–2008 and 2008–2011, in order to investigate the impact of the economic crisis on both drivers and industrial CO₂ emissions. The overall pattern of industrial CO₂ emissions was very similar in these countries, and the breakdown into two subperiods revealed substantial homogeneity across all four countries. Consumption-based drivers were the primary contributors to increases in industrial CO₂ emissions, but they did not contribute at the same level as production-based drivers. Moreover, the production of industrial products was more impacted by the economic crisis than by consumer expenditures.

Perrier, Guivarch, and Boucher [19] quantified how the different factors contributed to the decrease in emissions in Europe observed from 2009 to 2014. To this end, they made 28 input–output tables for each of the EU countries. This dataset allowed them to perform an analysis using the structural decomposition of European emissions after the economic crisis. The resulting papers shows that the most important driver of emissions decline was decreases in carbon intensity, although the economic recovery largely offset the decline in emissions. However, other less intuitive factors also played a major role in causing emissions to decline: changes in the production system, mainly caused by increases in imported goods; the evolution of final demand patterns; and a decline in emissions due to changes in domestic heating and the use of private transport, even after the inclusion of a small offset to account for population growth. However, significant large variations between EU countries were masked by these aggregate figures.

Martínez, Delgado, Martínez, and Alvarez [20] assessed the indirect environmental footprint of households in Spain by applying consumer expenditure surveys in combination with a multiregional input–output analysis that was environmentally extended. They studied 14 environmental impact categories in total during the period from 2006 to 2015. The impact categories all show a consistent trend, because they were all specifically
impacted by the economic crisis. This impact decreased from 2008 to 2013 during the economic recovery, and finally started to slightly increase again from 2014 to 2015.

Lastly, López, Arce, Morenate, and Zafrilla [21] presented a study on the evolution of the material footprint of households in Spain in the period from 2006 to 2013. Their proposed method combined Spanish government data on household consumption according to social group with a multiregional input–output model. The 2008 economic crisis affected the material footprint by causing the share of the material footprint of households in Spain, with respect to the total material footprint, to decrease dramatically from 70.7% in 2006 to 50.8% in 2011. By household type, the material footprint had a scale effect during the same period that consumption and income levels grew.

One of the goals of this study is to determine the impact that the economic activity of the productive sectors (measured through household consumption) has on GHG emissions before and after an economic crisis. Moreover, a comparative analysis of the results between the period before and after the crisis is carried out, highlighting GHG emissions produced by the consumption of young households. The results of this study thus provide added value in terms of the emissions produced by the consumption of different types of households, specifically those of young people, identifying the most representative productive sectors.

This paper is divided into five sections. The first contains an introduction and a review of the most recent literature related to the subject of the study. The Section 2 explains the methodology used and analyzes the GHG emissions by productive sector during the study period. The Section 3 presents the environmental impact caused by household consumption differentiated by age group, highlighting the "young people" age group. Lastly, a discussion is presented, together with the most relevant conclusions, facilitating an understanding of the reduction in GHG emissions of certain productive sectors mainly produced by the consumption of young households after an economic crisis.

2. Materials and Methods
2.1. GHG Emissions by Productive Sector

Before presenting the modeling carried out and the results, the data used are described, specifying the sources, and a descriptive–comparative analysis is made of the GHG emissions in Spain by each productive sector and in the years mentioned (2005 and 2015). A reduction is seen after the economic crisis despite an increase in production.

Regarding data, information from 2005 was considered because it was a year of economic growth representing the pre-crisis level, in addition to data from 2015, when the crisis ended, representing post-crisis levels. Therefore, the model used the symmetric input–output (IOT) tables for years 2005 and 2015 as databases. These were published by the National Institute of Statistics [22]. These tables gather 73 and 64 activities or productive sectors, respectively, according to the Classification of Products by Activity (CPA), and private household consumption was disaggregated for each of the sectors identifying the types of households grouped by age brackets. This disaggregation was performed based on the total household expenditure by age brackets for the reference years. In addition, the data were grouped into 12 consumption groups that come from the Household Budget Survey, according to the COICOP classification variables (3 digits), and are also provided by the NIS [22].

The data arrangement from the different classifications means that the correspondence between the expenditure groups and codes, and the productive sectors is not direct or univocal. This causes difficulties in the distribution of final household demand in the productive sectors, differentiating it by age group. Therefore, it was necessary to construct a conversion matrix that related consumption groups with the sectors on the basis of the matrix created by Cai and Vandick [23] to achieve a correspondence between the household consumption groups (as classified by COICOP) and the sectors (as classified by CPA).
Moreover, the total greenhouse gas emissions (in thousands of tons of CO\textsubscript{2} equivalent) for each productive sector of the IO tables of the years studied, obtained from the Air Emission Accounts provided by the National Institute of Statistics [24], were used.

The symmetrical input–output tables used were aggregated to 20 productive sectors (Table 1), according to the Statistical Classification of Products by Activities [25] of Eurostat.

| Reference | Sector |
|-----------|--------|
| A | Agriculture, forestry, and fishing |
| B | Mining and quarrying |
| C | Manufacturing |
| D | Electricity, gas, steam, and air conditioning supply |
| E | Water supply; sewerage, waste management and remediation activities |
| F | Construction |
| G | Wholesale and retail trade; repair of motor vehicles and motorcycles |
| H | Transportation and storage |
| I | Accommodation and food service activities |
| J | Information and communication |
| K | Financial and insurance activities |
| L | Real estate activities |
| M | Professional, scientific, and technical activities |
| N | Administrative and support service activities |
| O | Public administration and defense; compulsory social security |
| P | Education |
| Q | Human health and social work activities |
| R | Arts, entertainment, and recreation |
| S | Other service activities |
| T | Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use |

Source: EUROSTAT: NACE European Classification of Economic Activities Rev.2 (adjusted to the Classification of Products by Activity: CPA).

The reference years under study facilitate a comparison of GHG emissions before and after the 2008 crisis, for each productive sector. The following table shows the total production of the Spanish economy with total GHG emissions.

As shown in Table 2, there was an inverse relationship between GHG emissions and production in the Spanish economy after the 2008 crisis. While emissions fell by 37%, the total production of the economy grew by 15%. This was due to the important role played by the increase in renewable energies and improvements in energy efficiency promoted by national and international plans to mitigate climate change.

| 2005 | 2015 | Variation |
|------|------|-----------|
| Total Emissions | 442,075 | 277,836 | −37% |
| Total Production | 2,043,441 | 2,341,366 | 15% |

Source: made by the authors based on air emissions accounts (INE) and IO tables for 2005 and 2015.
Below (Table 3) is a breakdown of the total CO\textsubscript{2} equivalent emissions of the referenced years produced in each productive sector.

**Table 3.** CO\textsubscript{2} equivalent emissions (thousands of tons) in the period 2005–2015 and their variations (percentages).

| Sectors | 2005 Emissions | 2015 Emissions | Variation |
|---------|----------------|----------------|-----------|
| A       | 62,760.4       | 50,816.1       | −19.0%    |
| B       | 6292.4         | 1471.6         | −76.6%    |
| C       | 142,949.1      | 81,385.8       | −43.1%    |
| D       | 119,926.7      | 73,590.6       | −38.6%    |
| E       | 17,109.4       | 13,986.7       | −18.3%    |
| F       | 1761.5         | 492.2          | −72.1%    |
| G       | 10,663.2       | 6215.1         | −41.7%    |
| H       | 64,892.2       | 38,648.5       | −40.4%    |
| I       | 903.5          | 702.9          | −22.2%    |
| J       | 762.5          | 580.0          | −23.9%    |
| K       | 346.9          | 288.9          | −16.7%    |
| L       | 749.3          | 757.2          | 1.1%      |
| M       | 921.8          | 748.1          | −18.8%    |
| N       | 885.6          | 703.3          | −20.6%    |
| O       | 5762.2         | 4046.8         | −29.8%    |
| P       | 713.6          | 697.6          | −2.2%     |
| Q       | 1822.6         | 1205.3         | −33.9%    |
| R       | 289.3          | 249.5          | −13.8%    |
| S       | 2392.7         | 1099.5         | −54.0%    |
| T       | 170.2          | 150.2          | −11.8%    |
| Total   | 442,075.0      | 277,835.9      | −37.2%    |

Source: prepared by the authors based on air emissions accounts (INE) and IO tables for 2005 and 2015.

Emissions were observed to have reduced throughout all sectors except in the real estate activities sector (L). In particular, one of the sectors that reduced its emissions the most was extractive industries (B) with 76.6%. This significant decrease was due to the increased use of renewable energies as a primary energy source, to the detriment of the extraction of raw materials used to generate electricity. The construction sector (F) reduced its GHG emissions the most, 72.1%, largely due to the fact that the sector was the most affected by the 2008 crisis. In addition, GHG emissions caused by other services (S); manufacturing (C); the wholesale and retail trade; the repair of motor vehicles and motorcycles (G); and transportation and storage (H) reduced by 54%, 43.1%, 41.7% and 40.4%, respectively.

Moreover, the productive sectors that reduced their emissions the least during the economic crisis period were education (P), with a reduction of 2.2%; household activities (T), with a reduction of 11.8%; artistic, recreational, and entertainment activities (R), with a reduction of 13.8%; and financial and insurance activities (K), with a reduction of 16.7%.

Once the total GHG emissions and their distribution in each of the productive sectors were analyzed, the impact of variations in the consumption of Spanish households on GHG emissions was modeled. It was differentiated by age group, with emphasis made on the “young person” age group.
2.2. Methology

National accounting systems have come to be widespread in most economies, providing valuable information on a country’s economic situation. Thus, input–output tables were used and served as the main database for the economic analysis carried out. Using multisectoral modeling [26] on the input–output tables (IOT) published by the NIS [22], the impact of household consumption, differentiated by age bracket, on greenhouse gas (GHG) emissions was determined. A demand model was used, which was expressed in physical units, namely greenhouse gases (GHGs) measured in tons of CO$_2$ equivalent.

The input–output table can distinguish between the intermediate consumption matrix, the primary factor matrix, and the final demand matrix. Each column of the intermediate consumption matrix shows the intermediate products used by each productive sector to carry out its productive activity. The final demand matrix breaks down into different transactions (private consumption, public consumption, gross capital formation, and exports) the excess of resources of each sector over the intermediate demand made by all sectors. From these matrices, an input–output model was developed, wherein factor demands are independent of their prices, primary factor prices are exogenous, final demand is also exogenous, and product prices are independent of the structure of demand.

An input–output model defines sectoral production ($X_n$) by assuming a linear structure of intermediate consumptions ($x_{n1} + x_{n2} + \ldots + x_{nn}$) plus an exogenous sectoral final demand ($D_n$), where $x_{nj}$ is sector $j$’s intermediate consumption of products from sector $n$. The input–output model used consists of a system of linear equations, each of which describes the distribution of a sector’s products throughout the economy. These models are linear multisectoral models, where productive sectors are expressed as linear functions of the demand matrix. By defining the input–output technical coefficients ($a_{ij}$) as the relationship between the intermediate consumption ($x_{ij}$) and the total sectoral output ($x_j$) ($a_{ij} = x_{ij}/x_j$), the total production of any sector can be expressed as the sum of the transactions with the rest of the sectors, and the transactions through final demand. Thus, the matrix equation is as follows:

$$X_n = A_{nn} \cdot X_n + D_n$$  \hspace{1cm} (1)

where $D_n$ is an $n \times 1$ type of matrix (where $n$ is the number of productive sectors) that includes final demand, $X_n$ is an $n \times 1$ type of matrix composed of the total output of the sectors, and $A_{nn}$ is an $n \times n$ type of matrix formed by the average spending trends of the productive sectors (matrix of input–output technical coefficients).

Solving the equation:

$$X_n = (I - A_{nn})^{-1} \cdot D_n$$  \hspace{1cm} (2)

where $(I - A_{nn})^{-1}$ is the inverse matrix of Leontief. Each $c_{ij}$ element of the inverse matrix shows the change in the output of sector $i$ if sector $j$ receives an additional monetary unit since the final demand. The resulting matrix $X_n$ shows the degree to which an exogenous variation in the system may affect the total income of sectors.

Starting from the matrix in Equation (2), any variation in the income of the sectors (due to a variation in their final demand) is reflected in a variation of the production matrix, as described in the following equation:

$$\Delta X_n = (I - A_{nn})^{-1} \cdot \Delta D_n$$  \hspace{1cm} (3)

Expression $(I - A_{nn})^{-1}$ includes direct and indirect impacts on production when there is a change in final demand. An increase/decrease in final demand in a sector generates an increase/decrease in its production to meet the new demand (direct impact). This, in turn, causes that sector to increase/decrease its purchases from other sectors (indirect impact).

In addition to the impact on production, these models facilitate learning the impact on other macro magnitudes, as well as to express the impact in physical units, such as, in the case of this study, greenhouse gas (GHG) emissions.
To this end, the above modeling is used to assess the impact of changes in household consumption on GHG emissions caused by changes in economic activity (changes in production), implied by the modeled changes in household consumption.

This information is obtained using the unit coefficients of GHG emissions defined by the relationship between the emissions in physical terms \(E_i\) and the \(i\)th sector’s total output in monetary terms \(X_i\). Using this definition, we can rewrite the Expression (3), premultiplying the inverse matrix of the model by a diagonalized vector of unit coefficients of atmospheric emissions, \(E_n = \text{diag}(E_i/X_i)\), which shows the atmospheric emissions of a sector per unit of production. This yields the environmental effects of changes in household consumption.

\[
EMI_n = E_n(I - A_{nn})^{-1}D_n \Rightarrow \Delta EMI_n = E_n(I - A_{nn})^{-1}\Delta D_n
\]

Thus, it is possible to calculate changes in GHG emissions \(\Delta EMI_n\), both direct and indirect, caused by the variation in economic activity associated with changes in household consumption.

3. Results

The changes in household consumption patterns that occurred after the years of the economic crisis had an impact on the GHG emissions associated with this consumption. The availability of household consumption data disaggregated by age group facilitates an exhaustive analysis of how these emissions varied according to the type of household. The total GHG emissions distributed for each productive sector and the disaggregation of private household consumption by age bracket is explained in the section on methodology. This made it possible to perform a multisectoral modeling, specifically, a demand model expressed in physical units. In this case, the unit was GHG emissions measured in tons of CO\(_2\) equivalent, for each age group for the years 2005 and 2015. The results quantified the environmental impact caused by the consumption of each age group.

Once the CO\(_2\) equivalent emissions data for each of the productive sectors (Table 1) were obtained, a modeling process was performed to quantify the impact of the consumption of the different types of households by age brackets in 2005 and 2015 on greenhouse gas emissions. To this end, based on the demand model (Equation (2)), the demand vector (Equation (3)) was modified by only including the consumption of each of the age bracket where household consumption was disaggregated. Thus, (Equation (4)) only the greenhouse gas emissions caused by the consumption of each of the age brackets were obtained.

This process was repeated for each age group, reflecting the GHG emissions caused by the productive sectors due to the consumption of each type of household. Lastly, a comparative analysis was carried out to reveal the environmental effects before and after the economic crisis, highlighting the significant differences in emissions caused by the productive sectors, depending on the age group responsible for consumption in those sectors.

The following table shows the variation in total emissions produced by the most representative productive sectors because of household consumption. The highlighted sectors are those in which the variations are the highest, and the complete tables are shown in Appendix A, Appendix B, and Appendix C.

The results obtained in Table 4 show that the largest drop in GHG emissions is found in the group of households between 16 and 29, with a total reduction of 66.6%. The next age group that caused the greatest reduction in GHG emissions was the 30-49 age group, with 49.6%. This was followed by households between 50 and 64 years of age, with a 39.9% drop, and finally, those over 65 years of age, which reported a reduction of 13.9%. Therefore, it is seen that the older the primary provider is, the smaller the reduction in emissions associated with consumption is. The study also found that the sectors with the greatest reduction in emissions were, in this order, extractive industries (B), construction (F), manufacturing (C), commerce, (G) and transport and storage (H).
Table 4. CO₂ emissions linked to household consumption by age group (thousands of tons of CO₂ equivalent) and variations (percentage).

| YEAR 2005 | Sectors/Age | 16 to 29 | 30 to 49 | 50 to 64 | Over 65 |
|-----------|-------------|----------|----------|----------|---------|
| Sectors   | Emissions   |          |          |          |         |
| B         | 140         | 834      | 1083     | 406      |
| C         | 3050        | 18,018   | 23,525   | 8277     |
| F         | 11          | 66       | 84       | 38       |
| G         | 507         | 2570     | 3690     | 733      |
| H         | 1838        | 9770     | 12,006   | 3279     |
| Total Emissions | 11,350 | 66,711 | 86,320 | 32,448 |

| YEAR 2015 | Sectors/Age | 16 to 29 | 30 to 49 | 50 to 64 | Over 65 |
|-----------|-------------|----------|----------|----------|---------|
| Sectors   | Emissions   |          |          |          |         |
| B         | 16.42       | 145.77   | 225.01   | 120.72   |
| C         | 871.88      | 7678.19  | 11,816.85| 5858.82  |
| F         | 1.92        | 17.47    | 26.92    | 16.42    |
| G         | 140.40      | 1130.93  | 1620.29  | 551.82   |
| H         | 611.07      | 5036.37  | 7291.06  | 2733.86  |
| Total Emissions | 3796.39 | 33,599.00 | 51,868.59 | 27,926.33 |

| VARIATION | Sectors/Age | 16 to 29 | 30 to 49 | 50 to 64 | Over 65 |
|-----------|-------------|----------|----------|----------|---------|
| Sectors   | Emissions   |          |          |          |         |
| B         | −88.3%      | −82.5%   | −79.2%   | −70.3%   |
| C         | −71.4%      | −57.4%   | −49.8%   | −29.2%   |
| F         | −82.1%      | −73.5%   | −68.0%   | −57.2%   |
| G         | −72.3%      | −56.0%   | −47.6%   | −24.7%   |
| H         | −66.8%      | −48.4%   | −39.3%   | −16.6%   |
| Total Emissions | −66.6% | −49.6% | −39.9% | −13.9% |

Source: prepared by the authors. B: mining and quarrying; C: manufacturing; F: construction; G: wholesale and retail trade; repair of motor vehicles and motorcycles; H: transportation and storage.

The results in Table 4 also provide relevant information on which age bracket is most responsible for emissions in each of the productive sectors. In all sectors, the 50–64 age bracket stands out as the one causing the most emissions, followed by the 30–49 age bracket. The 16–29 age bracket, in addition to being the one that causes the least emissions, in some of the sectors, the difference with the rest of the age brackets was significant. The data for 2015 prove that the crisis had a greater impact on young people, as it was observed that in all sectors, the difference between the emissions associated with young people and those of the rest of the age groups was significant compared to the data for 2005.

Once the results of the environmental impacts in the years studied were presented and once the variations were analyzed, the results of the sectors reporting greater reductions in the emissions caused by young households after the economic crisis are discussed.

4. Discussion

In the most representative productive sectors, the one with the greatest reduction in GHG emissions in its variation was extractive industries (B), which showed a drop in GHG emissions of 88.3%, 82.5%, 79.2%, and 70.3% for each age bracket, respectively. The use of renewable energy technology was key to this result. For example, in a mineral processing plant in Granada, an industrial salinity solar pond was constructed, which generated heat to the water, partially replacing the fuel oil boiler [27]. Another example was the use of energy coming from the forests of Asturias as an alternative to coal, and it is important to note the location of the Biomass Logistics Center (BLC) in Oviedo due to its technical, economic and geographical advantages [28]. In addition, the Draft Law on Climate Change and Energy Transition [29] commits Spain to base its electricity system on renewable sources. As such, taking advantage of abandoned mining concessions for the
generation of heat from within the earth (geothermal energy) to heat and cool surrounding buildings is envisaged, as has been demonstrated by various studies [30,31].

The second sector that experienced the largest drop in GHG emissions is construction (F), with reductions of 82.1%, 73.5%, 68%, and 57%, for each age bracket, respectively. It is one of the sectors responsible for more than 30% of the world’s total energy consumption. As such, efforts have focused on establishing energy certifications for buildings and residences in order to improve the efficiency of buildings and thus reduce their emissions [32,33]. In addition, concentrating solar power (CSP) systems are used in the construction stage. The efficiency of this system has been reviewed in the literature by Islam, Huda, Abdullah, and Saidur [34], and has made Spain and the United States the world leaders.

Furthermore, another factor that has been successful in reducing carbon emissions has been the use of prefabricated construction methods. A study conducted in China has shown a decrease of up to 18% in emissions compared to conventional construction [35]. In addition, in recent years, there has been an improvement in energy efficiency in this type of construction, such as the use of precast concrete by eliminating heat treatment [36], or the production, recovery and transportation of components of steel structures [37]. Currently, research is being carried out on integrating photovoltaics into the prefabricated volumetric construction process [38] and the introduction of advanced technological devices, such as building information modeling (BIM) [39].

The next two sectors that reduced their emissions correspond to manufacturing (C) and wholesale and retail trade; and the repair of motor vehicles and motorcycles (G). It is difficult to list the numerous factors that have led to the reduction in these sectors, as the use of renewable energy affects the reduction in most sectors, especially manufacturing. Generating power via a hybrid system such as a turbine/solar (PAT-PV) and traditional diesel on fossil fuels has been shown to decrease environmental impacts by reducing the consumption of fossil energy and using the surplus energy in powering vehicles or power tools to achieve more sustainable agriculture [40]. Currently, and also related to transportation, there are electric vehicles that do not produce emissions when driving, but they do rely on a carbon-intensive electricity generation system, so a 100% renewable system would be necessary to reduce emissions by up to 74 million tons per year [41]. The introduction of urban electric buses over the next 10 years (2020 to 2030) would reduce emissions by up to 92.6% with respect to 2018 levels [42]. The question of how to reuse affordable electric vehicle batteries for greater sustainability is also being studied [43].

This research study helps to identify the environmental impacts caused by household consumption after an economic crisis, such as the current one, by reducing GHG emissions and considering the technological progress of energy sources. It thereby calls for energy policies to be undertaken that are directed at the consumption by different types of households in the productive sectors making up an economy such as the Spanish one. A potential focus for future research is a similar analysis of the current health crisis and its environmental effects.

Another future research line could study whether the changes in emissions can be explained by alternative factors, not only due to the economic crisis. Additionally, we are interested in assessing whether these changes reflect significant differences in typological terms: urban and rural areas. Finally, we also intend to analyze how these changes depend on household income.

5. Conclusions

This study shows the environmental impact on the Spanish economy via household consumption, one of the responsible parties for the 37.2% reduction in GHG emissions, while total production has grown by 15%, before and after the economic crisis analyzed. The different types of households, depending on their age, experience changes in patterns after an economic crisis, such as that of 2008, which, together with the increase in renewable
energies and improvements in energy efficiency, promoted by national and international plans, have led to a reduction in GHG emissions.

The results indicate that the older the age of the main household provider, the smaller the reduction in GHG emissions associated with their consumption is. Thus, the largest drop in emissions is found in the group of young households between the ages of 16 and 29, with a total reduction of 66.6%. This is followed by the next age bracket, between 30 and 49 years, with a drop of 49.6%, and the last age brackets are 50–64 years and those over 65 years old, with reductions of 39.9% and 13.9%, respectively.

In addition, it was confirmed that the sectors with the greatest reduction in emissions caused by the consumption of Spanish households were, in this order, extractive industries (B), construction (F), manufacturing industry (C), wholesale and retail trade; repair of motor vehicles and motorcycles (G), and transport and storage (H).

The increase in energy technology and the use of renewable energies, such as CSP systems, prefabricated construction methods, or hybrid systems that generate electricity are the main factors leading to a drop in emissions when applied to buildings, transportation, and manufacturing processes, mainly related to the highlighted sectors.

Therefore, while there are limitations in the model performed relating to the assumptions underlying the input–output method, such as assuming a fixed structure for each sector of the economy due to the coefficients of the technical coefficients matrix being constant, the goals set out were achieved, thus opening new lines of research.

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Appendix A

Table A1. CO$_2$ emissions associated with household consumption by age bracket and productive sector for 2005 (thousands of tons of CO$_2$ equivalent).

| Sectors/Age | 16 to 29 | 30 to 49 | 50 to 64 | Over 65 | Total       |
|-------------|----------|----------|----------|---------|-------------|
| A           | 1449     | 9132     | 12,591   | 5054    | 28,226      |
| B           | 140      | 834      | 1083     | 406     | 2464        |
| C           | 3050     | 18,018   | 23,525   | 8277    | 52,870      |
| D           | 3698     | 22,270   | 28,657   | 12,396  | 67,021      |
| E           | 448      | 2764     | 3592     | 1667    | 8471        |
| F           | 11       | 66       | 84       | 38      | 199         |
| G           | 507      | 2570     | 3090     | 733     | 6900        |
| H           | 1838     | 9770     | 12,006   | 3279    | 26,893      |
| I           | 57       | 302      | 398      | 107     | 865         |
| J           | 22       | 122      | 155      | 51      | 350         |
| K           | 12       | 82       | 103      | 41      | 238         |
| L           | 27       | 174      | 226      | 119     | 547         |
Table A1. Cont.

| Sectors/Age | 16 to 29 | 30 to 49 | 50 to 64 | Over 65 | Total |
|-------------|----------|----------|----------|---------|-------|
| M           | 12       | 69       | 89       | 30      | 199   |
| N           | 22       | 129      | 161      | 52      | 363   |
| O           | 0        | 0        | 0        | 0       | 0     |
| P           | 3        | 59       | 88       | 9       | 159   |
| Q           | 20       | 142      | 225      | 98      | 486   |
| R           | 10       | 62       | 75       | 22      | 169   |
| S           | 14       | 84       | 107      | 37      | 243   |
| T           | 10       | 61       | 65       | 31      | 166   |
| Total       | 11,350   | 66,711   | 86,320   | 32,448  | 196,829 |

Appendix B

Table A2. CO₂ emissions associated with household consumption by age bracket and productive sector for 2015 (thousands of tons of CO₂ equivalent).

| Sectors/Age | 16 to 29 | 30 to 49 | 50 to 64 | Over 65 | Total |
|-------------|----------|----------|----------|---------|-------|
| A           | 563.10   | 5174.34  | 8436.90  | 4790.80 | 18,965.13 |
| B           | 16.42    | 145.77   | 225.01   | 120.72  | 507.92 |
| C           | 871.88   | 7678.19  | 11,816.85 | 5858.82 | 26,225.74 |
| D           | 1275.36  | 11,549.10 | 18,013.83 | 11,230.10 | 42,068.38 |
| E           | 194.55   | 1771.42  | 2772.60  | 1756.73 | 6495.30 |
| F           | 1.92     | 17.47    | 26.92    | 16.42   | 62.72 |
| G           | 140.40   | 1130.93  | 1620.29  | 551.82  | 3443.43 |
| H           | 611.07   | 5036.37  | 7291.06  | 2733.86 | 15,672.36 |
| I           | 25.88    | 198.75   | 281.92   | 108.08  | 614.64 |
| J           | 7.00     | 61.29    | 90.10    | 42.31   | 200.70 |
| K           | 5.52     | 52.77    | 80.33    | 47.06   | 185.68 |
| L           | 18.25    | 169.39   | 267.58   | 186.05  | 641.27 |
| M           | 6.96     | 60.68    | 90.23    | 43.23   | 201.10 |
| N           | 10.88    | 97.86    | 142.63   | 64.08   | 315.45 |
| O           | 3.04     | 26.28    | 40.21    | 19.42   | 88.95 |
| P           | 6.44     | 56.32    | 101.72   | 15.81   | 180.29 |
| Q           | 7.68     | 77.10    | 140.39   | 93.76   | 318.93 |
| R           | 4.84     | 48.30    | 67.30    | 29.37   | 149.80 |
| S           | 21.21    | 206.51   | 301.78   | 172.83  | 702.32 |
| T           | 4.00     | 40.16    | 60.95    | 45.09   | 150.20 |
| Total       | 3796.39  | 33,599.00 | 51,868.59 | 27,926.33 | 117,190.31 |
### Appendix C

**Table A3.** Variation of CO\(_2\) emissions associated with household consumption by age bracket and productive sector for 2005–2015 (Percentages).

| Sectors/Age | 16 to 29 | 30 to 49 | 50 to 64 | Over 65 | Total |
|-------------|----------|----------|----------|---------|-------|
| A           | −61.1%   | −43.3%   | −33.0%   | −5.2%   | −32.8%|
| B           | −88.3%   | −82.5%   | −79.2%   | −70.3%  | −79.4%|
| C           | −71.4%   | −57.4%   | −49.8%   | −29.2%  | −50.4%|
| D           | −65.5%   | −48.1%   | −37.1%   | −9.4%   | −37.2%|
| E           | −56.6%   | −35.9%   | −22.8%   | 5.4%    | −23.3%|
| F           | −82.1%   | −73.5%   | −68.0%   | −57.2%  | −68.5%|
| G           | −72.3%   | −56.0%   | −47.6%   | −24.7%  | −50.1%|
| H           | −66.8%   | −48.4%   | −39.3%   | −16.6%  | −41.7%|
| I           | −54.9%   | −34.2%   | −29.2%   | 1.3%    | −28.9%|
| J           | −67.5%   | −49.8%   | −41.9%   | −16.8%  | −42.6%|
| K           | −55.1%   | −35.5%   | −22.1%   | 15.5%   | −21.8%|
| L           | −33.3%   | −2.7%    | 18.2%    | 56.4%   | 17.3% |
| M           | −41.3%   | −11.8%   | 1.8%     | 44.1%   | 1.0%  |
| N           | −50.4%   | −23.9%   | −11.3%   | 23.8%   | −13.1%|
| O           | 0.0%     | 0.0%     | 0.0%     | 0.0%    | 0.0%  |
| P           | 91.5%    | −3.8%    | 15.5%    | 66.4%   | 13.7% |
| Q           | −61.3%   | −45.8%   | −37.7%   | −4.7%   | −34.3%|
| R           | −49.9%   | −22.5%   | −10.2%   | 32.0%   | −11.5%|
| S \(^1\)    | 48.7%    | 145.0%   | 181.0%   | 368.0%  | 189.7%|
| T           | −59.0%   | −33.9%   | −6.4%    | 47.4%   | −9.7% |
| **Total**   | −66.6%   | −49.6%   | −39.9%   | −13.9%  | −40.5%|

\(^1\) The high value in the S sector is because its component activities are different in both years.

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