Highlights

- The gender pay gap, and the consumption of energy, aggravate the process of environmental degradation by the increase of in the EU.
- The economic growth, globalisation and urbanisation deepening do not aggravate the environmental degradation.
- The positive impact of gender inequality on environmental degradation can be related to consumption behaviours.
- A lower bargaining power of women makes it impossible to them take decisions about green energy investments and those that are environmentally friendly.

Is gender inequality an essential driver in explaining environmental degradation? Some empirical answers from the CO_2 emissions in European Union countries

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Is gender inequality an essential driver in explaining environmental degradation? Some empirical answers from the CO_2 emissions in European Union countries

Abstract: The effect of gender inequality on environmental degradation was examined for panel data of fourteen countries from the European Union (EU) from 1991 to 2016. The Quantile via Moments (QvM) and Fixed effects models were used to perform the empirical investigation. The results from the QvM and the Fixed effects models support that the gender gap pay and energy consumption increase the CO_2 emissions in the EU. However, the economic growth, globalisation and urbanisation deepening do not increase the environmental problem. This empirical investigation will contribute to the literature, policymakers, and governments. It will help develop more initiatives to reduces gender inequality at the same time it mitigates the environmental degradation in the EU countries. Finally, the empirical finds of this investigation will open a new topic of investigation in the literature about the relationship between environmental degradation and gender inequality.

Keywords: CO_2 emissions; energy consumption; environmental degradation; environmental problem; European Union; gender inequality.

1. Introduction

Carbon dioxide emissions (CO_2) is the most significant contributor to greenhouse gas emissions (GHGs), where it contributes to 77% of total GHGs (Khan et al., 2014). Indeed, between 1990 to 2014, these emissions grew fast, wherein 1990, the CO_2 emissions were 3.0991 metric tons per capita, and in 2016 reached a value of 4.6807 metric tons per capita. During this period, we had an increase of 1.5% in total emissions of CO_2 in the World (Koengkan & Fuinhas, 2020). In the European Union (EU), the situation is not different from the rest of the World, wherein 1971 the emissions of CO_2 were 8.0244 metric tons per capita and reached the value of 6.4684 metric tons per capita in 2016 as can be seen in **Figure 1** below.

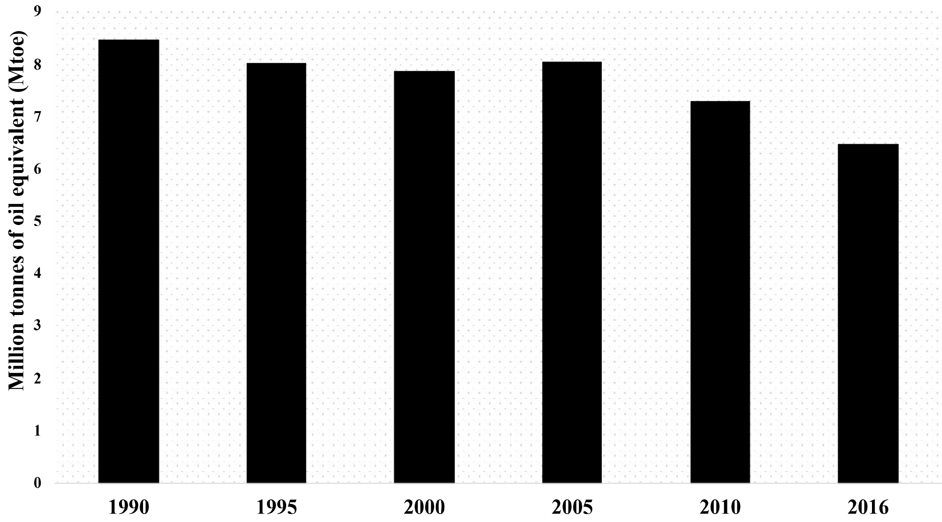

Figure 1. CO_2 emissions (metric tons per capita) in the European Union between 1990-2016. This figure was created by the authors and was based on the World Bank Open Data (2021).

Indeed, the CO_2 emissions in the EU remained relatively unchanged from 1990 to 2004. Though these emissions dropped sharply from 2005 to 2016, it was due to a decrease of 10.8% in the primary energy consumption, as can be seen in **Figure 2** below.

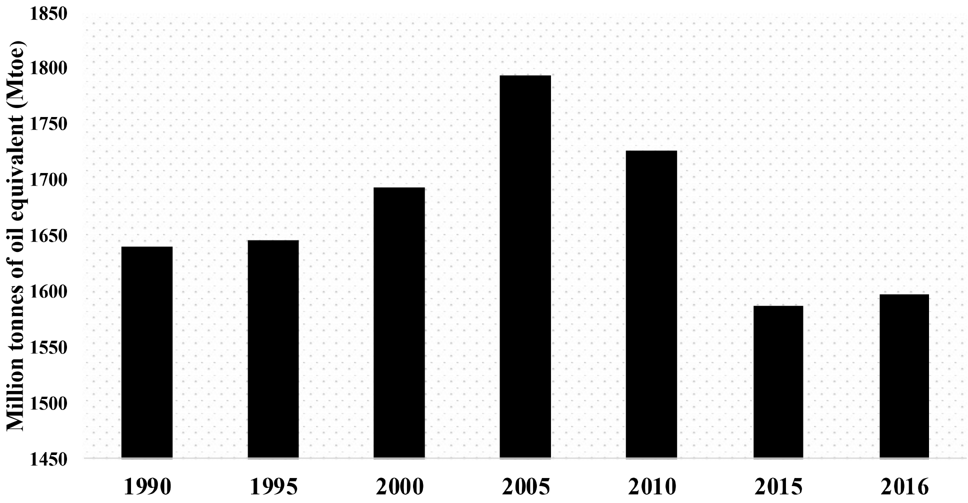

Figure 2. Primary energy consumption in the European Union between 1990-2016. This figure was created by the authors and was based on the database from IEA (2021).

In the EU, the consumption of energy in 1990 was 1.641 million tonnes of oil equivalent (Mtoe), and in 2004 reached a value of 1.789 Mtoe. However, this consumption declined between 2005 to 2016 and reached a value of 1.598 Mtoe in 2016. This decrease could be related to the economic depression/recession that occurred between 2007-2012. That depression impacted the economies of the EU and, consequently, affected the consumption behaviour of people. As they focused on consuming basic life needs and reduced other unnecessary consumption, it, consequently, impacted the energy-intensive sectors. Also, it could be related to the energy efficiency improvements caused by the globalisation process, which consequently reduces the consumption of energy. Furthermore, the decline of the urban population in the EU also could be related to this decrease.

In 1970, 93% of the EU's primary energy consumption came from fossil fuels energy sources, while only 6.90% come from renewable energy sources. However, this situation has been altered, and the contribution of fossil fuels had a decrease and reached a value of 75% of total primary energy consumption. In comparison, the consumption of renewable energy sources increased by 25% in 2016, as shown in **Figure 3** below.

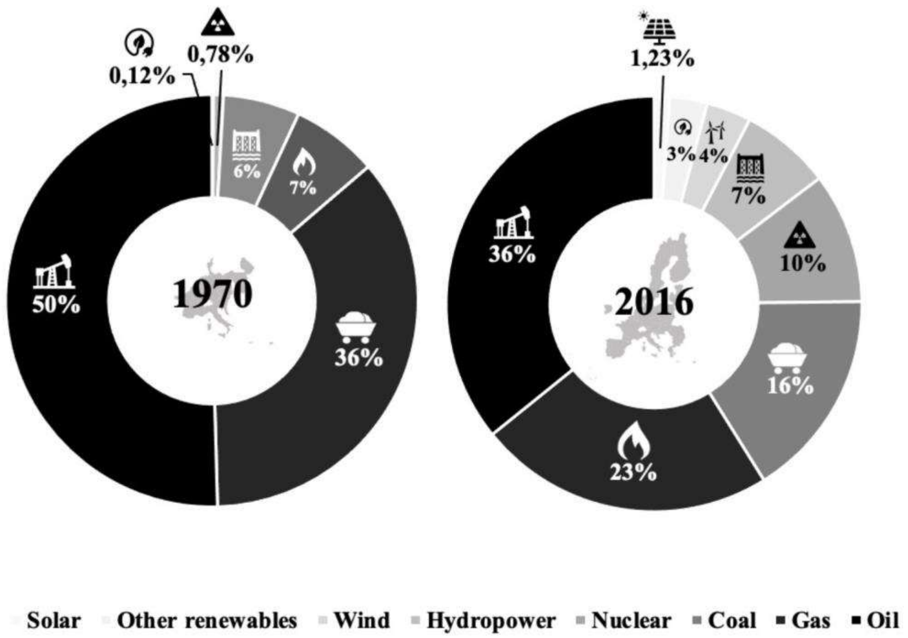

Figure 3. Consumption of Energy by the source in the European Union in 1970 and 2016. Energy consumption is measured in terawatt-hours (TWh). Other renewables include geothermal, biofuels, biomass, and waste energy. This figure was created by the authors and was based on the database from the Our World in Data (2021).

Beyond the consumption of fossil fuels, other drivers have been influencing the increase of CO_2 emissions, such as economic growth, globalisation, urbanisation, obesity, and the like. That substantial inequalities of power or wealth could run environmental degradation is long-established in the literature (Boyce, 1994). Nevertheless, the literature has given little attention to a possible connection between the gender inequality problem and the increase in environmental degradation, beyond what we already know, gender inequality.

Gender inequality can be defined as a social process. In this process, men and women are treated as non-equals. The difference in treatment arises from distinctions that are linked to (i) biology; (ii) psychology; and (iii) cultural norms. These differences are both empirically grounded and socially constructed. The focus on social gender inequality has evolved into an increasing consensus that drives it to a wider one, including economics (Maceira, 2017).

Gender's inequality has idiosyncratic characteristics that turn it different from the other forms of inequality. Indeed, it cannot be confounded with the ones that arise from race, caste, or social class. Gender inequality is present both outside the household as well as inside it. For example, economic theory considers the household as an entity (representative agent) where resources and incomes are pooled. Household members share common interests and preferences, and in some situations, an altruistic leader guarantees the allocations of goods and tasks in an equitable way. The literature is no exception in its assumptions about household unity. For example, the study of the effect of inequalities on cooperation among household members in the management of common-pool resources considers that the inequalities that can be identified originate from household-level heterogeneity. The most identified ones were wealth, social class, ethnicity, or even caste. Usually, they were regarded as the result of a conflict of interest. Nevertheless, intra-household inequalities were disregarded in the analysis.

Almost every hypothesis of the egalitarian model has been questioned by empirical evidence. The research on the principles behind the intrahousehold shares quizzed the assumptions of (i) shared preferences and interests; (ii) pooled incomes; and (iii) altruism. Indeed, gender is more often than not considered to be a central expression of differences in interests and preferences.

Incomes are not inevitably put together, and the manifestation of self-interest dwells basically in the same proportions both within the home and outside in all sort of markets. One important aspect of being considered is bargaining power. It disturbs the distribution between what one can does and who can do it. Women's situation cannot, any more, be taken as inevitably associated with their property status. Indeed, well-being was correlated to a household's property status in the past, but today this correlation has vanished.

In the EU, gender inequality has been seen primarily as an issue of equality and justice (Klasen & Minasyan, 2017). Governments and policymakers have often framed several discussions about the gender pay gap, gaps in employment rates, and under-representation of women in senior management and corporate boards and political representation disparities in the last years. However, the gender pay gap has called for policymakers and governments' attention due to their harmful impact on economic development in the short and long run. This problem reduces the average amount of human capital in a society and thus harms economic performance. It does so by artificially restricting the pool of talent to draw for education, thereby excluding highly qualified girls (and taking less qualified boys instead).

Indeed, according to European Institute for Gender Equality, the gender equality index in the 28 EU countries has been stabilising, wherein 2013 this index was 63.8 out of 100 points, and in 2020 reached a value of 67.9. Although there was an increase, the EU has a long way to reach gender equality. Moreover, most of the subcomponents of the gender equality index also have shown a stabilisation in their index (see **Figure 4**, below).

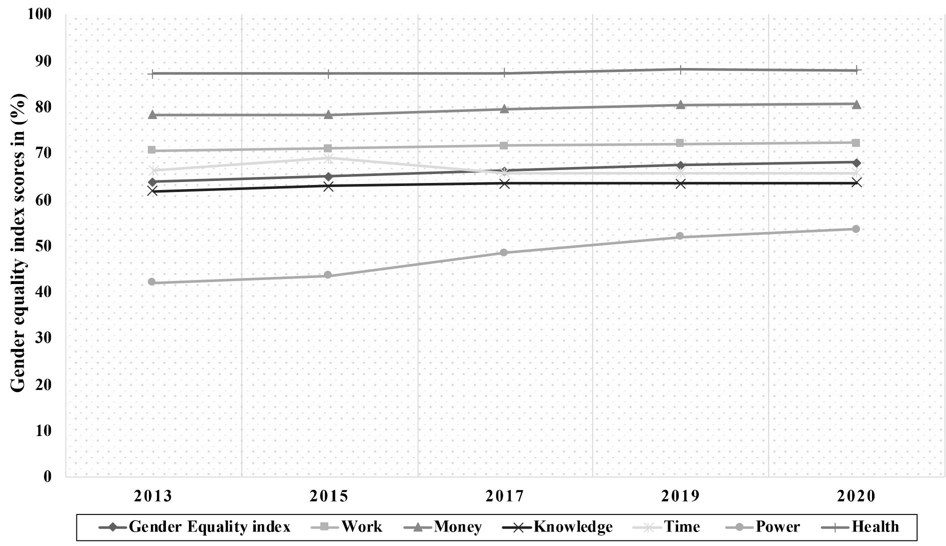

Figure 4. Gender equality index scores in (%) for 28 EU countries, between 2013-2020. This figure was created by the authors and was based on the database from European Institute for Gender Equality (2021).

According to the figure above, the work domain, which measures the extent to which women and men can benefit from equal access to employment and good working conditions. This domain, in 2013, indicated an index of 70.5 out of 100 and reached a value of 72.2 in 2020. The money domain measures the gender inequalities in access to financial resources and women's and men's economic situation. This domain in 2013 indicated an index of 78.4, and in 2020 reached a value of 80.6. The knowledge domain measures the gender inequalities in educational attainment, participation in education and training over the life course and gender segregation. This domain indicated an index of 61.8 in 2013, and 2020 reached a value of 63.6. The domain of time where measures gender inequalities in the allocation of time spent doing care and domestic work and social activities. This domain in 2013 indicated an index of 66.3 and in 2020 reached a value of 65.7.

Moreover, the domain health measures gender equality in three health-related aspects: health status, health behaviour and access to health services. This domain in 2013 indicated an index of 87.2 in 2013, and 2020 reached a value of 88. However, the only domain that had considerable growth was power. This domain measures gender equality in decision-making positions across the political, economic and social spheres. In 2013 the index of this domain indicated a value of 41.9, and in reached a value of 53.5.

Furthermore, when we talk about the women in the labour market, in the EU, they are less present in the labour market than men, where the gender employment gap stood at 11.7% in 2019, with 67.3 % of women across the EU being employed compared to 79% of men (European Commission, 2021). Indeed, when we approach the gender pay gap that is a subcomponent of the gender equality index as mentioned before and the gender inequality index, this index stands at 14.1% in 2019 and has only changed minimally over the last decade. It means that women earn 14.1% on average less per hour than men (see **Figure 5**, below).

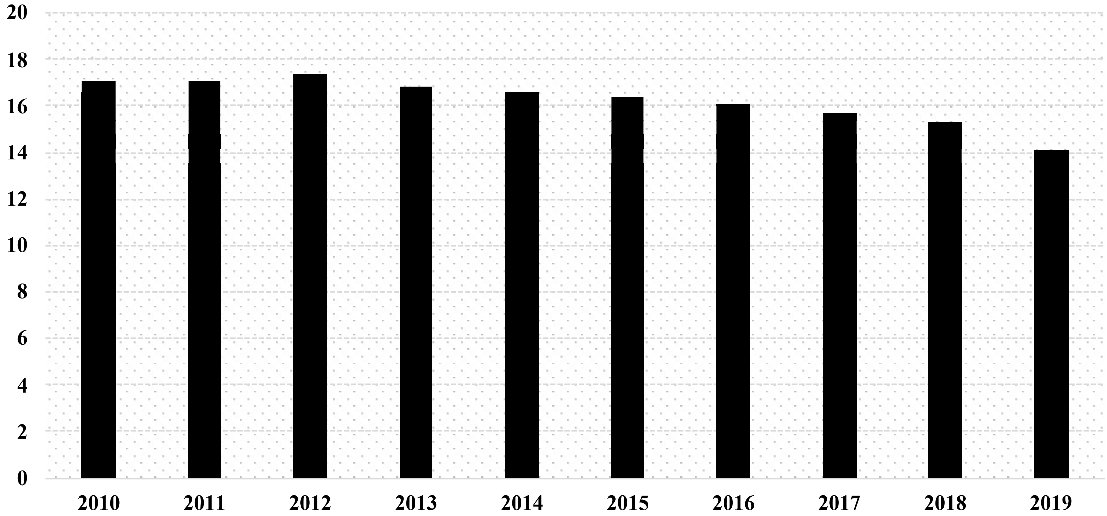

Figure 5. The unadjusted gender pay gap in (%) for 28 EU countries, between 2010-2019. This figure was created by the authors and was based on the database from Eurostat (2021).

Indeed, when we approach each country from the EU, we identify a considerable difference between the countries. The gender pay gap ranges from less than 5% in Luxembourg and Italy to more than 19% in Austria, Germany, and Estonia in 2019 (see **Figure 6**, below).

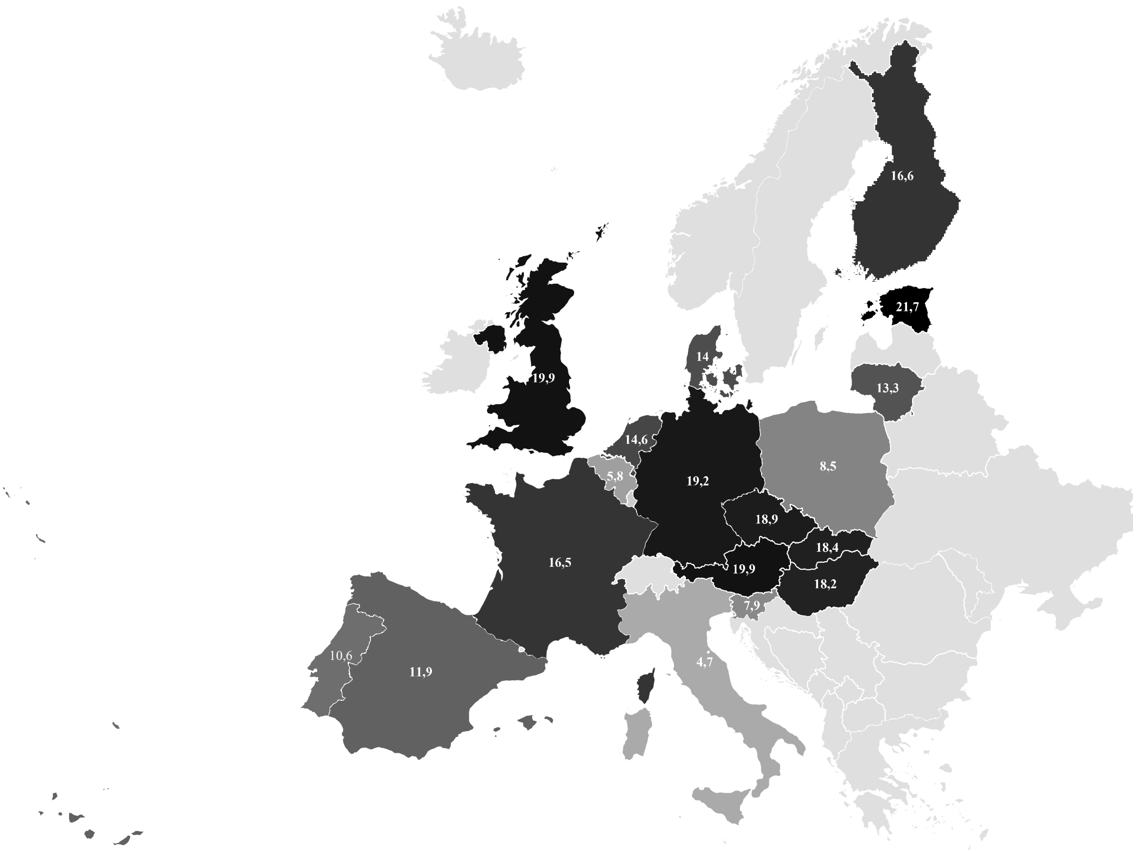

Figure 6. The unadjusted gender pay gap in (%) for 19 EU countries in 2019. This figure was created by the authors and was based on the database from Eurostat (2021).

However, in those countries, the gender pay gap has decreased somewhat, growing in a few and stabilising in others. Women in the EU even earned 36.7% less than men overall in 2018. One of the reasons is that, on average, women spend fewer hours in paid work than men. Only 8% of men in the EU in 2019 worked in p-time, almost a third of women across the EU (30.7%) did so (European commission, 2021).

Moreover, the gender pay gap by working time in the EU ranges from negatively in Italy in part-time and full-time, and in Belgium in full-time in 2019. Indeed, in some countries, the gender pay gap by part-time ranges from less than 5%, as in Hungary, Germany, Denmark, Lithuania, Netherlands, Sweden, and Belgium, while in other countries ranges to more than 10%, such as in Slovakia, Croatia, Portugal, and Spain. However, the gender pay gap by full-time ranges to more than 10% in Hungary, Slovakia, Germany, Finland, Denmark, Bulgaria, Lithuania, Netherlands, Croatia, and Portugal in 2019 (see **Figure 7**, below).

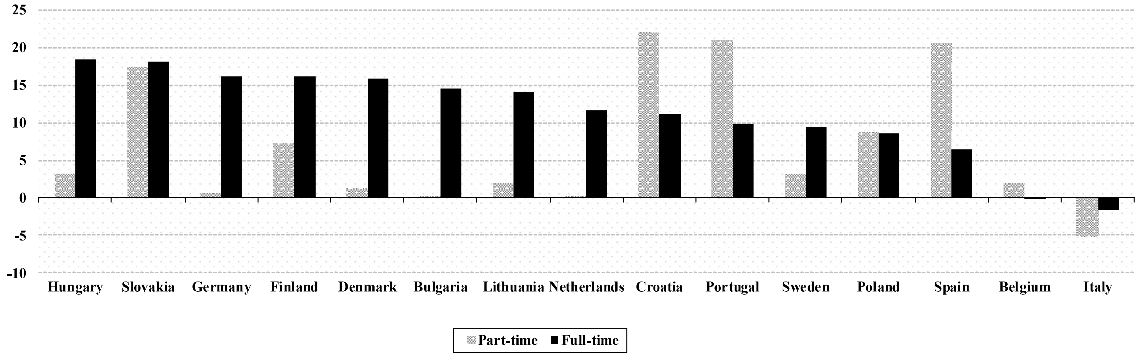

Figure 7. The unadjusted gender pays gap by working time (%) for 15 EU countries in 2019. This figure was created by the authors and was based on the database from Eurostat (2021).

When we approach the gender pay gap by economic activity in the EU economies in 2019, we can identify that in the Business economy activities, the gender pay gap ranges to more than 10% in most countries from the EU. In manufacturing activities, the gender pay gap ranges less than 5% in Sweden, while most countries range to more than 10%. In Electricity, gas, steam and air conditioning supply activities, the gender pay gap ranges less than 5% in Belgium, Croatia, Poland, Portugal, Slovenia, and Sweden, while in most countries ranges to more than 10%. In water supply, sewerage, waste management and remediation activities, the gender pay ranges to less than 5% in Czechia, Denmark, Germany, Estonia, France, Croatia, Netherlands, Poland, Portugal, Slovenia, Slovakia, Finland, and Sweden, while in some countries ranges to more than 10%, for example, Belgium, Spain, Lithuania, and Hungary. In construction activities, the gender pay gap ranges to less than 5% in most countries from the EU, while in some countries ranges to more than 10%, for example, Estonia. The gender pay gap ranges to more than 10% in most countries in information and communication activities. In financial and insurance activities, the gender pay gap ranges to more than 10% in all countries from the EU. In real estate activities, the gender pay gap ranges to more than 10% in most countries from the EU, while in some countries ranges less than 5%, such as Croatia and Slovenia. Finally, in professional, scientific, and technical activities, the gender pay gap ranges to more than 10% in all countries from the EU (see **Figure 8**, below).

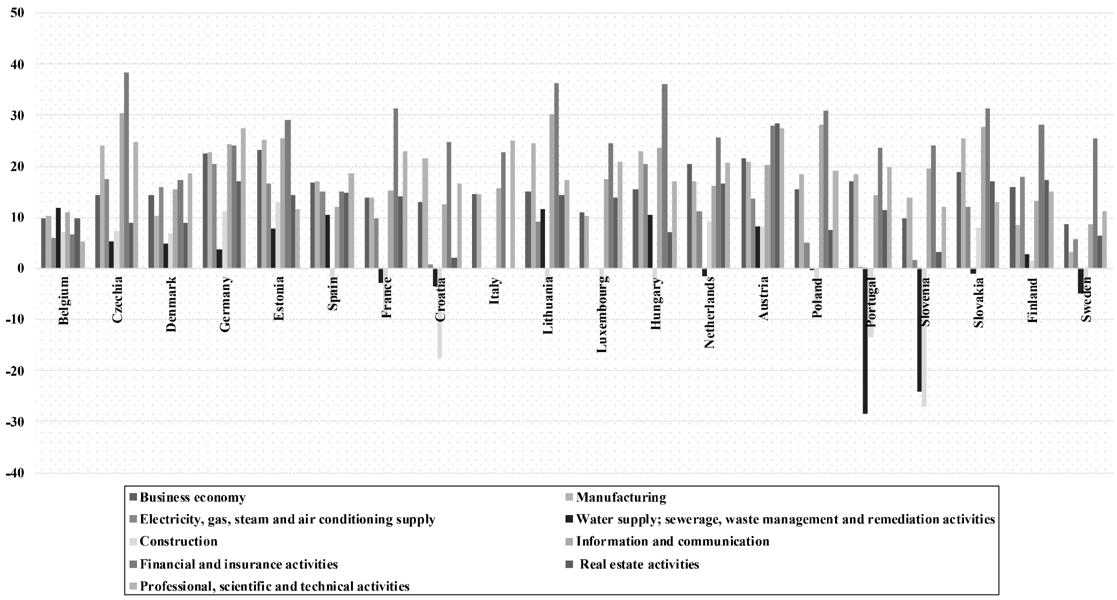

Figure 8. The unadjusted gender pay gap by economic activity (%) for 20 EU countries in 2019. This figure was created by the authors and was based on the database from Eurostat (2021).

Moreover, when we approach the gender pay gap by economic control, we can identify that in the private sector, the gender pay gap is higher if compared with the public sector in the EU in 2019 (see **Figure 9**).

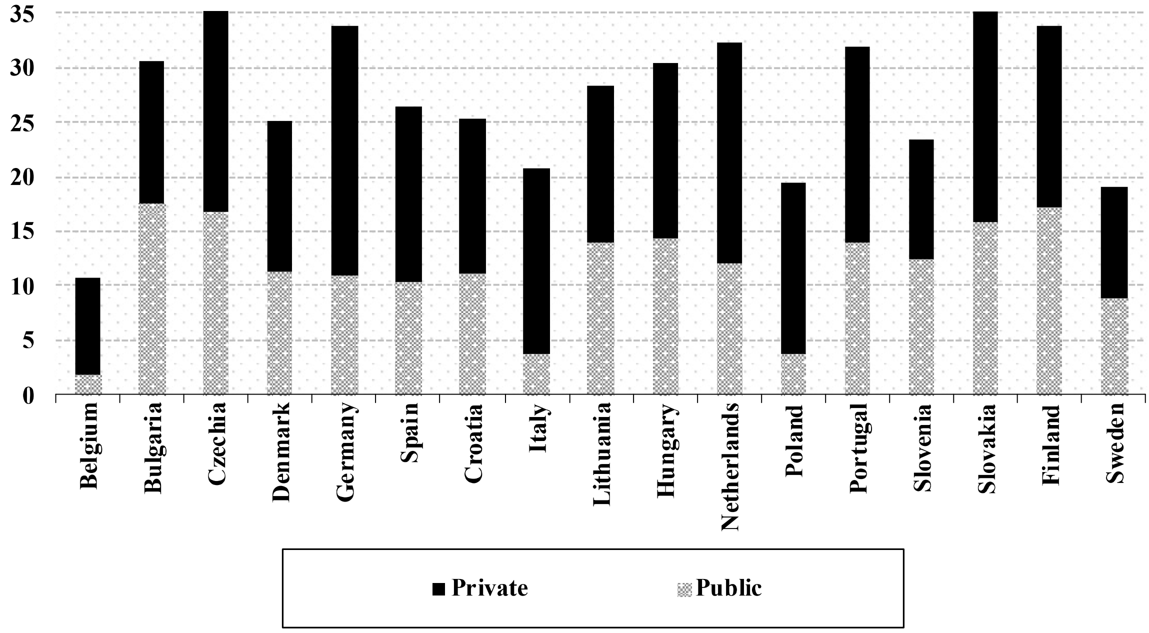

Figure 9. The unadjusted gender pay gap by economic control (%) for 17 EU countries in 2019. This figure was created by the authors and was based on the database from Eurostat (2021).

Therefore, this gender gap pay negatively affects women and households' green consumption choices. This problem restricts access to energy-efficiency appliances and their willingness to participate in energy-saving programmes (Li et al., 2019). Therefore, households' incapacity in purchasing energy-efficiency appliances and saving energy is related to lower women's bargaining power within the family caused by gender gap pay. A lower bargaining power makes it impossible for women to make decisions regarding green energy investments and reduce the family savings and productive family investments. It also turns impossible that these savings and investment may be used to alleviate the environmental impacts of subsistence labour. Additionally, the limitation of credit caused by lower wages and gender discrimination because of the culture of masculinity in some countries (Le & Stefańczyk, 2018), difficult the purchase of green energy technology or energy-efficient appliances by the women and families. This limitation increases energy poverty, where dirty or polluting fuels are used to meet the households' basic needs.

For this reason, the main objective of this empirical investigation is to identify the effect of gender inequality on environmental degradation in the EU using a macroeconomic approach. Indeed, the following research question was formulated. **Does gender inequality influence the increase in environmental degradation in the European Union?** To analyse this possible phenomenon, a group of fourteen countries from the EU, between 1991 and 2016, is positioned well to that task.

This research follows the best practices, i.e., take a theoretically sound base, do a pre-analysis of variables, transform the raw data when necessary, to make them operational, choose an econometric technique suitable to both to handle the properties of variables and to handle the nature of the relationships under analysis. Following the best practices, we limit the probability of achieving wrong conclusions, which is different to meet the "true" model representing the reality under analysis. The main restriction of modelling the relationship between gender inequality and environmental degradation is the lack of literature that can be used as a theoretical guide to decide what to include or not in the modelisation. It is our conviction that our research performs well in the present state of the art. Furthermore, we believe that our research can stimulate knowledge development in this field with significant policy implications.

This investigation is innovative and contributes to the literature for six reasons. First, to analyse the effect of gender inequality on environmental degradation in the EU. This research topic is few explored by the literature and opens a new line of investigation in literature related to environmental degradation and social problems. Second, to use the Quantile via Moments (QvM) methodology approach. This econometric technic is new and scarcely explored by literature. Third, to addresses the countries from the EU, bearing in mind that this region is not outlined in the literature in general about this topic of study. Fourth, this investigation is following the Sustainable Development Goals (SDGs) of the United Nations. Finally, to help the policymakers develop more initiatives to reduces gender inequality at the same time that reduce environmental degradation.

This research is organised as follows. **Section 2** presents the methodology and data approach. **Section 3** presents results and a brief discussion. **Section 4** presents the limitations of the study. **Section 5** presents the conclusions and research policy implications. **Section 6** reveals the future research.

2. Methodology and data

This section's main objective is to evidence clearly and briefly the methodology approach and the data/variables and group of countries that will use in our experimental study.

2.1. Methodology

This empirical investigation will use as the main econometric method the Quantile via Moments (QvM) model approach. This method is an alternative for the quantile regression, and Machado & Silva (2019) developed that. According to Koengkan et al. (2020), this method can differentiate out individual effects in the panel data models. The QvM, according to the same authors, can also be used to provide information on how the regressor affects the entire conditional distribution and estimate the presence of cross-sectional and endogenous variables (Koengkan & Fuinhas, 2020). This method is not based on the estimation of conditional means but on the moments' conditions that identify the conditional means under exogeneity. Besides, it can identify the exact structural quantile function. Therefore, this investigation opted to use this method approach to take advantage of these features.

After a brief explanation of the main methodology approach, it is necessary to show the equation of Quantile via Moments (see **Equation (1)**) below.

$$A_{it} = a_i + Y_{it}'\beta + (\delta_i + Z_{it}'\gamma)U_{it}\,, \qquad \textbf{(1)}$$

where A_{it}, Y_{it}' from a panel of N individuals i = 1, …, N over T time-periods with $P\{\delta_i + Z_{it}'\gamma > 0\} = 1$.

However, to verify the robustness of results that the QvM model found, this empirical investigation will use the Fixed effects model. Indeed, this model follows **Equation 2** below.

$$Y_{it} = \beta_1 X_{1,it} + \cdots \beta_k Z_{k,it} + \alpha_i + \mu_{it} \qquad \textbf{(2)}$$

With $i = 1, \cdots, n$ and $t = 1, \cdots, T$ .The α_i are entity-specific intercepts that capture heterogeneities across entities. This model will be used in this investigation because it can capture differences in the constant term. The intercept term of the regression model varies across the cross-sectional units. In this model, α_i is the intercept term that represents the fixed country effect. However, before the realisation of QvM and the Fixed-effects models, it is necessary to detect the proprieties of variables that will be used in this empirical study, as well as to verify the existence of singularities, which it is not taken into account and could lead to inconsistent and incorrect interpretations. To this end, some preliminary tests that will be applied in the study can be seen in **Table 1** below.

Table 1. Preliminary tests for QvM and the Fixed effect models

Tests	Objective
Shapiro-Wilk and Shapiro-Francia test (Royston 1983)	To verify the normality of the model.
Skewness and Kurtosis test (D'Agostino et al., 1990)	To check the normality based on the combination of skewness and kurtosis tests into an overall test statistic.
Variance inflation factor (VIF) (Belsley et al., 1980)	To check for the presence of multicollinearity between the variables.
Cross-section dependence (CSD) (Pesaran, 2004)	To identify the presence of cross-sectional dependence (CSD) in the panel data.
Panel unit root test (CIPS) (Pesaran, 2007)	To identify the presence of unit roots.
Westerlund panel cointegration test (Westerlund, 2007)	To identify the presence of cointegration between the variables.

Hausman test	To identify heterogeneity, i.e., whether the panel has random effects (RE) or fixed effects (FE).
Bias-corrected LM-based test (Born & Breitung, 2015, and Wursten, 2018)	To check the presence of serial correlation in the fixed-effects panel model.

Notes: This table was created by the authors.

In the regression of QvM and the Fixed effects models, it is necessary to apply some post-estimation tests to identify if the models' approach is adequate. Some post-estimation tests will be applied in this investigation, as can be seen in **Table 2** below.

Table 2. Post-estimation tests for QvM and the Fixed effects models

Test	Objective
The QvM model	
Wald test (Agresti, 1990)	To verify the global significance of the estimated models.
The fixed-effects model	
Modified Wald test (Greene, 2002)	To assesses the panel groupwise heteroskedasticity in the residuals of FE estimation.
Wooldridge test (Wooldridge, 2002)	To assesses the autocorrelation in panel data.
Pesaran's test (Pesaran, 2004)	To assesses the cross-sectional independence of residuals.
Breusch and Pagan Lagrangian Multiplier test (Breusch & Pagan, 1980)	To assesses the independence for contemporaneous correlation of residuals.

Notes: This table was created by the authors.

All estimations and testing procedures will be accomplished using **Stata 16.0**, and all Stata' commands used in this empirical analysis will be provided in the notes of tables. Indeed, using the QvM model to explain the possible increase in environmental degradation makes this study innovative. It is one of the differentials that this research brings for the literature if compared with the others. The following subsection will show the data/variables and the group of countries from the EU that will be used to realise the empirical investigation.

2.2.Data

This subsection will present the data/variables that will be used in this empirical analysis. Fourteen countries from the EU (e.g., **Austria**, **Belgium**, **Czech Republic**, **Denmark**, **Finland, Germany**, **Greece**, **Hungary**, **Ireland**, **Italy**, **Poland, Portugal, Slovakia,** and **Sweden**) were selected to realise this investigation. Other countries (e.g., **Estonia**, **France**, **Lithuania**, **Luxembourg**, **Netherlands**, **Slovenia**, **Spain**, and **United Kingdom**) from the EU were excluded from this study. The exclusion was because they have insufficient data for the "Gender pay gap" variable or missing values in the database from these countries in Our World in Data (2021). If we considered these countries, we could have problems estimating the Pesaran CD-test and Panel Unit Root test (CIPS-test) and, consequently, could invalidate our investigation.

Moreover, other countries from the EU (e.g., **Bulgaria**, **Chipre**, **Croatia**, **Latvia**, **Malta,** and **Romania**) were not considered in our investigation because of the absence of data for these countries in the Our World in Data (2021). Our investigation followed a rigorous process of selection of countries, so we do not have problems in the estimation process. Moreover, these group of countries that were selected presented to share the same characteristics, mainly in the variable "Gender pay gap", where at the beginning of 1990s to 2002 the gender pay gap was extraordinarily high and from 2004 to 2010 registered a period of decrease, and from 2011 to 2016 a period of stabilisation. Pesaran CD-test confirms the suspicion that the selected countries share the same characteristics (see **Table 9**).

Indeed, the period of data from 1991 to 2016 was used in this research. The time series began in 1991 and end in 2016 due to the data availability for the variable "gender gap pay". In some countries (e.g., **Belgium**, **Czech Republic**, **Denmark**, **Germany**, **Greece**, **Hungary**, **Ireland**, **Italy**, **Poland, Portugal,** and **Slovakia**), the data of the variable "gender gap pay" began in 1991 and ended in 2016. In other countries (e.g., **Austria**, **Finland**, and **Sweden**), we have data from 1975 to 2016. However, to create a balanced panel and do not have estimation problems due to an unbalanced panel, was used the data from 1991 to 2016. The description of variables used to investigate gender inequality in environmental degradation is shown in **Table 3** below.

Table 3. Variables

CO_2 emissions (kg per capita 2011 in purchasing power parity (PPP) $ of Gross Domestic Product (GDP) was retrieved from World Bank Open Data (2021) and named in this investigation as **CO2_pc**. This variable will be used as a proxy of environmental degradation.
GDP per capita, PPP (constant 2011 international $) was retrieved from World Bank Open Data (2021) and named in this investigation as **GDP_pc**.
Gender gap pay in median earnings was retrieved from Our World in Data (2021) and named in this investigation as **GPG**. The gender gap pay is defined as the difference between men and women's median earnings compared to men's median earnings. The estimates refer to full-time employees and to self-employed. This variable will be used as a proxy of gender inequality because it can measure inequality of gender and captures a concept that is broader than the concept of equal pay for equal work. Indeed, as early know, the difference in pay between men and women also can capture differences among many possible dimensions, including occupation, experience, and worker education.
Electric power consumption kilowatt-hour (Kwh) per capita was retrieved from World Bank Open Data (2021) and named in this investigation as **ENE_pc**.
Globalisation index *De facto* that measures the economic, social, and political dimensions of globalisation on a scale from 1 to 100, was retrieved from KOF the Index of Globalisation (2021) and named in this investigation as **GLOBA**. This variable can reach three different dimensions, namely economic, political, and social ones.
Urban population (% of the total population) is a proxy of the urbanisation process and was retrieved from World Bank Open Data (2021) and named in this investigation as **URBA**.

The variables that were used in the model are based on economic principles. Furthermore, it is worth remembering that the variables, for example, **GDP_pc**, **ENE_pc**, **GLOBA**, and **URBA**, are already used by the literature to explain the increase of CO_2 emissions that is a proxy of environmental degradation. However, only the variable **GPG**, which is a proxy of gender inequality, was not approached by literature to explain the increase of environmental degradation, as shown in **Table 4** in the **Appendix**. It makes this study innovative if compared with others that approach a similar topic.

Indeed, the descriptive statistics of all variables used in this empirical investigation are shown in **Table 5** in the **Appendix**. In this empirical analysis, we opted to use the variables in per capita values because they allow us to reduce the disparities between the variables caused by population growth over time (Koengkan et al., 2020). In this subsection, we approached the group of countries and the variables used in our empirical study. The next section shows the empirical results from the main model and the robustness check and the possible explanations for the found results.

3. Empirical results and deliberations

This section will present the results from the main model and the robustness check, the possible explanations for the impact of gender inequality on environmental degradation, and a brief explanation for other variables' impact. The preliminary tests mentioned before (see **Table 1**, above) indicate that the variables used in this empirical analysis have characteristics, such as the non-presence of normality in the model's residuals. The null hypothesis of both tests (e.g., Shapiro-Wilk and Shapiro-Francia test and Skewness and Kurtosis test) are rejected (see **Tables 6** and **7** in the **Appendix**). Were confirmed the presence of low multicollinearity between the variables (see **Table 8** in the **Appendix**) and the presence of cross-sectional dependence in the variables in logarithms (see **Table 9** in the **Appendix**). Indeed, these test results indicate that the countries share the same characteristics and shocks as indicated by Fuinhas et al. (2017). Moreover, the variables being on the borderline between the I(0) and I(1) orders of integration (see **Table 10** in the **Appendix**).

Moreover, the non-presence of cointegration was identified between the variables **LogCO2_pc, LogGDP_pc**, **LogENE_pc**, **LogGLOBA**, and **LogURBA**. The Westerlund panel cointegration test's null hypothesis cannot be rejected (see **Table 11** in the **Appendix**). The presence of fixed effects, where the Hausman test's null hypothesis can be rejected (see **Table 12** in the **Appendix)**. The serial correlation is up to the second-order, where the null hypothesis of the Bias-corrected LM-based test can be rejected (see **Table 13** in the **Appendix**).

The next step after the realisation of preliminary tests is to carry out the QvM model regression. Indeed, the 25th, 50th, 75th, and 100th quantiles were respectively calculated to assess the non-linearities of the effect of gender gap pay that is a proxy for gender inequality on environmental degradation. These quantiles were used to simplify the exhibition of empirical results. **Table 14** below shows the results from the QvM model regression.

Table 14. QVM estimation

Independent variables	Dependent variable **(LogCO2_pc)**			
	Quantiles			
	25th	**50th**	**75th**	**100th**
LogGDP_pc	-1.0879***	-1.0856***	-1.0831***	-1.0901***
LogGPG	0.0796***	0.0721***	0.0641**	0.0869**
LogENE_pc	0.8611***	0.8404***	0.8186***	0.8809**
LogGLOBA	-0.7560***	-0.7341***	-0.7111***	-0.7770***
LogURBA	-2.6868***	-2.6336***	-2.5776***	-2.7379***
Obs	245	245	245	245
F/Wald test	Chi2(5)=713.04***	Chi2(5)=1321.57***	Chi2(5)= 805.14***	Chi2(5)= 338.74***

Notes: The Stata command *xtqreg* was used; ***, ** denote statistically significant at the 1% and 5% levels, respectively; "**Log**" denotes variables in natural logarithms.

Therefore, the outcomes from the QvM model regression indicate that in the 25th, 50th, 75th, and 100th quantiles, the variable gender gap pay that is a proxy of gender inequality and consumption of energy, aggravate the process of environmental degradation by the increase of CO_2 emissions in the EU. In contrast, the economic growth, globalisation, and urbanisation process do not aggravate this process. The empirical results answer the central question of this research, which was mentioned in the introduction. Additionally, the post-estimation test result mentioned before (see **Table 2**, above) was computed in each quantile. The same results indicate that the model estimator that this study chooses is adequate to perform this analysis.

We have now reached a crucial point in this investigation to verify if the results revealed by the QvM model regression are robust and reliable when we perform a change in the econometric method approach. This approach to finding if the model approach is robust and reliable is not new, and there was already used by some authors, such as Koengkan et al. (2020) and Fuinhas et al. (2017). This study opted to use the Fixed effects model to perform this verification. Besides, this analysis opted to compute the following estimators from the Fixed effects model (e.g., FE robust standard errors (FE Robust), and FE Driscoll and Kraay (FE D.-K.)).

The FE D.-K. was used in this analysis due to the possible presence of first-order autocorrelation and heteroscedasticity that will be confirmed in the post-estimation tests for the fixed effects model, right below. As already known, this estimator can produce standard errors robust to the phenomena that were found in the sample errors. Also, not satisfied in carrying out only one regression, this investigation added dummy variables in the model regression to check if the model is also robust in the presence of shocks. The fixed-effects model regression before the inclusion of shocks can be seen in **Table 15** in the **Appendix**.

Indeed, these dummy variables were added to the model because, during the analysis period, the EU suffered some shocks (e.g., economic, political, and social). If not considered, these shocks could produce inaccurate results that lead to misinterpretations. Before adding these dummy variables in the model, this empirical analysis followed a triple criterion of choice that was developed by Fuinhas et al. (2017). For example: **(i)** the potential relevance of recorded social, economic, and political events at the country level; **(ii)** a significant disturbance in the estimated residuals; and **(iii)** the occurrence of international events known to have disturbed the European region. Therefore, the dummy variables that were added to the regression are the following: **IDEU_2012** (EU, the year 2012) and **IDEU_2013** (EU, the year 2013).

- **IDEU_2012:** This is a break in the GDP of all countries in the model. The European debt crisis caused this break (often referred to as the eurozone crisis or the European sovereign debt crisis). Indeed, several eurozone members (e.g., Greece, Portugal, and Ireland) were unable to repay or refinance their government debt.

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These breaks affected the economic growth, consumption behaviour, industrial production, energy consumption, and so, the emissions of CO_2 in these countries. **Table 16** below displays the results from the Fixed effects model regression controlling for shocks.

Table 16. The fixed effects estimation (controlling for shocks)

Independent variables	Dependent variable (**LogCO2_pc**)			
	FE		**FE Robust**	**FE D.-K.**
IDEU_2012	-0.1015	***	***	***
IDEU_2013	-0.1014	***	***	***
LogGDP_pc	-1.0383	***	***	***
LogGPG	0.0625	***	*	***
LogENE_pc	0.7255	***	**	***
LogGLOBA	-0.7359	***	**	***
LogURBA	-2.1647	***	*	***
Constant	15.8008	***	***	***
Obs	245		245	245

Notes: The Stata command *xtreg* was used; ***, **, * denotes statistically significant at the 1%, 5%, and 10% levels, respectively; "**Log**" denotes variables in natural logarithms.

In summary, the results from **Table 16** also show that the proxy for gender inequality, the consumption of energy, aggravates environmental degradation by increasing CO_2 emissions in the EU. In contrast, the economic growth, globalisation, and urbanisation process do not increase the CO_2 emissions. That is, the results obtained from the model regression confirms that the results of this investigation are robust and reliable when we perform the change of method and, as well as when we introduce the dummy variables. Concerning the statistical significance at the 1% level of the dummy variables supports the decision to include them in the model.

Moreover, the post-estimation tests for the Fixed effects model (see **Table 2**, above) indicate the rejection of the modified Wald and Wooldridge tests' null hypothesis at the 1% level. That is, indicating the presence of heteroscedasticity and first-order autocorrelation. However, it cannot reject the null hypothesis of Pesaran's test, indicating the non-presence of correlation. The Breusch and Pagan Lagrangian multiplier test could not be computed because the residuals' correlation matrix was singular. This last situation occurs because the number of crosses understudy is less than the number of years. The outcomes from these tests can be seen in **Table 17** in the **Appendix**. It is worth remembering that the post-estimation tests were applied in the model controlling for shocks. Besides, **Figure 10** below summarises the effect of independent variables on dependent ones. This figure was based on the results from QvM and the fixed-effects models. These effects were also supported by the Granger causality tests of Dumitrescu-Hurlin (2012). We do not reject that all variables Grange cause CO_2 emissions at 1% level, except for globalisation at 10% level.

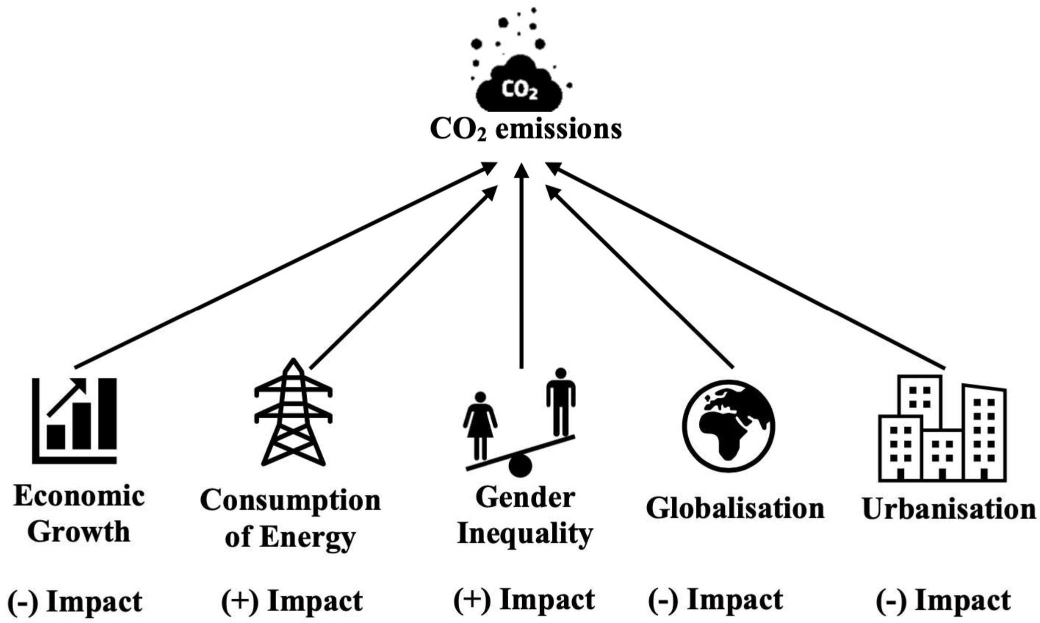

Figure 10. Summary of the variable's effect.

After identifying that gender inequality aggravates environmental degradation by increasing CO_2 emissions, we raise the following question. **What are the explanations for this phenomenon?** The possible explanation for the positive impact of gender inequality on environmental degradation can be related to consumption behaviours. That is, the gender gap pay will impact households' green consumption choices. This response will impact the use of energy-efficiency appliances and their willingness to participate in energy-saving programmes (Li et al., 2019).

Indeed, households' incapacity in purchasing energy-efficiency appliances and saving energy is related to lower women's bargaining power within the family caused by gender gap pay. A lower bargaining power makes it impossible for women to make decisions regarding green energy investments and reduce the family savings and productive family investments. It also turns impossible that these savings and investment may be used to alleviate the environmental impacts of subsistence labour. Additionally, the limitation of credit caused by lower wages and gender discrimination, due to the prevalence of a culture of masculinity in some countries (Le & Stefańczyk, 2018), turn difficult to purchase green energy technology or energy-efficient appliances by women and families. This limitation increases energy poverty, where dirty or polluting fuels are used to meet the households' basic needs.

Despite our limitations related to the existence of literature that approaches this topic directly, this investigation opted to support the explanations of results with close literature. It is worth remembering that this research's main motivation is to identify the effect of gender inequality on environmental degradation and evidence the possible reasons for the phenomenon that was found. Indeed, the other results that were found will be explained briefly. Since they are already widely studied in the literature, it is essential to identify the new drivers for environmental degradation and understand how they work and indicate possible solutions.

Therefore, the negative effect of economic growth on emissions of CO_2 emissions could be related to three factors. First, it could be related to an intense depression or recession that impacted the region. That is, this depression or recession have impacted the consumption behaviour of people. This behavioural change was consequential when it focused on consuming the basic life needs and reducing unnecessary consumption. Consequently, it impacted the energy-intensive sectors, energy consumption, and finally, the emissions of CO_2. Second, it could be related to the existence of a U-shaped relationship between economic growth and the emissions of CO_2. An increase in economic growth initially leads to a decline of CO_2 emissions level that, consequently, reaches a threshold. Indeed, the intensification in the level of economic activity can be achieved at the cost of environmental degradation. Indeed, when a country industrialises, this will lead to an increase in pollution. Third, it could be related to policies that limit the level of pollution in industries. That encourages the adoption of environmentally friendly production techniques and processes. The production and consumption of renewable energy sources by industries and families and the consumption of environmentally friendly technologies were encouraged too. Indeed, some authors found this impact (e.g., Koengkan & Fuinhas, 2020; Muhammad et al., 2020; Aye & Edoja, 2017), and see **Table 4** in the **Appendix**.

The positive influence of consumption of energy on CO_2 emissions could be related to two factors. First, it could be related to energy consumption in panels of countries that are not environmentally friendly. The consumption of fossil fuels can be associated with a high level of CO_2 emissions. These results can also indicate that the group of countries of this investigation could depend on this energy source to grow, as it occurs in developing countries. Second, it could be related to the inefficiency of renewable energy policies that encourage green energy consumption and the development of green technologies in some countries of this panel. Indeed, this impact was found by several authors (e.g., Koengkan & Fuinhas, 2020; Adedoyin et al., 2020; Yazdi & Dariani, 2020; Muhammad et al., 2020; Salahuddin et al., 2019; Koengkan, 2018; Fuinhas et al., 2017; Aye & Edoja, 2017; Poumanyvong & Kaneko, 2010), and can be seen **Table 4** in the **Appendix**.

On the other hand, one explanation for the negative impact of globalisation on CO_2 emissions could be related to globalisation's capacity causes technological enhancement in the EU countries. It contributes to a decrease in environmental degradation. Besides, the globalisation process has another implication, the transfer of responsibility from the state to the private sector. This transfer corresponds to the shifting of regulatory attributes to independent governmental regulatory authorities. In other words, "regulation for competition". Indeed, this transference has, consequently, improved energy efficiency, diversification of energy sources with the inclusion of renewable sources in the energy matrix, energy supply routes, and the possibility of reducing energy prices for consumers in a high of oil and gas prices. Some authors found this impact (e.g., Chishti et al., 2020; Muhammad et al., 2020; Koengkan, 2018); see **Table 4** in the **Appendix**.

Furthermore, the negative impact of urbanisation on CO_2 emissions could be related to two factors. First, it could be related to reducing the urban population that will impact the consumption of energy from non-renewable energy sources from industries, households, and the transport sector. Second, it could be related to (i) the improvement of energy efficiency caused by the introduction of new energy technologies; (ii) the diversification of energy sources, with the inclusion of renewable sources in the energy matrix in larges urban centres; and (iii) the introduction of environmental regulations, that encourages the acquisition of technologies that are environmentally friendly by industries and families, as well as that it restricts the use of fossil fuel-powered cars, or other transportation in the urban centres, as it occurs in some large cities in the EU. Additionally, the massive investment in public transports, powered by alternative energy sources, reduces the use of individual transport. Indeed, some authors found this effect (e.g., Muhammad et al., 2020; Salahuddin et al., 2019; Poumanyvong & Kaneko, 2010); see **Table 4** in the **Appendix**.

This section showed the results from the main model and the robustness check, the possible enlightenments for the impact of gender inequality on environmental degradation, and a brief explanation of other variables' impact. The following section will reveal some of the study's limitations.

4. Limitations of the study

This investigation is not free from limitations inherent to the research process. The dimension of the analysed time series was limited by data availability for the gender pay gap. It has limited the analysis to fourteen countries for the period from 1991 to 2016. In some countries from European Union (e.g., **Belgium, Czech Republic, Denmark, Germany, Greece, Hungary, Ireland, Italy, Poland, Portugal**, and **Slovakia**), the time series began in 1991 and ended in 2016. In other countries (e.g., **Austria**, **Finland,** and **Sweden**), we have data from 1975 to 2016. Another limitation is related to the existence of few (or absence of) observations for many other countries from the European Union (e.g., **Bulgaria, Chipre, Croatia, Latvia, Estonia**, **France**, **Latvia, Lithuania**, **Luxembourg**, **Malta**, **Netherlands**, **Slovenia**, **Spain**, **Romania,** and **United Kingdom)**.

Another limitation is related to the lack of data for gender inequality in public and private sectors. For economic activity in European Union (e.g., Construction, Business Economy, Manufacturing, and the like), we only have data for the year 2019, and even for few countries. Indeed, the lack of data in specific sectors (e.g., the private sector with a higher gender pay gap if compared with the public sector) does not allow us to identify if gender inequality is related to the increase in environmental degradation and ecological footprint. Moreover, we were confronted with the limitation of scarce literature to support our results. There are very few studies that approach this topic of investigation directly.

Therefore, all these limitations prevented us from carrying out a deep investigation related to the gender inequality and environmental degradation in European Union and getting a better and complete picture for the region. However, as mentioned before, this investigation is a kick-off regarding the effect of gender inequality on environmental degradation, and these limitations are not an impediment to conduct further investigations. Therefore, in future studies, we will experiment with new variables related to gender inequality to explain environmental degradation.

The following section reveals the conclusions of this experimental investigation and the possible policy implications caused by the founded results.

5. Conclusions and policy implications

This analysis explored the effect of gender inequality on environmental degradation in a group of fourteen countries from the EU between 1991 and 2016. Indeed, this investigation is in the early stages of maturation, where will supply a solid foundation for second-generation research regarding this topic. That is, this study is a kick-off regarding the effect of gender inequality on environmental degradation, as well as on other aspects such as energy consumption. This empirical research has been based on economic principles to construct a model that provides an accurate explanation of why gender inequality can increase environmental degradation.

As a proxy of gender inequality, this research used the variable gender gap pay and the variable CO_2 emissions as a proxy of environmental degradation. The QvM model was used, and to verify the robustness of results found by the main model, the fixed effects were also used. The results from the preliminary tests indicated that the non-presence of normality in the residual of the model, the presence of low multicollinearity between the explanatory variables, the presence of cross-sectional dependence in the variables in logarithms, and that the variables are on the borderline between the I(0) and I(1) orders of integration. Moreover, the non-presence of cointegration between the variables, the presence of fixed effects, and serial correlation up to the second-order was also identified.

The results from the QvM and the fixed effects models indicated that the gender gap pay and consumption of energy aggravate environmental degradation by the increase of CO_2 emissions in the EU. In contrast, economic growth, globalisation, and urbanisation do not aggravate this process. Moreover, the post-estimation test outcomes, applied after the QvM model regression, indicated that the model estimator chosen is adequate to perform the investigation. The post-estimation test applied after the fixed effects model regression indicated the presence of heteroscedasticity, first-order autocorrelation, and non-presence of correlation. That is, the results from both models can answer the research questions that arose in this study.

This investigation is not free from limitations inherent to the research process. The dimension of the analysed time series was limited by the availability of data for the variable gender pay gap, which is limited to the period between 1991 to 2016 for some countries of our investigation. Another factor that limited our investigation is related to the existence of a few pieces of literature to support the positive effect of the variable gender pay gap on CO_2 emissions and the existence of few variables in the macroeconomic aspect that approaches gender inequality to explain our model. Indeed, despite data limitations, the obtained results have relevant policy implications and warnings.

As mentioned before, the possible explanation for the positive impact of gender inequality on environmental degradation can be related to consumption behaviours. The gender gap pay will impact households' green consumption choices. Indeed, households' incapacity in purchasing energy-efficiency appliances and saving energy is related to lower women's bargaining power within the family caused by gender gap pay. A lower bargaining power makes it impossible for women to take decisions regarding green energy investments and those that are environmentally friendly. Indeed, the limitation of credit caused by lower wages and gender discrimination due to the culture of masculinity in some countries challenging to purchase green energy technologies or energy-efficiency appliances by women and families. This limitation increases energy poverty, where dirty or polluting fuels are used to meet the households' basic needs.

In the face of this discovery, another question arises. **What can be done to reverse the contribution of gender inequality to the increase of environmental degradation in the European Union**? Several policies can be implemented to reduce the gender inequality caused by the gender pay gap. For example, create policies that encourage de salary negotiation by showing salary ranges. Those policies include: (i) multiple women in shortlists for recruitment and promotions; (ii) introduce transparency to the promotion, pay, and reward processes; (iii) improve workplace flexibility for men and women; (iv) increase mentorship and extra efforts to boost the number of women in traditionally male occupations, and in positions of political leadership; and (v) increase government funding of high-quality day-care options to enable parents, with highlight to mothers, to work outside the home if they so desire, and to do so without fear that their finances or their children's well-being will be compromised. All these policies have a proposal to increase the women's bargaining power within the families and increase the possibility of green consumption choices by women. It will encourage the women to acquire green energy or energy-efficiency technologies that will reduce the consumption of fossil and, consequently, decrease environmental degradation.

However, this problem is not limited to reduce gender inequality to mitigate the environmental degradation problem. It is necessary to change the way of producing and consuming energy in the EU. Although the region is a leader in the World in the decarbonisation of its economy by introducing several policies and initiatives that reduce the consumption of fossil fuels in the region, it is necessary to make more. These policies and initiatives lose their efficiency over time and with the changes in governance. Policymakers need to increase the efficiency of the current policies. They have to make adjustments related to the current economic, political, and social situation. This adjustment can bring more accessibility to renewable energy technologies, increase social justice and equality, and also reduces environmental degradation.

The EU deserve to take advantage of the current situation of its economy and the globalisation process to reduce the barriers to products and technologies that improve energy efficiency and the production of green energy. This reduction could benefit the households and industries with the acquisition of renewable energy technologies and reduce the prices of these products. Besides, the region needs to encourage more local technological development to take advantage of each country's natural characteristics in the EU.

6. Further research

Based on the limitations of this investigation, future studies related to this topic needs to be developed to help understand how this problem occurs in the European Union. Therefore, according to data available for some countries (e.g., **Bulgaria, Chipre, Croatia, Latvia, Estonia**, **France**, **Latvia, Lithuania**, **Luxembourg**, **Malta**, **Netherlands**, **Slovenia**, **Spain**, and **Romania**), new studies will be necessary.

It is missing to investigate how gender inequality in a specific sector of the economy contributes to the increasing environmental degradation or ecological footprint in European Union. For example, as we already know, the gender inequality in the private sector is higher than in the public one, principally in some countries from the European Union (e.g., **Croatia**, **Italy**, **Germany**, **Netherlands**, **Poland**, **Portugal**, **Spain**, **Slovakia**, **Netherlands**). Therefore, identifying whether gender inequality in the public and private sectors contributes to increasing the environmental problem becomes essential in these countries to develop new policies to reduce these disparities and environmental degradation.

Other aspects related to gender inequality and environmental degradation also could be focused on future investigations. For example, explore the effect of energy consumption (e.g., fossil fuels) on economic growth and health (e.g., obesity). All these aspects are related to gender inequality and an increase in environmental degradation. Therefore, this investigation can open new fields of study related to how gender inequality impacts energy consumption from fossil fuels and energy poverty in households. For example, if the gender inequality caused by the gender pay gap limits women and families to access equipment with high energy efficiency or green energy technologies. This type of obstacles increases energy consumption from fossil fuels and, consequently, the environmental degradation (CO_2 emissions) in developed countries (e.g., European Union). The same questions can be put in developing countries with higher gender inequality than the European Union (e.g., Latin America and the Caribbean, Asia, and the Middle Eastern region).

This study can also encourage the development of investigations related the gender inequality and some aspects of health (e.g., obesity in women). The gender inequality caused by the gender pay gap encourages the increase of obesity by consuming processed foods and, consequently, increasing food production, land use, consumption of energy, and environmental degradation (see Koengkan & Fuinhas, 2020).

Finally, this study opens up the opportunity to develop new investigations and develops new indicators. For example, statistical agencies (e.g., Eurostat) and science institutes (e.g., European Institute for Gender Equality) could develop new indicators related to gender inequality in energy, environmental quality, and natural resources. These new indicators could measure the extent to which women and men can benefit from equal access to green or clean energy and energy efficiency technologies and measure how women and men can benefit from equal environmental quality and natural resources access.

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Appendix

Table 4. The use of variables by literature

Authors that found the positive and negative impacts

	GDP		Gender gap pay		Electric power consumption/Energy		Globalisation		Urbanisation	
	Impact on environmental degradation/CO2 emissions									
Authors	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative	Positive	Negative
Koengkan &Fuinhas (2020)		✓ (green)	N.A	N.A	✓ (red)		N.A	N.A	✓ (red)	
Adedoyin et al. (2020)	✓ (red)		N.A	N.A	✓ (red)		N.A	N.A	N.A	N.A
Chishti et al. (2020)	✓ (red)		N.A	N.A	N.A	N.A		✓ (green)	N.A	N.A
Yazdi and Dariani (2020)	✓ (red)		N.A	N.A	✓ (red)		✓ (red)		✓ (red)	
Muhammad et al. (2020)		✓ (green)	N.A	N.A	✓ (red)			✓ (green)		✓ (green)
Salahuddin et al. (2019)	✓ (red)		N.A	N.A	✓ (red)		✓ (red)			✓ (green)
Koengkan (2018)	✓ (red)		N.A	N.A	✓ (red)			✓ (green)	N.A	N.A
Fuinhas et al. (2017)	✓ (red)		N.A	N.A	✓ (red)		N.A	N.A	N.A	N.A
Aye & Edoja (2017)		✓ (green)	N.A	N.A	✓ (red)		N.A	N.A	N.A	N.A
Poumanyvong & Kaneko (2010)	✓ (red)		N.A	N.A	✓ (red)		N.A	N.A		✓ (green)

Notes: N.A denotes not available; the icon with red colour means that the variable increase the environmental degradation/CO_2 emissions, while in green colour means a decrease in environmental degradation/CO_2 emissions.

Table 5. Descriptive statistics

Variables	Descriptive Statistics				
	Obs.	**Mean**	**Std.-Dev.**	**Min.**	**Max.**
LogCO2_pc	364	-1.3195	0.4227	-2.4003	-0.0069
LogGDP_pc	364	10.2976	0.3546	9.1613	11.0319
LogGPG	245	2.6216	0.4980	-0.9162	3.2958
LogENE_pc	364	8.7303	0.4550	7.8923	9.7561
LogGLOBA	360	5.0204	0.1314	4.4220	5.1882
LogURBA	364	4.2555	0.1714	3.8809	4.5841

Notes: The Stata command *sum* was used; "**Log**" denote variables in natural logarithms; Obs. denotes the number of observations in the model; Std.-Dev. denotes the Standard Deviation; Min. and Max. denote Minimum and Maximum, respectively.

Table 6. Shapiro-Wilk W-test for normal data

Variables	Obs.	W	V	Z	Prob>z
Resid	245	0.9218	13.930	6.122	0.0000

Notes: The command *sktest* of Stata was used. The null hypothesis of this test is the presence of normality.

Table 7. Skewness/Kurtosis tests for Normality

Variables	Obs.	Pr(Skewness)	Pr(Kurtosis)	adj chi2(2)	Prob>Chi2
Resid	245	0.0000	0.0000	44.15	0.0000

Notes: The command *sktest* of Stata was used. The null hypothesis of this test is that the data is normally distributed.

Table 8. VIF-test

Variables	VIF	1/VIF	Mean VIF
	LogCO2_pc		
LogGDP_pc	3.19	0.3134	
LogGPG	1.60	0.6230	
LogENE_pc	3.32	0.3016	2.62
LogGLOBA	3.00	0.3337	
LogURBA	2.01	0.4967	

Notes: The Stata command *estat vif* was used; "**Log**" denotes variables in natural logarithms.

Table 9. Pesaran CD-test

Variables	CD-test	
LogCO2_pc	44.47	***
LogGDP_pc	41.74	***
LogENE_pc	27.15	***
LogGLOBA	46.80	***
LogURBA	6.58	***

Notes: The Stata command *xtcd* was used; **"Log"** denote variables in natural logarithms; *** denotes statistical significance at the 1% level.

Table 10. Panel Unit Root test (CIPS-test)

Variables	Panel Unit Root test (CIPS) (Zt-bar)		
	Without trend		With trend
	Lags	Zt-bar	Zt-bar
LogCO2_pc	1	1.908	2.239
LogGDP_pc	1	4.019	1.972
LogGPG	1	0.450	-2.665 ***
LogENE_pc	1	0.090	2.317
LogGLOBA	1	0.745	-0.690
LogURBA	1	1.842	5.367

Notes: The Stata command *multipurt* was used; "**Log**" denotes variables in natural logarithms; the null for CIPS test is series have unit root; the lag length (1) and trend were used in this test; *** denotes statistically significant at the 1% level.

Table 11. Westerlund cointegration test between **LogCO2_pc**, **LogGDP_pc**, **LogENE_pc**, **LogGLOBA**, and **LogURBA**.

Statistics	Value	Z value	p-value	Robust p-value
Gt	-2.594	1.114	0.867	0.249
Ga	-3.997	5.786	1.000	0.996
Pt	-6.100	3.734	1.000	0.799
Pa	-3.851	4.362	1.000	0.927

Notes: The Stata command *xtwest* was used. Bootstrapping regression with 800 reps. H_0: No cointegration; H_1 Gt and Ga test the cointegration for each country individually, and Pt and Pa test the cointegration of the panel as a whole.

Table 12. Hausman test

chi2(5) =39.58 ***

Notes: The Stata command *hausman* (with the options, sigmamore) was used; *** denotes statistically significant at the 1% level. The null hypothesis of this test is that the difference in coefficients is not systematic, where the random effects are the most sustainable estimator.

Table 13. Bias-corrected LM-based test

Variables	LM(k)-stat	p-value
LogCO2_PC	4.69	0.000
LogGDP_PC	3.75	0.000
LogGPG	1.65	0.099
LogENE_PC	3.66	0.000
LogGLOBA	3.49	0.000
LogURBA	1.89	0.059

Notes: The Stata command *xtqptest* was used; **"Log"** denotes variables in natural logarithms; under H0, LM(k) ~ N(0,1). The null hypothesis of this test is the non-presence of serial correlation of order k.

Table 15. Fixed effects model estimation

Independent variables	Dependent variable (**LogCO2_pc**)		
	FE	**FE Robust**	**FE D.-K.**
LogGDP_pc	-1.0857 ***	***	***
LogGPG	0.0724 ***	**	***
LogENE_pc	0.8411 ***	**	***
LogGLOBA	-0.7349 ***	*	***
LogURBA	-2.6354 ***	**	***
Constant	17.2428 ***	***	***
Obs	245	245	245

Notes: The Stata command *xtreg* was used; ***, **, * denotes statistically significant at the 1%, 5%, and 10% levels, respectively; "**Log**" denotes variables in natural logarithms.

Table 17. Post-estimation tests for fixed effects model

Statistics	Modified Wald test	Wooldridge test	Pesaran's test	Breusch and Pagan Lagrangian Multiplier test
	chi2 (14) =502.26***	F(1,13) =12.856**	23.423***	N.A

Notes: *** denotes statistically significant at 1% level; H_0 of Modified Wald test: sigma(i)^2 = sigma^2 for all i; H_0 of Wooldridge test: no first-order autocorrelation; H_0 of Pesaran's test: residuals are not correlated; H_0 of Breusch and Pagan Lagrangian Multiplier test: no dependence between the residuals; N.A denotes not available.