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Are Green Buildings an Indicator of Sustainable Development?

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Abstract: The world's population keeps growing together with the construction rate of buildings that need to reduce their environmental footprint in order to mitigate global warming. This paper analyses if the spread of green buildings can be used as an indicator of broader sustainable development. The study is carried out with data taken from Eurostat Database and green buildings directories for 27 EU countries in the 10-year period spanning from 2010 to 2019. The relationship between the indicators is examined through simple linear regressions, and the results confirm the Environmental Kuznets Curve hypothesis: in developed countries, a growing economy (more GDP) is related to an environmental improvement (fewer GHG emissions). In addition, this study proves that the variance of green buildings expresses with a consistent probability the variance of GDP per capita (p-value = 0.0004 and R^2 = 0.8475) and the variance of GHG emissions (p-value = 0.0002 and R^2 = 0.8825), meaning that green buildings are indeed an indicator of sustainable development. This is due to the upfront cost required to implement advanced construction technologies that ultimately cut GHG emissions during the building lifecycle. This also points out that policy makers should encourage green building implementation through tax relieves and grants.

Keywords: European Union; climate change; Environmental Kuznets Curve; sustainable development; green buildings

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1. Introduction

According to the International Monetary Fund, the Gross Domestic Product (GDP) measures the monetary value of goods and services produced in a region in a defined period [1]. Typically, its growth does not consider the environmental degradation of the resources adopted to achieve it. For this reason, effective economic growth represents the highest possible growth of GDP obtained by meeting the restrictions imposed by environmental protection [2].

Accordingly, sustainable development is seen as the fulfilment of present needs without compromising the ability of future generations to meet their own needs [2]. From the perspective of the scope of this paper, the most important goal is the growth of GDP with a simultaneous reduction in Greenhouse Gas (GHG) emissions, which is the most common indicator used to express environmental degradation [3] since GHGs (e.g., water vapor, carbon dioxide, methane, nitrous oxide, etc.) trap heat causing global warming once they are released into the atmosphere.

One of the models that represent the link between economic growth and GHG emissions is the Environmental Kuznets Curve (EKC), which illustrates that the relationship between environmental degradation and GDP has an inverted U-shaped form, as seen in Figure 1 [4].

The curve shows that a developing region is characterised by an initial fast economic growth that typically goes along with an increase in environmental degradation. The advances in the region generally lead to the development of new technologies that reverse the trend of the graph. From the turning point, the economy continues to grow together with environmental improvement, as shown by the decrease in GHG emissions [4]. Therefore, GDP is seen as both the cause and the cure for environmental degradation [5].

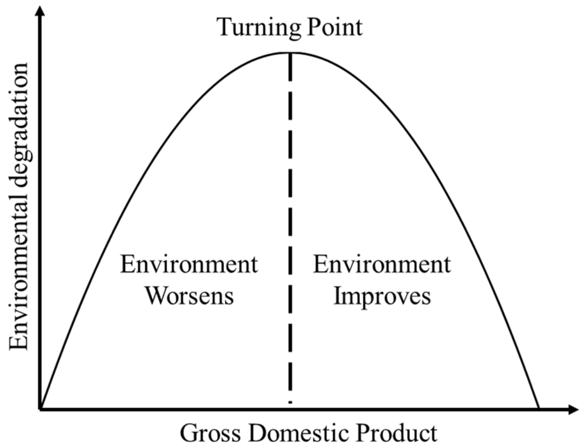

Figure 1. Environmental Kuznets Curve (EKC).

A study [6] develops the allometric regression line of the global annual anthropogenic CO_2 emissions as predicted isometrically by the global GDP. The statistical method introduces the R^2, an indicator that represents the proportion of the variance for a dependent variable (in this case, GDP) that is obtained from an independent variable (in this case, CO_2 emissions) in the regression model. However, the study [6] only considers the anthropogenic industrial and domestic emissions of goods and services but does not analyse the origin of the emissions. Globally, the GDP regression as a function of CO_2 emissions is characterised by a consistent R^2, valid also during COVID-19 lockdowns where the global GDP and CO_2 emissions dropped, respectively, by 7% and 7.29% [7].

Another study [8] assessed the relationship between GDP and GHGs to check the validity of the EKC curve in the European Union (EU), Norway and Switzerland between 1995 and 2010 using the data taken from the Eurostat database [8]. In addition to R^2, the *p*-value is introduced to explain the probability of obtaining results as extreme as the observed results of a statistical hypothesis test. The lower the *p*-value, the greater the statistical significance of the observed difference. However, the results of the assessment [8] show that in some cases, the model does not yield any significant results because R^2 values are very small and the *p*-value is too big.

In 2015 the United Nations Member States adopted the 2030 Agenda for Sustainable Development, which states that growth must balance social, economic and environmental sustainability [9]. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries—developed and developing—in a global partnership to tackle several issues [10].

The share of the world's population in developing countries (e.g., China, India, South America, etc.) is bigger than the one in developed countries (e.g., North America, Europe, Japan, Australia, etc.) [11]. This, together with the constant urbanisation process, has been defined as the most important cause of the continuous growth of global GHG emissions [11]. In 2018, the United Nations estimated that the share of the world's population living in urban areas was 55%, a proportion expected to increase up to 68% by 2050 [12].

Since the construction rate of buildings and cities keeps steadily growing, the overall quality of buildings must be improved in order to mitigate climate change, whose main driving force is unanimously recognised to be human activity [13]. Buildings need to reduce their environmental footprint during their entire lifecycle, from the design/construction to the operation and dismantling, and the only way to achieve this challenging target is through a coordinated global effort.

In 2020, the European Commission stated that buildings in the EU were responsible for 36% of GHG emissions [14], which mainly stem from construction, usage, renovation and demolition. With this background, the European Commission sets the 2030 Climate Target Plan to reduce GHG emissions to at least 55% below 1990 levels by 2030 in order to reach carbon neutrality by 2050 [15]. Accordingly, the Communication on Resource Efficiency Opportunities in the Building Sector was released to meet the need for a common European approach to reduce the environmental impact of buildings throughout their whole lifecycle [16]. This intended to establish some order among the various Green Building Rating Systems (GBRS), which are globally recognised tools to assess building sustainability through the process of identifying, measuring and evaluating alternative green solutions. Green buildings come with the most innovative technologies in the construction sector, and they comprise the advances achieved in developed countries to guarantee continuous economic growth along with environmental improvement, as expressed by the EKC curve.

The first GBRS was launched in the United Kingdom in 1990 under the name of Building Research Environmental Assessment Method (BREEAM) [17]. At present, in addition to BREEAM, the most widely spread GBRSs in the EU are Leadership in Energy and Environmental Design (LEED), originally from the US [18]; Deutsche Gesellschaft für Nachhaltiges Baden (DGNB) from Germany [19]; and Haute Qualité Environnementale (HQE) from France [20]. Other countries in the EU have been developing their own schemes with a local adaptation; however, none has reached a comparable diffusion, and international recognition and thousands of buildings are now certified under the four GBRS mentioned [21].

Green buildings have always been considered essential to lowering global GHG emissions. A study from 2008 [22] already states that energy-efficient buildings are one of the most affordable methods to mitigate climate change, but the actual effect is not quantified.

Another study [23] confirms that the construction industry plays a vital role in the economic growth of a country even though it generates implications for the environment since 40% of the world's resource and energy use is linked to the construction and maintenance of buildings. The study shows that green building practices can reduce CO_2 emissions by up to 39%, but it does not quantify the related economic growth [23].

A more recent study [24] presents a spatial regression method to measure the impacts of GBRS on energy consumption and GHG emissions. The results imply that GBRSs guarantee a 13.2% reduction in energy consumption (with R^2 = 0.572) and a 3.24% abatement in GHG emissions (with R^2 = 0.626). However, the research ignores the economic implications and considers only Energy Star as GBRS and buildings located in an area limited to Seattle, the 18th largest city in the US [24].

As shown in this review, the literature delineates that there is a direct link between the GDP and GHG emissions, which, in the case of a developed region such as the EU, consists of growth of the first one with a simultaneous reduction in the latter one (i.e., sustainable development).

However, there is no evidence of a relationship between those two indicators and GBRS certifications. Therefore, the goal of this study is to quantitatively evaluate if the adoption of GBRS can be used as an indicator of a higher level of sustainability reached within a region. Therefore, it will be clarified if the spread of GBRS can reflect sustainable development within society. If the answer is positive, policy makers will be asked to adopt additional tax exemptions and subsidy schemes to stimulate the spread of GBRS and meet GHG reduction targets while improving the economy, with a broader effect on society.

The relationship between GDP, GHG emissions, renewable energy consumption, climate conditions and GBRS are assessed with statistical methods. The resulting equations define how one independent variable can predict the outcome of the dependent variable, and R^2 and p-value are used to determine the proportion of the variance between the variables and the probability of predicting results.

This is aligned with the targets set by the Sustainable Development Goals, which, among the overall social, economic and environmental aspects addressed, focus on the following:

- Goal 7: Affordable and clean energy—with the commitment to increase the share of renewable energy consumption [25];
- Goal 11: Sustainable cities and communities—with the incentive to spread the implementation of green buildings [26];
- Goal 13: Climate action—focusing on reducing GHG emissions to limit global warming [27].

In particular, considering data from the Eurostat Database for the 27 EU countries in the 10-year-period between 2010 and 2019, the study investigates the linear equations that correlate the following:

- Green buildings certifications (dependent variable) with GDP per capita (independent variable);
- Green buildings certifications (dependent variable) with GHG emissions (independent variable).

2. Methodology

Currently, the methodology illustrates the research approach followed, the data analyses and the data collection method.

2.1. Research Approach

The relationship between the variables is examined through simple linear regressions that, in statistical modelling, are used to estimate the correlation between a dependent variable and an independent variable. The relationship is defined with an equation representing the line that better fits the data according to a specific mathematical criterion. The quality of the equation is expressed through the following:

- R^2, which is an indicator that represents the proportion of the variance for a dependent variable that is obtained from an independent variable. An $R^2 = 1$ shows that the variance of one variable expresses exactly the variance of the second variable.
- *p*-value, which is an indicator that explains the probability of predicting results from the dependent variable to the independent variable. A p-value < 0.05 (i.e., probability > 95%) is the threshold assumed to guarantee statistical significance.

2.2. Data Analysis

The following indicators are used to evaluate if the adoption of GBRS can be used as an indicator of a higher level of sustainability reached within a region:

- GBRS as an indicator of the adoption of green solutions in the construction sector.
- GHG emissions as an indicator of environmental degradation.
- GDP as an indicator of economic growth.

In addition, two additional indicators are introduced to better understand the behaviour of the three main variables:

- Share of renewable energy as an indicator of the adoption of advanced power generation technologies since energy production is the first source of GHG emissions [28].
- Heating degree day (HDD) as an indicator of the climate since the energy demand of buildings is directly related to external conditions.

Regarding climate conditions, heating degree day (HDD) is adopted as a weather-based technical index used by Eurostat to describe the need for heating energy requirements in buildings based on observations from about 3000 weather stations across Europe [29]. HDD measures the severity of the cold in a specific period taking into consideration the daily mean outdoor air temperature (T_m) and the average room temperature (i.e., the need for heating). HDD is calculated with the following equations:

$$\text{If } T_m > 15^\circ\text{C, HDD} = 0 \tag{1}$$

$$\text{If } T_m \leq 15\ ^\circ\text{C, HDD} = \textstyle\sum_i (18\ ^\circ\text{C} - T_m{}^i) \tag{2}$$

where T_m is the mean outdoor air temperature of day i, 15 °C is the threshold below which heating is typically activated and 18 °C is the average room temperature used as a set point when heating is activated.

Cooling degree days (CDD) have not been considered in the study since they are less relevant compared to the heating degree days (HDD) because:

- The region analysed is mainly characterised by heating demand rather than cooling demand due to its geographical location. For this reason, cooling accounts for negligible energy use compared to heating.
- Cooling power is provided through electric heat pumps that do not directly emit GHGs even if electric power at a regional level is still partially generated by fossil fuels, whose share is decreasing following the recent EU directives. On the other side, heating is one of the main sources of energy consumption and GHG emissions in buildings due to the consistent use of fossil fuel-based energy resources [30].

The trend presented in Figure 2 shows that, in the last decade, yearly HDD has been decreasing significantly, highlighting warmer and warmer winters due to climate change. In particular, 2014 stands out as the hottest year and the lowest HDD (outlier shown in red in the chart). This may affect the trend of the linear regressions since it impacts, respectively, the typical energy demand of buildings (especially during winter), their energy consumption and, in turn, GHG emissions. Therefore, to obtain a more realistic picture, it could be required to remove 2014 from the analysis.

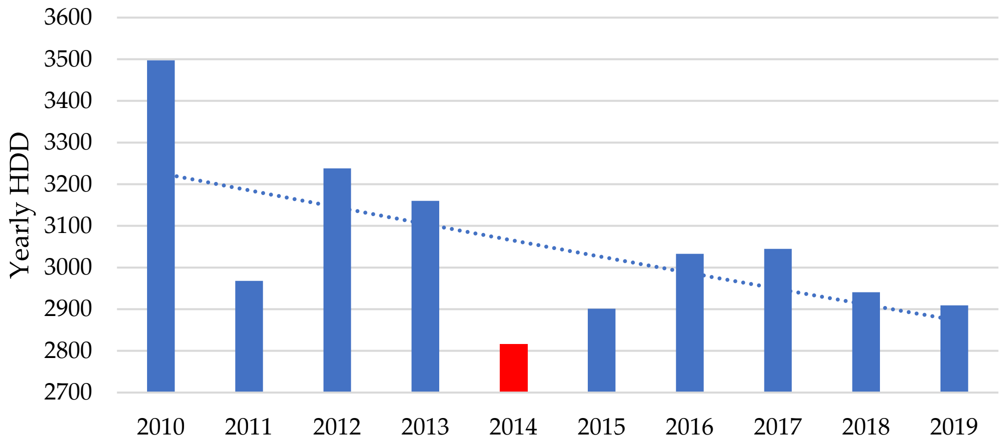

Figure 2. Yearly heating degree days in the EU.

Regarding GBRS, their multi-criterion nature based on indicators and benchmarks is intended to reduce the environmental footprint of buildings. These tools go beyond the simple energy benchmarking since they also assess areas such as pollution, water, materials and resources, waste, land use and ecology, health and wellbeing, and transportation that together contribute to GHG emission [2].

The consumption of fossil fuel-based energy resources is commonly recognised as the main driving factor behind GHG emissions, and the first step to reducing buildings' primary energy consumption is to minimise energy demand through the adoption of passive strategies (e.g., insulation, shading devices, etc.) [31]. However, a small portion of the energy is always required (e.g., for process, lighting, etc.), but it can come from renewable energy technologies. If this happens, we are in front of a Net Zero Energy Building (NZEB). Off-site renewable energy generation can also be employed if the on-site renewable systems are not enough since they are both characterised by no GHG emissions during the power generation process [32]. The reduction in energy use, the energy production from renewable sources and the improvement of energy performances in the construction sector also help to reduce the EU's energy dependency on foreign countries [33].

Even though building energy consumption in the operation phase is commonly recognised as the main source of GHG emissions in buildings, a lifecycle approach shows that embodied GHG emissions during the production, transportation and construction of building components also cover an important portion of the total GHG emissions [34].

Green buildings are characterised by an extra cost during development and construction due to the more expensive technologies adopted. However, the cost savings during the operation and maintenance of the building offset the upfront cost and guarantee a reasonable return on investments [35]. However, the extra cost needed to implement advanced features justifies the faster spread of green buildings in more developed regions. However, the extra cost needed to implement advanced features justifies the faster spread of green buildings in more developed regions.

This study considers BREEAM, LEED, DGNB and HQE, which are the GBRS with the highest diffusion and international recognition, as seen in Figure 3.

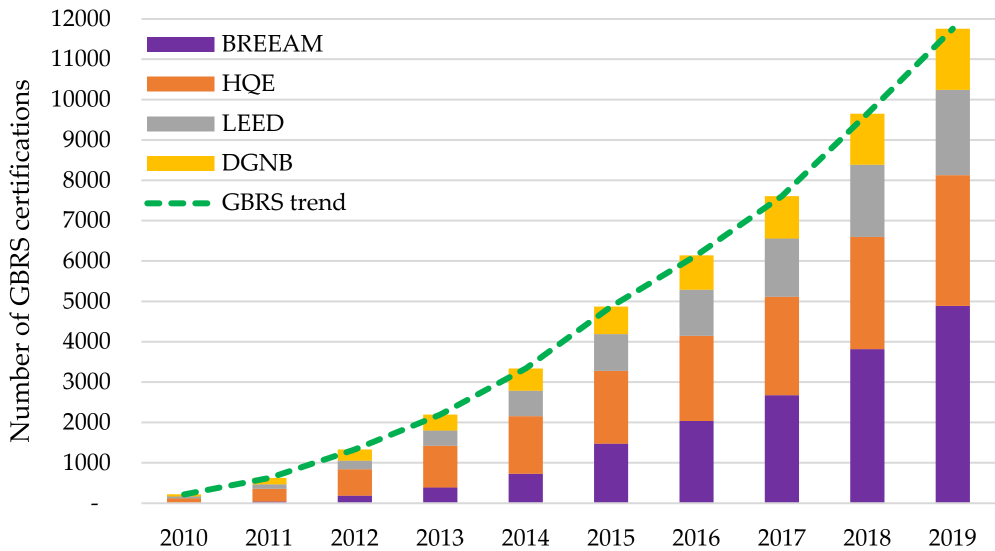

Figure 3. Cumulative GBRS in the EU.

During the last decade, in the EU, GBRS have been spreading at different speeds (e.g., BREEAM arrived in 2012, but it is now predominant) and in a different way in every country. However, Figure 3 shows that the cumulative trend is exponential, and at the end of 2019, the situation was as follows:

- France was leading BREEAM with 1197 certified buildings, followed by The Netherlands (872), Sweden (500), Poland (479) and Spain (429) [17].
- Spain was leading LEED with 376 certified buildings, followed by Germany (316), Sweden (283), Italy (245) and Finland (205) [18].
- Germany was leading DGNB with 1392 certified buildings, followed by Austria (57), Denmark (21), Luxembourg (16) and Spain (6) [19].
- France was leading HQE with 3195 certified buildings, followed by Germany (26), Belgium (6), Poland (5) and Luxembourg (2) [20].

Overall, the EU country with more GBRS was France (4465), followed by Germany (1902), The Netherlands (905), Spain (812) and Sweden (783).

2.3. Data Collection Method

The analysis involves data taken from the Eurostat Database and the GBRS Public Directories with more than 100,000 values within the following extent:

- Twenty-seven EU countries (EU-27): Belgium, Bulgaria, Czechia, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania,

Luxembourg, Hungary, Malta, Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland and Sweden.
- The 10-year period between 2010 and 2019.
- LEED, BREEAM, DGNB and HQE-certified buildings of any function (residential, office, retail, industrial, logistic, etc.) and typology (new constructions, refurbishments, in operation).

The long timeframe (10 years) and the big geographical boundary (EU-27) are intended to show the long-term trend and smooth, punctual events such as economic crises, social protests or geopolitical tensions.

The 27 EU countries are similar enough according to the EKC curve and can be considered as a unique region with consistent accuracy. However, a slightly different state of sustainable development has already been anticipated and will be detailed in the following sections.

At the same time, GBRS are considered cumulative between the four schemes to mitigate the commercial and regional appeal of each one. The cumulative number does not consider private projects (not visible in the public directories), whose amount is negligible anyway.

3. Results and Discussion

The relationship between GDP, GHG emissions, renewable energy consumption, climate conditions and GBRS is now examined through several regression models to establish if there are accurate equations that can indicate sustainable development from green building adoption.

3.1. GDP and GHG Emissions

The relationship between the average GDP per capita in the EU (dependent variable) and GHG emissions per capita (independent variable) is studied through simple linear regression with data taken from Eurostat Database.

The ten points in Figure 4 (blue dots) represent the years between 2010 and 2019. The trendline is linear with an equation of $y = -0.2685x + 15.997$, a p-value = 0.0099 and an $R^2 = 0.5852$. However, if we do not consider 2014 (highlighted with a red triangle in Figure 5 and characterised by extreme climate conditions with significantly fewer heating degree days compared to other years), the chart assumes a more linear equation $y = -0.2996x + 16.862$ with more accurate p-value = 0.0027 and $R^2 = 0.7446$.

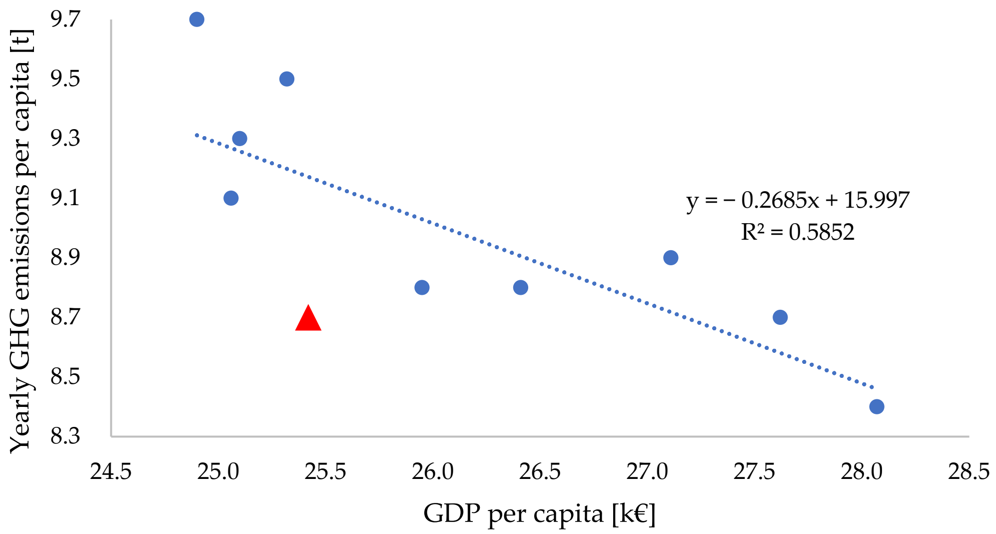

Figure 4. Relationship between GDP per capita and GHG emissions per capita in the EU (2010–2019).

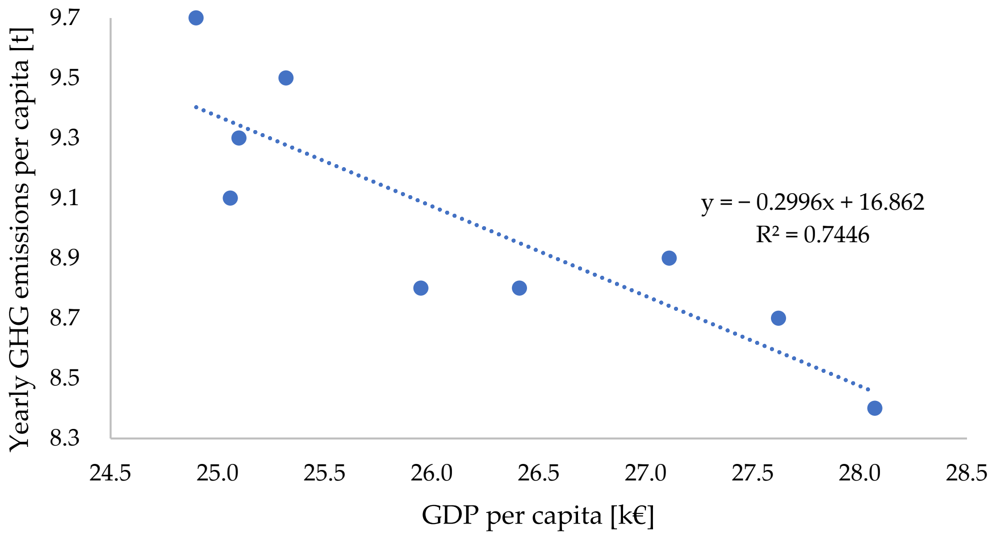

Figure 5. Relationship between GDP per capita and GHG emissions per capita in the EU (2010–2013 and 2015–2019).

According to the assumptions stated in the Methodology, *p*-value and R^2 are consistent, and the equation that correlates the two variables is accurate with a strong significance.

As illustrated by the EKC curve, in a developed area such as the EU, a higher income per capita is related to fewer GHG emissions per capita due to the best technologies already in place. This confirms the outcomes of another study [7] but differs from the ones from the second study [8] that assessed data in a mutating economic period within the EU (1995–2010) with the simultaneous presence of the left and right side of the EKC curve.

3.2. Energy and GHG Emissions

The relationship between the average share of renewable energy in gross final energy consumption (dependent variable) and GHG emissions (independent variable) is studied through simple linear regression with data taken from Eurostat Database.

The ten points in Figure 6 (blue dots) represent the years between 2010 and 2019. The trendline is linear with an equation of $y = -8453.7x + 5438.7$, a *p*-value = 0.0001 and an $R^2 = 0.8841$. However, if we do not consider 2014 (highlighted with a red triangle in Figure 7 and characterised by extreme climate conditions with significantly fewer heating degree days compared to other years), the chart assumes an even more linear equation $y = -8346.8x + 5432.5$ with more accurate *p*-value = 0.0000 and $R^2 = 0.9368$.

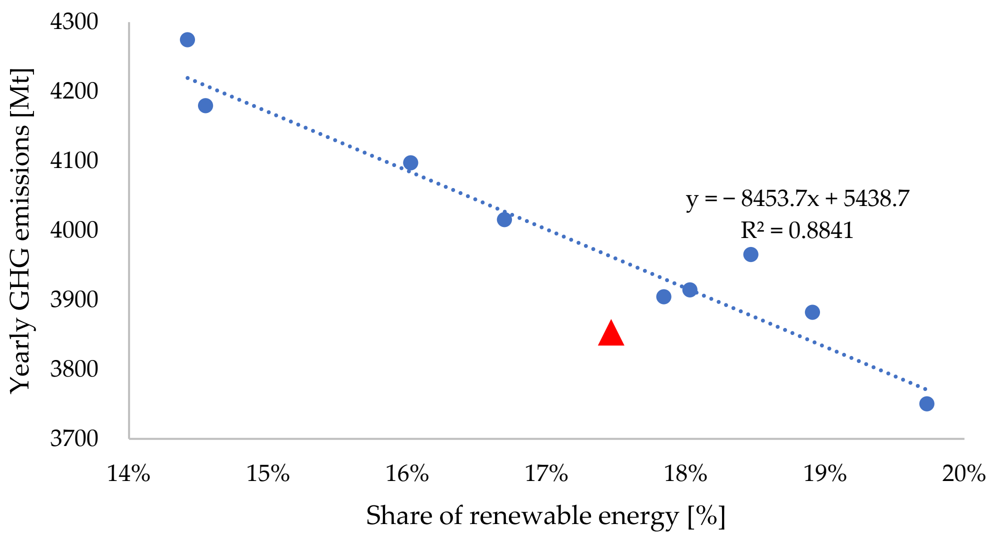

Figure 6. Relationship between % of renewable energy and GHG emissions in the EU (2010–2019).

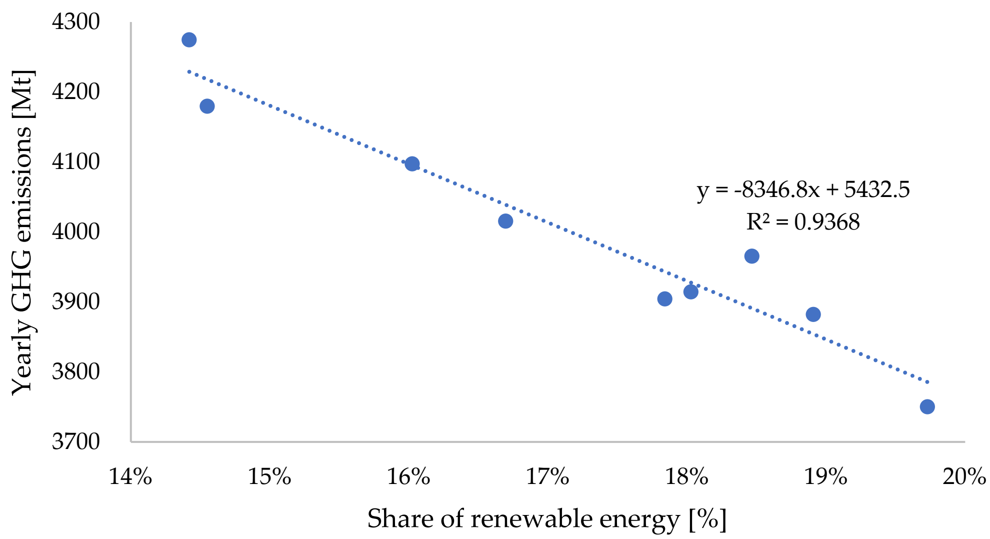

Figure 7. Relationship between % of renewable energy and GHG emissions in the EU (2010–2013 and 2015–2019).

According to the assumptions stated in the Methodology, *p*-value and R^2 are consistent, and the equation that correlates the two variables is extremely accurate with a strong significance.

As expected, more renewable energy utilisation is related to fewer GHG emissions due to less dependency on fossil fuels. This is confirmed by the literature that states that around 3/4 of the GHG emissions come from energy production [28] and that renewable energy consumption halves GHG emissions compared to fossil energy consumption in EU countries [36]. Moreover, another study affirms that renewable energy mitigates carbon emissions while non-renewable energy increases them, supporting the EKC curve [37].

3.3. Climate and GHG Emissions

The relationship between the yearly HDD (dependent variable) and GHG emissions from buildings (independent variable) is studied through simple linear regression with data taken from Eurostat Database.

The ten points in Figure 8 (blue dots) represent the years between 2010 and 2019. The trendline is linear with an equation of y = 0.4321x + 327.26, a *p*-value = 0.0003 and an R^2 = 0.8237. However, if we do not consider 2014 (highlighted with a red triangle in Figure 9 and characterised by extreme climate conditions with significantly fewer heating degree days compared to other years), the chart assumes a more linear equation y = 0.479x + 176.93 with more accurate *p*-value = 0.0003 and R^2 = 0.8673.

According to the assumptions stated in the Methodology, *p*-value and R^2 are consistent, and the equation correlates the two variables in a very accurate way with a strong significance.

As expected, fewer heating degree days are related to fewer GHG emissions from buildings due to less dependency on space heating and fossil fuel-based energy generation. This is aligned with the findings of a study [38] that highlights how global warming is decreasing the energy needed in heating-dominated zones. However, global warming will be an issue for the cooling-dominated zones, where the electricity demand and related GHG emissions will increase exponentially [39].

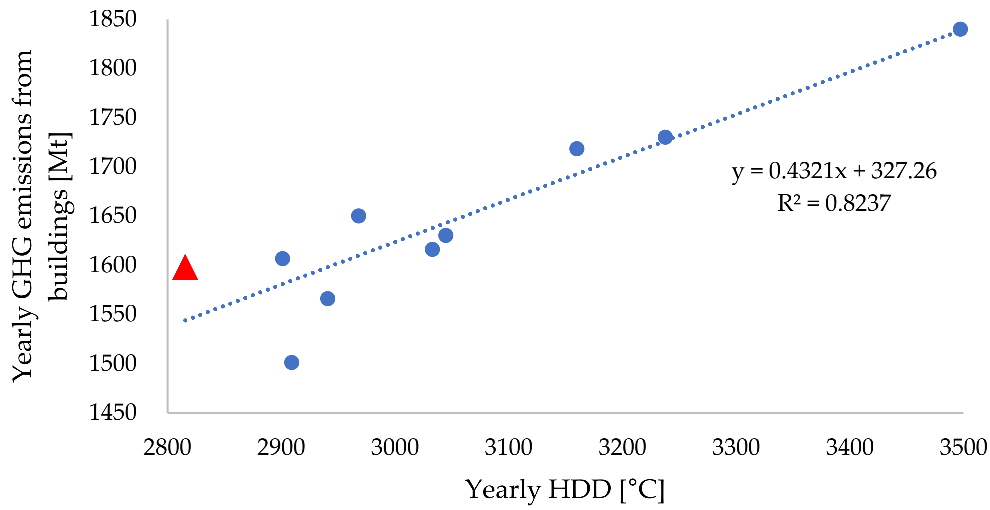

Figure 8. Relationship between HDD and GHG emissions from buildings in the EU (2010–2019).

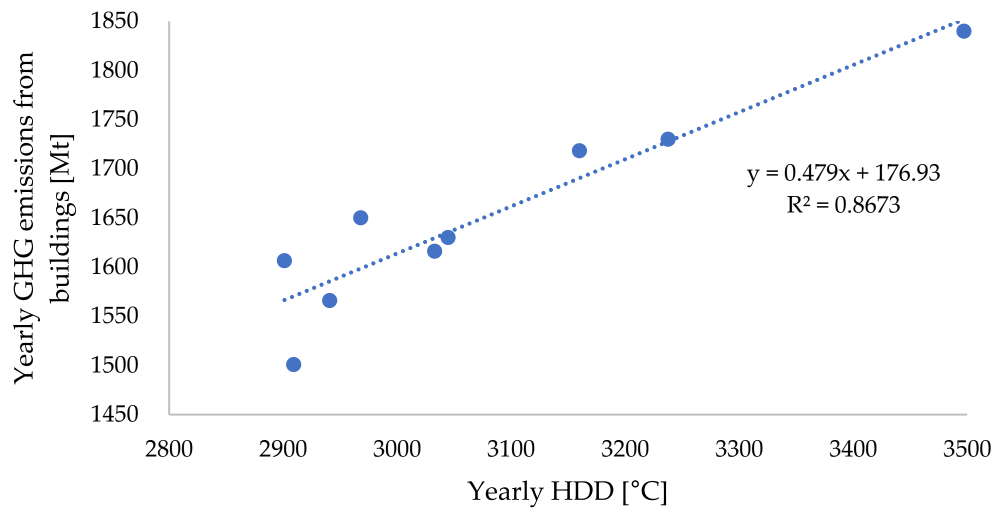

Figure 9. Relationship between HDD and GHG emissions from buildings in the EU (2010–2013 and 2015–2019).

3.4. GBRS and GDP

The relationship between the amount of GBRS certifications per year (dependent variable) and the average GDP per capita in the EU (independent variable) is studied through simple linear regression with data taken from Eurostat Database and GBRS Public Directories.

The ten points in Figure 10 (blue dots) represent the years between 2010 and 2019. The trendline is linear with an equation of y = 0.0016x + 24.213, a p-value = 0.0004 and an R^2 = 0.8059. However, if we do not consider 2014 (highlighted with a red triangle in Figure 11 and characterised by extreme climate conditions with significantly fewer heating degree days compared to other years), the chart assumes a more linear equation y = 0.0016x + 24.286 with more accurate p-value = 0.0004 and R^2 = 0.8475.

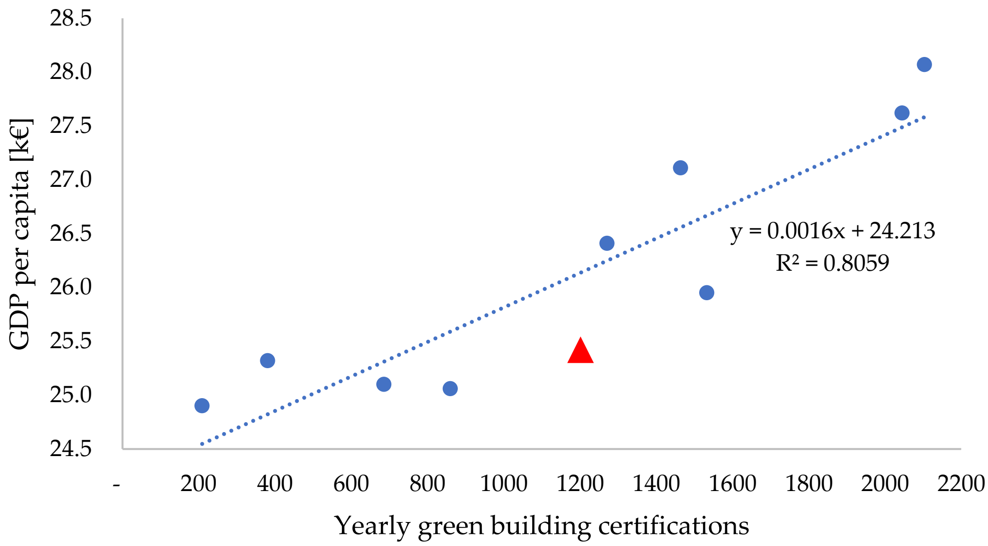

Figure 10. Relationship between GBRS and GDP per capita in the EU (2010–2019).

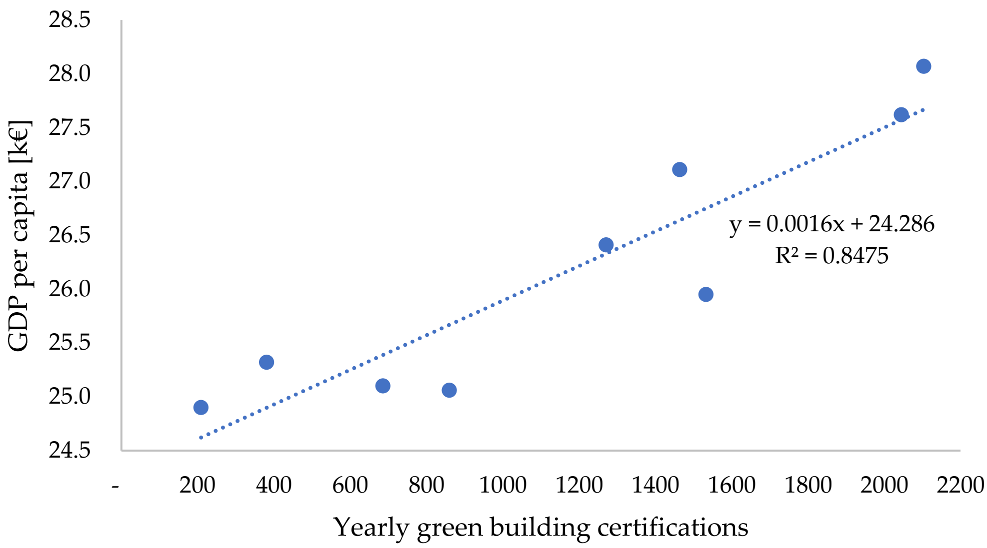

Figure 11. Relationship between GBRS and GDP per capita in the EU (2010–2013 and 2015–2019).

According to the assumptions stated in the Methodology, *p*-value and R^2 are consistent, and the equation correlates the two variables in a very accurate way with a strong significance.

The insights illustrate the economic implications that have not been considered in similar studies published in the literature [23,24]. As forecasted by the EKC, in a developed area such as the EU, more GBRS certifications are related to a higher income per capita due to the extra cost needed to implement advanced construction features. This is in line with the spread of GBRS, that are mostly localised in the EU countries characterised by the highest GDP [17–20].

3.5. GBRS and GHG Emissions

The relationship between the amount of GBRS certifications per year (dependent variable) and GHG emissions from buildings (independent variable) is studied through simple linear regression with data taken from Eurostat Database and the GBRS Public Directories.

The ten points in Figure 12 (blue dots) represent the years between 2010 and 2019. The trendline is linear with an equation of $y = -0.1399x + 1810.1$, a *p*-value = 0.0006 and an $R^2 = 0.7917$. However, if we do not consider 2014 (highlighted with a red triangle in Figure 13 and characterised by extreme climate conditions with significantly fewer heating degree days compared to other years), the chart assumes a more linear equation $y = -0.1391x + 1819.6$ with more accurate *p*-value = 0.0002 and $R^2 = 0.8825$.

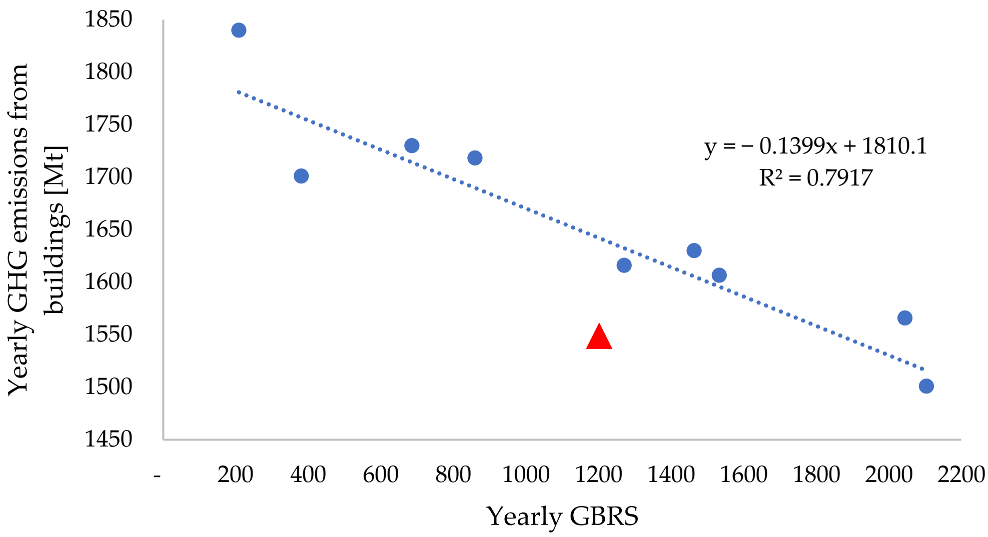

Figure 12. Relationship between GBRS and GHG emissions from buildings in the EU (2010–2019).

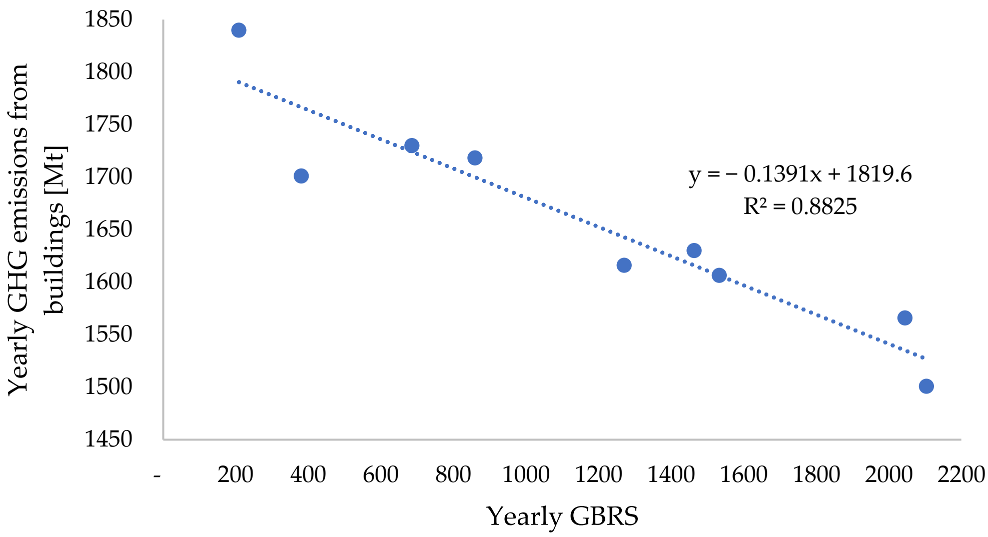

Figure 13. Relationship between GBRS and GHG emissions from buildings in the EU (2010–2013 and 2015–2019).

According to the assumptions stated in the Methodology, *p*-value and R^2 are consistent, and the equation correlates the two variables in a very accurate way with a strong significance.

As expected, more GBRS certifications are related to fewer GHG emissions due to the nature of green buildings that comprise the most innovative technologies in the construction sector in order to cut GHG emissions during the entire lifecycle. The figures presented quantify in detail, which is already illustrated in the literature [23,24].

4. Conclusions

This study intended to establish whether a direct link between green buildings (GBRS) and sustainable development (GDP and GHG) can be determined.

Considering data from the Eurostat Database for the 27 EU countries in the 10-year-period between 2010 and 2019, the spread of green buildings is estimated through the adoption of GBRS certifications (LEED, BREEAM, DGNB and HQE) taken from the public directories. This indicator is compared to GDP and GHG emissions as measures of sustainable development. GDP and GHG emissions are also correlated to renewable energy consumption and climate conditions to prove the assumptions of the EKC curve that, in a developed region such as the EU-27, it assumes a growing economy (more GDP) along with an environmental improvement (fewer GHG emissions). The relationship between the indicators is examined through a simple linear regression to determine the equation representing the line that better fits the data of a dependent variable as a function of an independent variable.

The results confirm the hypothesis of the EKC curve and the outcomes of another study [7], showing that a higher income per capita is related to fewer GHG emissions per capita due to the best technologies already in place. The outcomes are different from a second study [8] that assessed data in a mutating period within the EU (1995–2010).

The correlations are consistent, especially if 2014 is excluded from the 10-year period since it was characterised by extreme climate conditions with significantly fewer heating degree days compared to other years, affecting the trend of the linear regressions. Moreover, global warming is decreasing the energy demand in the heating-dominated zones but is increasing way more electricity demand in the cooling-dominated zones, causing higher GHG emissions [38,39].

The results finally show that the adoption of GBRS can be used as an indicator of sustainable development within the EU-27. More green buildings certifications (dependent variable) are related to both:

- Higher GDP per capita (independent variable), with a linear equation $y = 0.0016x + 24.286$, p-value = 0.0004 and $R^2 = 0.8475$.
- Fewer GHG emissions (independent variable), with a linear equation $y = -0.1391x + 1819.6$, p-value = 0.0002 and $R^2 = 0.8825$.

The regressions are characterised by a consistent statistical significance since the p-value is lower than the conventional threshold of 0.05 (i.e., probability > 95%): the variance of GBRS certifications expresses a consistent probability of the variance of GDP per capita and GHG emissions.

This is mainly due to the extra upfront cost needed to implement advanced construction technologies that, in the end, cut GHG emissions during the building lifecycle.

This is confirmed by the fact that, at the end of 2019, within the EU, the majority of the GBRS certifications were in France (4465), Germany (1902), The Netherlands (905), Spain (812) and Sweden (783) [17–20]. These countries are characterised by both a prosperous GDP and a decreasing GHG, thanks to a consistent share of renewable energy sources [40–43].

On the contrary, at the end of 2019, countries with less GBRS were Cyprus (0), Slovenia (1), Malta (3) Croatia (3), Latvia (16), Estonia (23) and Greece (30). These countries are in a previous phase of the EKC curve, with less GDP and less adoption of renewable energy sources [44–50].

The findings demonstrate that the amount of GBRS that will populate the EU in the next years can be estimated by knowing the trend of the GDP and the GHG emissions. This theoretical outcome can be adopted for practical purposes, such as asking policy makers to incentivise the construction of green buildings to obtain, in turn, a growing economy and a reduced environmental footprint. Tax relief and grants to implement GBRS are critical, especially in more developing countries in order to support the economy and meet the EU's GHG emissions reduction target of 55% by 2030 and carbon neutrality by 2050. Regulators should also focus on the importance of reducing the energy demand and relying on renewable energy sources that can directly reduce GHG emissions compared to fossil fuels [36,37].

The research is also characterised by some limitations. First, the linear equations presented are valid only for the EU-27 and in standard conditions (e.g., without financial crises, geopolitical tensions, atmospheric disruptions, catastrophic events, etc.). Second, the equations presented refer to the sum of the most recognised GBRS and do not consider the individual distribution of each rating system across the different countries. Third, legislation that may influence each country's behaviour has not been considered. Fourth, environmental footprint has been associated with GHG emissions, but there are other relevant indicators (e.g., water use, waste management, biodiversity, etc.) that are relevant as well—and that are included in GBRS.

Further research would be beneficial to forecast decarbonisation roadmaps and economic growth according to the different diffusion rates of GBRS. Additional studies may also estimate different future scenarios in case of the diverse adoption rate of renewable energy sources while boosting economic growth and environmental improvement.

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