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# Assessment of the Impact of Digitalization on Greenhouse Gas Emissions on the Example of EU Member States

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**Abstract**
Digitization and climate neutrality are among the development priorities of EU member states. This causes wide scientific and practical interest in the description of these processes, including their mutual influence. In this case, digitalization is a factor, and climate neutrality, largely characterized by greenhouse gas emissions, is the answer. Therefore, the purpose of the study is to assess the impact of digitalization on greenhouse gas emissions using the example of EU member states. The scientific novelty of the obtained results is the proposition of hypotheses, the proof of which will allow us to estimate the level of influence of the digitalization process on the volume of greenhouse gases per capita of the EU member states using economic and mathematical tools. It is justified that the direct impact of digitalization on the level of greenhouse gas emissions cannot be considered significant and statistically significant. The impact of digitalization on the processes of reducing greenhouse gas emissions with a delay of 1 to 4 years has not been identified. Considering the low degree of correlation-regression dependence between greenhouse gas emissions and the level of digitization, it can be assumed that either (1) other factors have a significant impact (list), or (2) the observation horizon is "captured" only by the part of the Kuznets curve, which corresponds to the descending part parabolas. Consequently, the conducted analysis shows that there are serious reasons to believe that digitalization is not the main (leading) factor in reducing greenhouse gas emissions. This necessitates further research with the inclusion of a wide range of variables (related to regulatory policy, tax policy, investment policy, the culture of consumption) in the model.

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## 1. Introduction

At the moment, there are two dominant trends in the EU that determine further way of its economic development. The first trend provides for the digitalization of the economy. The second trend is aimed at introducing a “green deal” in the context of achieving the Sustainable Development Goals.

“One of the top priorities of the European Union so far, with a promise that until 2050 the European Member states will become climate neutral, is the focus on climate change and digitalization of the EU” (Stoican, and Chirieac, 2021). These two issues are closely intertwined and both of them are seen as a non-alternative imperative for further economic development EU (at least for nearest decades). So that, the pool of main EU’s goals for long-term period includes (1) decrease emissions of greenhouse gases (hereinafter “GHG”) as a part of climate neutrality and (2) increase digital level of the economy.

From a theoretical standpoint, it is clear that digitalization and the achievement of climate neutrality cannot be considered as independent processes. We cannot see climate neutrality as a factor and digitalization as a response. Only the inverse relationship makes sense. So, the digitalization of the EU economy is a tool for achieving climate neutrality. However, digitalization is the only one from many other tools such as regulatory policy (for example, limiting and burdening the activities of industries with a significant carbon footprint), tax policy (for example, carbon tax), investment policy (for example, a moratorium on investment in new coal mines), changing the culture of consumption (for example, consumption of products with a low environmental footprint). “As a consequence, the European Union presents yearly reports upon the situation of the environment and climate change and the conclusion is that there is a need of developing new partnerships and funding the transition to a new digital era. … Therefore, protecting EU values, as well as fundamental rights and the security of citizens, is a key element of the digital transition, with the digital technology playing a key role in transforming the European economy and society, in order to achieve a climate-neutral EU by 2050, a goal agreed by EU leaders” (Stoican and Chirieac, 2021).

Thus, there are high expectations about the positive impact of digitalization on achieving climate-neutral EU economy. However, there are alternative points of view on the positive impact of digitalization on the economic (Vyshnevskyi et al., 2020), social (Kwilinski et al., 2020) and environmental spheres (Shvakov and Petrova, 2019; Dźwigoł et al., 2021; Dzwigol et al., 2021). “The experience of the top 10 countries in terms of the level of digital competitiveness in 2019 has shown that digitalization does not contribute to the development of either a shared economy, or a “green” and circular economy, or an energy-efficient economy, and even hinders their development” (Shvakov and Petrova, 2019).

The presence of opposite positions is testifying, that the potential for research in this area has not been exhausted. This determined the choice of the topic and aim of the study.

A priority object of study for continuing work in this direction is the EU, which, on the one hand, has a common institutional, economic and digital space, and on the other, has a special features of nation states. It is a unique synthesis of the general (EU) and the particular (member states).

In view of this, the purpose of the study is to assess the impact of digitalization on greenhouse gas emissions using the example of EU member states using the method of statistical analysis and economic-mathematical tools.

## 2. Literature review

As part of the digital transition to the development of the national economy, many normative acts have been adopted (Kwilinski et al., 2020; Rovňák et al., 2022) and comprehensive studies are being carried out (Vyshnevskyi et al., 2019; Orbik and Zozulakova, 2019; Vyshnevskyi et al., 2020; Albu and Albu, 2021; Kurniawan et al., 2022; Ma and Zhu, 2022; Ozturk and Ullah, 2022; Purnomo et al., 2022; Reza-Gharehbagh et al., 2022; Yang et al., 2022; Zhou et al., 2022; Orzeł and Wolniak, 2022; Brodny and Tutak, 2022; Kuzior et al., 2022; Mynenko and Lyulyov, 2022; Mańka-Szulik and Krawczyk, 2022;

The situation is the same with the second trend – the transition to a green economy (European Commission, 2019; Kwilinski et al., 2019; Kuzior et al., 2019; Kuzior et al., 2021; Dźwigoł et al., 2021; Dzwigol et al., 2021; Astawa et al., 2021; Kuzior et al., 2022; Midor, 2022, Deja et al 2019).

These questions are often examined simultaneously in many studies (Bonire and Gbenga-Ilori, 2021; Stoican and Chirieac, 2021; Li et al., 2021; Li, Liu and Ni, 2021;  et al., 2021; Ma et al., 2022; Nham and Ha, 2022; Wang et al., 2022; Li and Wang, 2022; Wang et al., 2022; Zhang et al., 2022a; Zhang et al., 2022b).

The issues of the impact of digitalization on reducing greenhouse gas emissions are considered from different perspectives. Some researchers show that there is an U-shaped form of dependence (Li, Fang and Liu, 2021). As theoretical basis they use Environmental Kuznets Curve (hereinafter “EKC”). “The model showed an inverted U-shaped relationship between $CO_2$ emissions and the digitalization, which is consistent with the EKC hypothesis. At the beginning of digitalization, firms produce more goods because of technological progress, thus releasing more $CO_2$ emissions, which are greater than the reduction of CO2 due to digitalization. When the digitalization level is high, the treatment amount of $CO_2$ is greater than $CO_2$ emissions, as firms produce goods at a stable level and technological progress leads to green economy” (Li, Liu and Ni, 2021). Results is “based on the fixed-effects model of the global panel data of 190 countries from 2005 to 2016” (Li, Liu and Ni, 2021).

Despite the wide range of scientific research on the chosen topic, the multifacetedness and debatable nature of certain issues require further development. And especially the solution to this problem is actualized at the current stage of global green transformations of various sectors of economic activity in the context of the implementation of the concepts of smart specialization, digitalization and sustainable development.

## 3. Experimental

Based on the aim of the study and review of previous papers (Bonire and Gbenga-Ilori, 2021; Stoican and Chirieac, 2021; Li, Fang and Liu, 2021; Li, Liu and Ni, 2021; Kovacikova, Janoskova, & Kovacikova, 2021; Ma et al., 2022; Nham, & Ha, 2022; Wang et al., 2022; Li & Wang, 2022; Wang, Luo and Zhu, 2022; Zhang et al., 2022a; Zhang et al., 2022b), the following scientific hypotheses can be proposed for their subsequent verification.

*Hypothesis H0:* There is not any relationship between GHG emissions and the digital economy level in member states EU-27.

*Hypothesis H1:* There is relationship between GHG emissions and the digital economy level in member states EU-27. Form of relationship is an inverted parabola according to EKC curve (*Appendix A, Figure 1*, curve OAB).

According to this pattern, three phases can be identified. On the first phase both GHG emissions and the digital economy level increase. On the second phase the digital economy level increase, but GHG emissions not significantly change. On the third phase the digital economy level increase while GHG emissions decrease.

So, in this study, three hypotheses are put forward, which must be proved or denied using the method of statistical analysis and economic-mathematical tools. The authors do not introduce any restrictions in their assumptions and when analysing the dynamics of statistical data.

*Hypothesis H11:* Increasing digital economy level in member states EU-27 leads to an increase in GHG emissions.

*Hypothesis H12:* Increasing digital economy level in member states EU-27 does not impact to GHG emissions.

*Hypothesis H13:* Increasing digital economy level in member states EU-27 leads to a decrease in GHG emissions.

To estimate digital economy level is used the Digital Economy and Society Index (hereinafter "DESI"). As have shown in previous analysis DESI more relevant for member countries EU-27 than the ICT Development Index, The Digital Adoption Index and others indexes, which describes process of economy digitalization (Vyshnevskyi et al., 2020). And only DESI is calculated specifically for the EU countries.

DESI scores and GHG emissions were compared comprehensively and their dependence was evaluated, which covered the following steps:

Step 1. Graphical testing of hypothesis H1 based on the entire set of raw data. In this case, all observations are considered as equivalent, regardless of the year and from which country they were made.

Step 2. Analysis of behaviour of different part of dataset depend on level of digitalization of economy (testing H11, H12, H13 hypothesis).

Step 3. Regression analysis of the impact of the level of digitalization on greenhouse gas emissions.

Therefore, the basic hypothesis assumes the presence of a U-shaped curve, which, as shown by some researchers, describes the relationship between digitalization and $CO_2$ emissions (the main greenhouse gas) and is generally called the Kuznets curve. DESI (Digital Economy and Society Index) was chosen as a measure of digitalization, and the volume of greenhouse gases per capita was defined as a measure of greenhouse gas emissions. The results of the study indicate that an increase in the level of digitalization leads to an increase in the range of variation. High digital level countries more quickly decrease GHG emissions than low and middle digital level countries. A study of data for 2015-2020 in EU member states did not confirm the presence of a statistically significant relationship.

## 4. Results and discussion

Whole set of observations (*Appendix B, Table 1*) will be investigated from differences sides. In the first step, the entire dataset is treated as homogeneous, regardless of time period and country. The main characteristics of this extremely aggregated data are as follows.

An increase in the level of digitalization (*Appendix C, Figure 2*) only in some cases leads to a de-crease in greenhouse gases. Whereas, predominantly, there are an increase both, the volatility (range of variation) and the average of greenhouse gas emissions. The correlation coefficient between DESI and GHG emissions is only 0.26.

There is no clear inverted U-shaped curve between greenhouse gas emissions and the level of digitalization. If, nevertheless, we assume that such a connection exists, then the corresponding parabola will not differ significantly from a straight line (*Appendix D, Figure 3*). If the quadratic dependence still takes place, then the inflection current is located has coordinates (86.8; 11.38). In this case, we can assume that in the medium term, an increase in the level of digitalization will lead to a decrease in volumes. However, the statistical significance of such forecasts is negligible and cannot be used for scientifically based forecasts.

So that it's necessary go from aggregate dataset to individual values in context of countries and years.

Comparing the dynamics of GHG emissions indicator and the level of digitalization, expressed in DESI (*Appendix A, Table 1*) at time axis, it becomes noticeable that while DESI is increasing on average, at the same period GHG emissions is decreasing on average. In the table 1 it's given raw data. From 2016 to 2020, the average value of DESI increased from 36.58 to 47.63 scores, while greenhouse gas emissions decreased on average from 9.56 to 8.40 tons per capita. At the same time, both indicators tend to increase the homogeneity of the sample, measured by the coefficient of variation. Thus, the variation coefficient for the DESI indicator for 5 years decreased from 21.8% to 19.2%. And the coefficient of variation for the GHG emissions indicator decreased from 36.1% in 2016 to 32.7% in 2020.

In 2020, the minimum value in the DESI sample was 29.98 scores, and the maximum was 62.80 scores. Therefore, the maximum exceeds the minimum by 2.1 times. In the GHG emissions sample, the maximum value exceeds the minimum by 3.6 times (in 2020).

Quite a wide range of values may mean the presence of various dependencies, including the U-shaped one. Based on this, the relationship between the DESI and GHG emissions seems quite possible.

The TOP-5 countries in EU-27 according to the DESI rating include: Finland – 62.80 scores; Denmark – 61.78 scores, Sweden – 61.55 scores; Netherlands – 58.88 scores, Malta – 56.47 scores. At the same time TOP-5 countries in EU-27 according to minimum of greenhouse gases emissions significant differ from DESI TOP-5 (Malta – 4.30 tons per capita; Sweden – 4.80 tons per capita; Croatia – 5.76 tons per capita; Spain – 5.80 tons per capita; Portugal – 5.99 tons per capita). So, there are only Malta and Sweden in the both groups simultaneously.

At the same time, Croatia, which ranks 20th in terms of digitalization, ranks 3rd in terms of greenhouse gas emissions.

Due to the small number of observations available on the time scale (only 5, from 2016 to 2020), it is not possible to conduct a deep statistically significant analysis of time series in the context of the influence of the DESI on the GHG emissions. Result of such horizontal analysis can be used only for forming general trends.

The vertical analysis is more promising due to the fact that it has 27 observations (number of EU members).

However, graphical analysis calls the hypothesis H1 into question by the absence of any visually noticeable functional relationships and indicates the need for more in-depth studies (*Appendix E, Figure 4*).

Analysis of the dynamics of changes in these indicators for 5 years (*Appendix F, Table 2*) shows that the aggregate of changes for DESI is more homogeneous than for GHG emissions.

Graphical analysis (*Appendix G, Figure 5*) in this case indicates the presence of a certain linear trend (with the exception of Estonia, where there is an abnormally sharp decrease in greenhouse gases by 6.5% at once per year), the consistency of which can be investigated by static methods. The quadratic (U-shaped) dependence is imperceptible, which is also confirmed by analytical calculations.

The all TOP-5 countries by DESI (Denmark, Finland, Sweden, Netherlands, Estonia) show for 5 years significant increase digital level with decrease GHG emission (*Appendix H, Figure 6*). On average, this part of the sample showed an increase in the DESI by 12.28 scores (+25.77% compared to 2016) with a decrease in greenhouse gas emissions by 0.65 tons per person (-22.84% compared to 2016). Such dynamics corresponds to H13 hypotheses. But Estonia, who last from TOP-5 by DESI, it shown progress in decreasing of GHG emission 4 times than Denmark (minus 42% and minus 11% respectively).

The lower part of the sample by DESI (Hungary, Poland, Bulgaria, Greece, Romania) shows that progress in the level of digitalization occurs against the backdrop of less significant reductions in GHG emissions (*Appendix K, Figure 7*). On average, this part of the sample showed an increase in the DESI by 9.46 scores (+37.5% compared to 2016) with a decrease in GHG emissions by 0.55 tons per person (-6.64% compared to 2016). Such dynamics corresponds to an intermediate state between the H12 and H13 hypotheses.

If we divide the sample on the three equal parts there will be notice significant difference between them. High digital level countries more quickly decrease GHG emission than low and middle digital level countries (*Appendix L, Figure 8*).

After analysis of the different parts of the sample we will make statistically investigation of the whole one to test hypotheses H11, H12, and H13. At the first stage, the regression between GHG emissions and DESI was analyzed in each of the years of the period under review (*Appendix M, Table 3*, columns 2-6).

A very low coefficient of determination and a predominantly high p-level indicate that there is no statistically significant impact of digitalization on greenhouse gas emissions. The situation is similar when analyzing dependence with a time lag (*Appendix M, Table 3*, columns 7-11).

To find out the influence of factors other than the level of digitalization, a regression of the Yt=b0+b1Xt+b2Yt-1 type was considered (*Appendix N, Table 4*). We can assume that the variable Yt-1 includes all other factors (regulatory policy, tax policy, investment policy, the culture of consumption) except for digitalization.

The characteristics of this regression model show that the coefficient of determination is very large (in all four cases it exceeds 0.9, and in two cases even 0.99), while the role of the significance of digitalization and the previous level of emissions is significantly different. The level of digitalization in 3 out of 4 cases is not statistically significant. The main role is played by the emission of greenhouse gases in the previous period.

## 5. Summary and conclusion

The results obtained are mixed. In general, the H1 hypothesis has not been proven. Therefore, we can accept the alternative hypothesis H0. However, hypotheses H12, H13 can be considered partially confirmed.

This is confirmed by the research results of other scientists. So, D. Ma & Q. Zhu (2022) emphasize that the digital economy can directly stimulate high-quality environmental development, and industrial structure adjustment and green technology innovation are important mediating mechanisms. At the same time, it has a positive nonlinear effect on high-quality green development, but the marginal effects are clearly reduced.

A comprehensive index of the digital economy of 30 provinces in China from 2006 to 2017 is proposed, and the relationship between the digital economy and $CO_2$ emissions is estimated using the system-generalized method of moments (SYS-GMM) (Wang et al., 2022). The results show that (1) the digital economy indexes of eastern coastal provinces are higher than those of other provinces in China; (2) the digital economy has a negative impact on $CO_2$ emissions; in other words, a 1% increase in the digital economy index will reduce $CO_2$ emissions by 0.886%; (3) in terms of the digital economy sub-indicators, infrastructure, innovation and application, as well as economic growth and jobs in the digital economy also have a negative impact on $CO_2$ emissions; and (4) the digital economy indirectly reduces $CO_2$ emissions by expanding the economies of scale of tertiary industries, reducing the share of coal consumption, and promoting green technology innovation.

Li & Wang (2022) note that the digital economy is of great importance for reducing carbon emissions. To estimate the impact of the digital economy on carbon emissions, they performed a nonlinear analysis combining the Spatial DURBIN Model (SDM) and the Panel Threshold Model (PTM). The effect of reducing carbon emissions is decomposed into a direct part and a spatial spill over part, and the mechanism of action is further analysed from the point of view of technological progress, energy use and industrial structure. Empirical findings indicate that the digital economy and carbon emissions have an inverted U-shaped relationship. Similarly, the effect of the spatial distribution of the digital economy on carbon emissions is also shaped like an inverted U. The digital economy first increases and then reduces carbon emissions. At the same time, the active demonstration of the modernization of the industrial structure and technological effects contribute to the side effect of the digital economy on carbon emissions in the long term. It was established that the realization of the carbon peak and carbon neutrality requires the strengthening of the digital economy and the promotion of regional cooperation in environmental governance. The green integration of the digital economy and traditional industries is of great importance for reducing carbon emissions (Li & Wang, 2022).

The results (Zhang et al., 2022) show that digital economy is gradually becoming an essential driver for regional low-carbon development (LCD). Environmental governance, technological innovation, and industrial structure upgrade are the three primary channels for digital economy to influence LCD. The intermediary role of industrial structure upgrade is the largest, while technological innovation is the smallest. Results of heterogeneity analysis show that the decarbonisation of digital economy is better in the eastern region but not significant in the central and western regions. In addition, since the launch of the carbon emissions trading pilot in China, digital economy has significantly contributed to low-carbon development.

Based on the above, we can come to the following conclusion. If there is an inverted U-shaped relationship between the change in greenhouse gas emissions and the level of digitalization, then now this process in the EU member states is at a turning point, when an increase in the already sufficiently high level of digitalization comes to a decrease in greenhouse gas emissions. And the higher the level of digitalization, the faster greenhouse gas emissions are reduced.

The following conclusions can be reached as a result of the conducted research.

1. In general, ehe direct impact of digitalization on the level of greenhouse gas emissions cannot be considered significant and statistically significant. The impact of digitalization on the processes of reducing greenhouse gas emissions with a delay of 1 to 4 years has not been identified. Consequently, the conducted analysis shows that there are serious reasons to believe that digitalization is not the main (leading) factor in reducing greenhouse gas emissions. This necessitates further research with the inclusion of a wide range of variables (related to regulatory policy, tax policy, investment policy, the culture of consumption) in the model.

2. The contradictory nature of the practical results regarding the testing of the hypothesis about the impact of the level of digitalization of the economy on emissions of greenhouse gases can be resolved through their consideration as general and particular. Take the environmental smith curve as a general pattern that describes the impact of digitalization of the economy on greenhouse gas emissions. Then the absence of dependence in general (during length of whole curve) can be interpreted as a process state on separate "section" ("fragment") of this curve. EU countries with low and middle level of digitalization of the economy is between the phases of direct and inverse dependence, and is characterized by the absence of significant changes in greenhouse gas emissions despite the increase in the level of digitalization (predominantly hypothesis H12). EU countries with high level of digitalization of the economy provide decreasing of greenhouse gas emissions (hypothesis H13).

3. Digitalization can contribute to progress in the environmental transformation of the national economies of European countries. For example, in Germany, the Digital Agenda in the field of German environmental policy was developed and presented. It formulates the strategic goals and principles of the digitalization process in accordance with the requirements of climate protection, nature conservation and ecology. At the same time, it should be noted that rapid digitalization entails serious consequences for the environment. The main project of the future should be a digital product passport. It should record all data about a particular product – from its manufacture to disposal. It's kind of like a digital summary of the entire life cycle. Based on this data, consumers will be able to make more informed purchasing decisions.

Digital technologies and artificial intelligence must be put at the service of environmental protection and climate protection. If they are created with a focus on saving energy and respecting resources, then there will be huge opportunities for climate protection. Thus, a scientific study by the Wuppertal Climate Institute (Germany) showed that blockchain technologies are much better than their reputation, and they can make a significant contribution to climate protection and environmental protection. Blockchain technology can help organize such trade while taking into account the stability of the network and the security of supply, and thus stimulate ecological transformation. It is also suitable for providing transparency along the entire supply chain or facilitating emissions trading.

In addition, it is worth emphasizing that there is an urgent need for further research to analyse individual sectors through different stages of digitization. This is due to the fact that each type of economic activity has its own specific features (for example, in the agro-food sector, due to the increase in the efficiency of the use of resources, a decrease in gas emissions is expected), which should be taken into account when developing concepts and strategic programs for the development of the digital and green economy in countries EU members.

Further studies, it is planned to evaluate the relationship between the digital economy and society index and the environmental efficiency index using statistical and economic-mathematical tool.

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# Appendix

## Appendix A

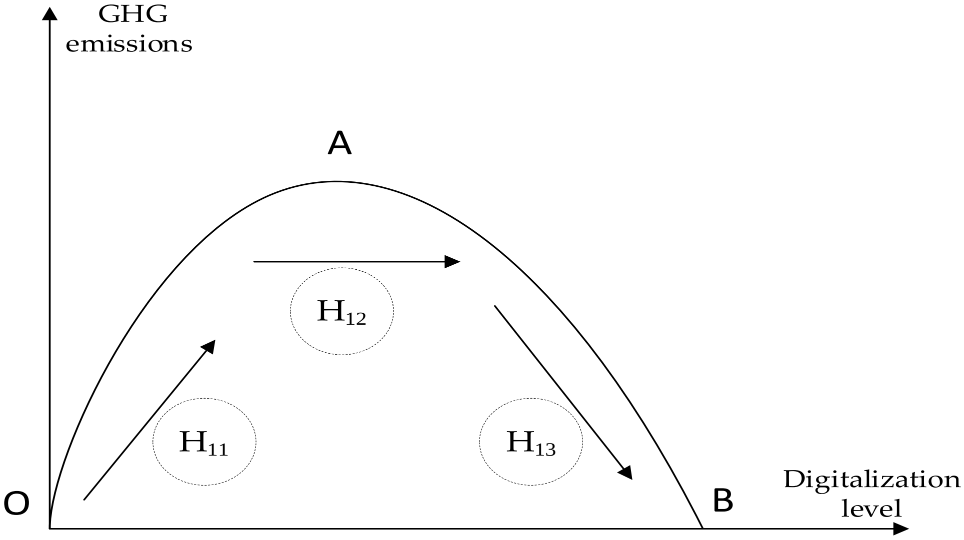


**Fig. 1.** EKC curve of GHG emissions and digitalization level: **hypothesizes** $H_{11}$, $H_{12}$, $H_{13}$

*Source:* Based on (Li, Liu and Ni, 2021).

## Appendix B

**Table 1.** The DESI value and greenhouse gases emissions in 2016–2020 in EU-27

| No. | Country | DESI, score | | | | | GHG, tons per capita | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2016 | 2017 | 2018 | 2019 | 2020 | 2016 | 2017 | 2018 | 2019 | 2020 |
| 1 | Austria | 39.80 | 42.59 | 45.24 | 47.72 | 50.22 | 8.21 | 8.52 | 8.17 | 8.51 | 7.60 |
| 2 | Belgium | 38.85 | 41.58 | 44.08 | 46.10 | 51.13 | 10.59 | 10.48 | 10.44 | 10.34 | 9.56 |
| 3 | Bulgaria | 25.97 | 28.11 | 30.89 | 32.72 | 34.43 | 8.49 | 8.89 | 8.40 | 8.28 | 7.65 |
| 4 | Croatia | 30.08 | 33.13 | 35.28 | 38.37 | 40.50 | 5.79 | 6.03 | 5.81 | 5.86 | 5.76 |
| 5 | Cyprus | 29.45 | 32.03 | 34.60 | 36.98 | 39.29 | 10.30 | 10.53 | 10.46 | 10.05 | 9.72 |
| 6 | Czech | 33.02 | 34.91 | 38.44 | 41.13 | 43.81 | 11.32 | 11.16 | 11.6 | 10.52 | 10.23 |
| 7 | Denmark | 50.14 | 53.33 | 54.83 | 57.92 | 61.78 | 15.50 | 15.41 | 15.62 | 14.26 | 13.80 |
| 8 | Estonia | 44.36 | 46.50 | 49.52 | 52.12 | 54.66 | 15.63 | 16.56 | 15.74 | 11.46 | 9.08 |
| 9 | Finland | 49.52 | 52.06 | 55.04 | 58.13 | 62.80 | 11.31 | 10.73 | 10.93 | 10.37 | 9.20 |
| 10 | France | 35.25 | 37.99 | 40.69 | 43.95 | 47.24 | 7.08 | 7.10 | 6.81 | 6.67 | 6.02 |
| 11 | Germany | 38.05 | 39.94 | 42.21 | 45.08 | 49.05 | 11.72 | 11.54 | 11.16 | 10.52 | 9.56 |
| 12 | Greece | 23.54 | 26.00 | 27.76 | 30.06 | 32.86 | 9.47 | 10.01 | 9.91 | 9.45 | 8.17 |
| 13 | Hungary | 28.98 | 31.63 | 33.45 | 35.29 | 38.53 | 6.88 | 7.16 | 7.19 | 7.08 | 6.94 |
| 14 | Ireland | 40.35 | 43.32 | 46.83 | 49.13 | 54.08 | 15.78 | 16.10 | 16.23 | 15.54 | 12.97 |
| 15 | Italy | 29.76 | 32.77 | 35.26 | 38.52 | 40.82 | 7.44 | 7.44 | 7.35 | 7.30 | 6.62 |
| 16 | Latvia | 38.47 | 40.89 | 43.15 | 44.51 | 47.21 | 6.28 | 6.48 | 6.80 | 6.86 | 6.36 |
| 17 | Lithuania | 37.64 | 40.37 | 44.29 | 46.70 | 49.44 | 8.11 | 8.60 | 8.97 | 9.17 | 9.03 |
| 18 | Luxembourg | 44.12 | 47.27 | 49.60 | 51.54 | 55.46 | 17.40 | 17.11 | 16.86 | 17.29 | 15.77 |
| 19 | Malta | 43.13 | 45.17 | 48.48 | 51.96 | 56.47 | 4.96 | 5.29 | 5.28 | 5.43 | 4.30 |
| 20 | Netherlands | 45.91 | 49.05 | 52.10 | 54.46 | 58.88 | 12.64 | 12.35 | 11.95 | 11.54 | 10.29 |
| 21 | Poland | 26.24 | 28.81 | 31.48 | 33.94 | 37.60 | 10.91 | 11.37 | 11.30 | 10.78 | 10.33 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | Portugal | 36.76 | 39.28 | 42.09 | 44.31 | 47.47 | 6.59 | 7.08 | 6.76 | 6.44 | 5.99 |
| 23 | Romania | 21.39 | 23.21 | 25.68 | 27.08 | 29.98 | 5.88 | 6.11 | 6.20 | 6.02 | 5.77 |
| 24 | Slovakia | 30.65 | 33.39 | 36.34 | 37.68 | 39.70 | 7.59 | 7.78 | 7.76 | 7.34 | 6.88 |
| 25 | Slovenia | 38.12 | 40.53 | 43.00 | 45.93 | 48.20 | 9.08 | 9.30 | 9.19 | 8.98 | 8.54 |
| 26 | Spain | 39.68 | 42.94 | 46.29 | 49.55 | 52.75 | 7.19 | 7.47 | 7.33 | 6.90 | 5.80 |
| 27 | Sweden | 48.33 | 50.94 | 55.34 | 58.39 | 61.55 | 6.05 | 5.79 | 5.59 | 5.38 | 4.80 |
| | minimum | 21.39 | 23.21 | 25.68 | 27.08 | 29.98 | 4.96 | 5.29 | 5.28 | 5.38 | 4.30 |
| | maximum | 50.14 | 53.33 | 55.34 | 58.39 | 62.80 | 17.40 | 17.11 | 16.86 | 17.29 | 15.77 |
| | Range | 28.75 | 30.12 | 29.66 | 31.32 | 32.82 | 12.43 | 11.82 | 11.58 | 11.90 | 11.46 |
| | average | 36.58 | 39.18 | 41.92 | 44.42 | 47.63 | 9.56 | 9.72 | 9.61 | 9.20 | 8.40 |
| the coefficient of variation | | 21.8% | 20.7% | 19.9% | 19.4% | 19.2% | 36.1% | 35.1% | 35.1% | 33.0% | 32.7% |

*Source:* Compiled by the authors based on the data of the European Commission (DESI, 2021) and Eurostat (2021).

**Appendix C**

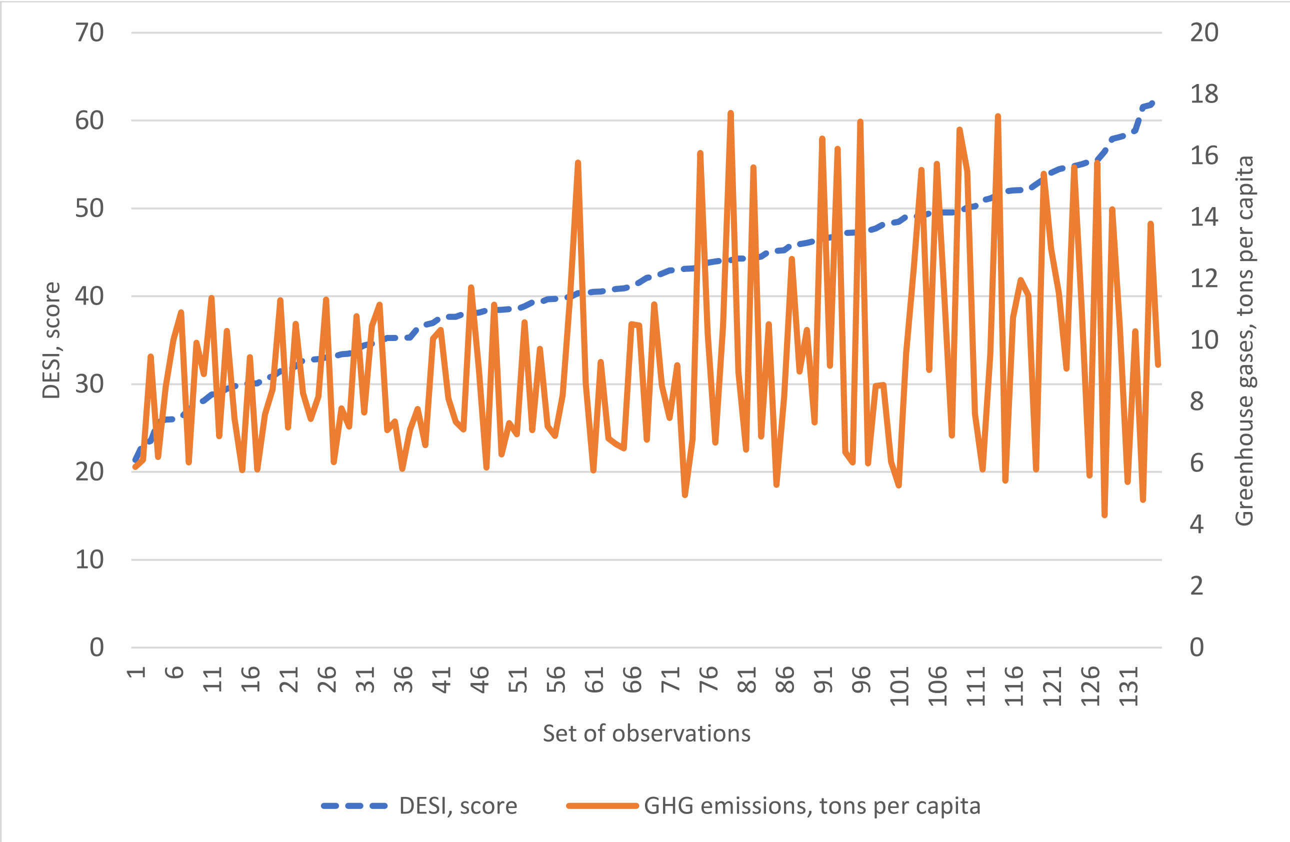


**Fig. 2.** Dynamic of sorted DESI and GHG emissions in 2016-2020 (EU-27)

*Source:* Constructed by the authors based on Table 1.

**Appendix D**

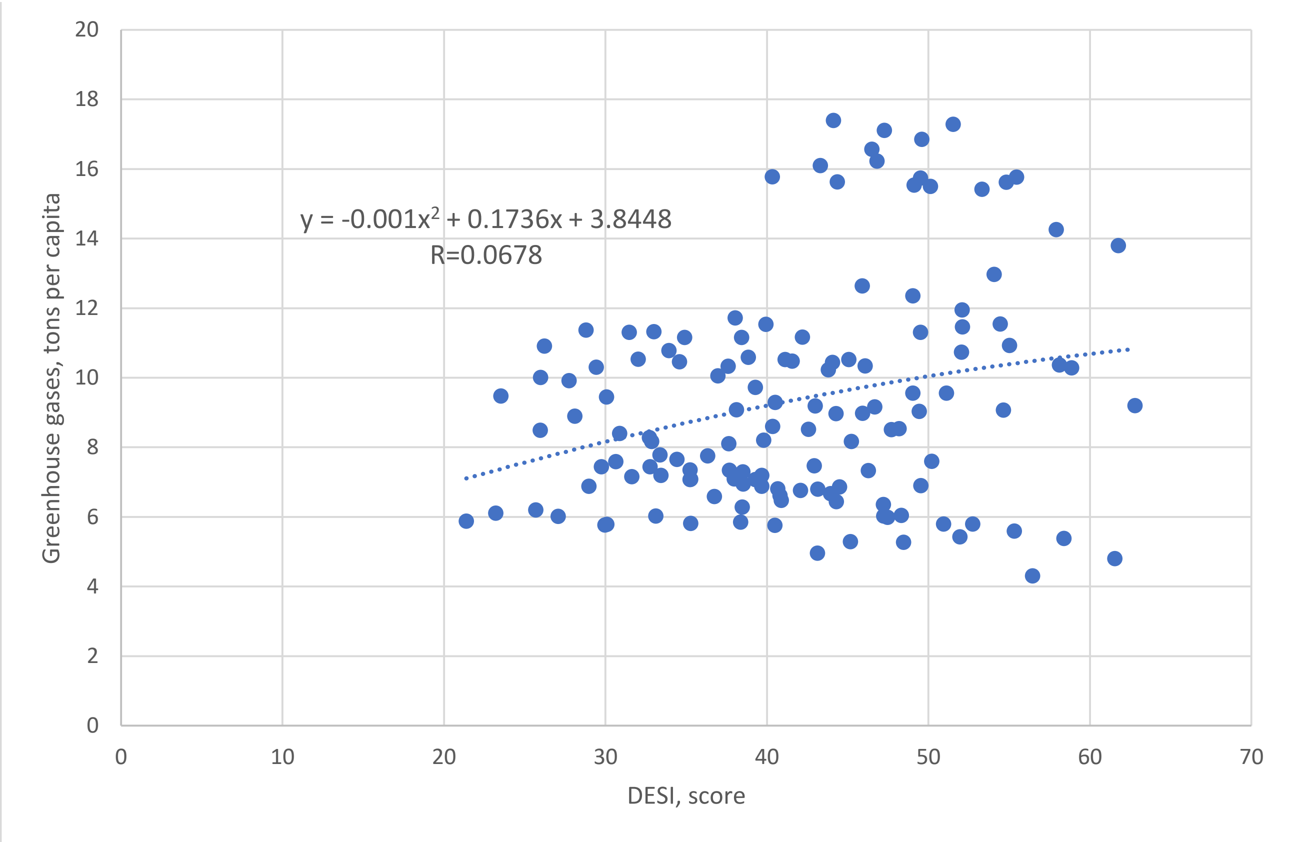


**Fig. 3.** Scatterplot of DESI and **GHG** emissions in 2016-2020 (EU-27)

*Source:* Constructed by the authors based on Table 1.

**Appendix E**

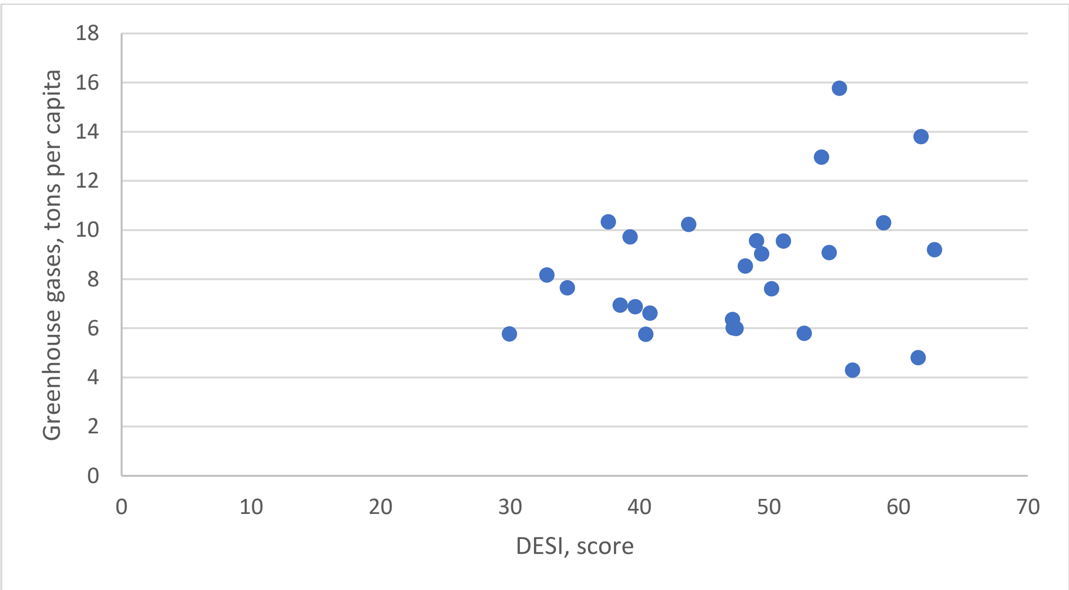


**Fig. 4.** Scatterplot DESI and GHG emissions in 2020 (EU-27)

*Source:* Constructed by the authors based on Table 1.

**Appendix F**

**Table 2.** Change of DESI and GHG emissions in 2016–2020 (EU-27)

| no | Country | Change in 2016-2020 | | # | Country | Change in 2016-2020 | |
|---|---|---|---|---|---|---|---|
| | | **DESI, score** | **GHG, tons per capita** | | | **DESI, score** | **GHG, tons per capita** |
| 1 | Austria | 10.42 | -0.61 | 15 | Italy | 11.06 | -0.83 |
| 2 | Belgium | 12.28 | -1.03 | 16 | Latvia | 8.74 | 0.07 |
| 3 | Bulgaria | 8.46 | -0.84 | 17 | Lithuania | 11.80 | 0.92 |
| 4 | Croatia | 10.41 | -0.03 | 18 | Luxembourg | 11.34 | -1.63 |
| 5 | Cyprus | 9.84 | -0.58 | 19 | Malta | 13.34 | -0.66 |
| 6 | Czech | 10.79 | -1.09 | 20 | Netherlands | 12.98 | -2.35 |
| 7 | Denmark | 11.64 | -1.70 | 21 | Poland | 11.37 | -0.58 |
| 8 | Estonia | 10.30 | -6.55 | 22 | Portugal | 10.71 | -0.60 |
| 9 | Finland | 13.27 | -2.11 | 23 | Romania | 8.59 | -0.11 |
| 10 | France | 11.99 | -1.05 | 24 | Slovakia | 9.05 | -0.70 |
| 11 | Germany | 11.00 | -2.16 | 25 | Slovenia | 10.08 | -0.55 |
| 12 | Greece | 9.32 | -1.30 | 26 | Spain | 13.07 | -1.40 |
| 13 | Hungary | 9.55 | 0.06 | 27 | Sweden | 13.22 | -1.25 |
| 14 | Ireland | 13.73 | -2.81 | | | | |
| | | | | | minimum (EU-27) | 8.46 | -6.55 |
| | | | | | maximum (EU-27) | 13.73 | 0.92 |
| | | | | | average (EU-27) | 11.05 | -1.16 |
| | | | | | range (EU-27) | 5.27 | 7.48 |
| | | | | | the coefficient of variation (EU-27) | 14.3% | -116.4% |

*Source:* Compiled by the authors based on the data in Table 1.

**Appendix G**

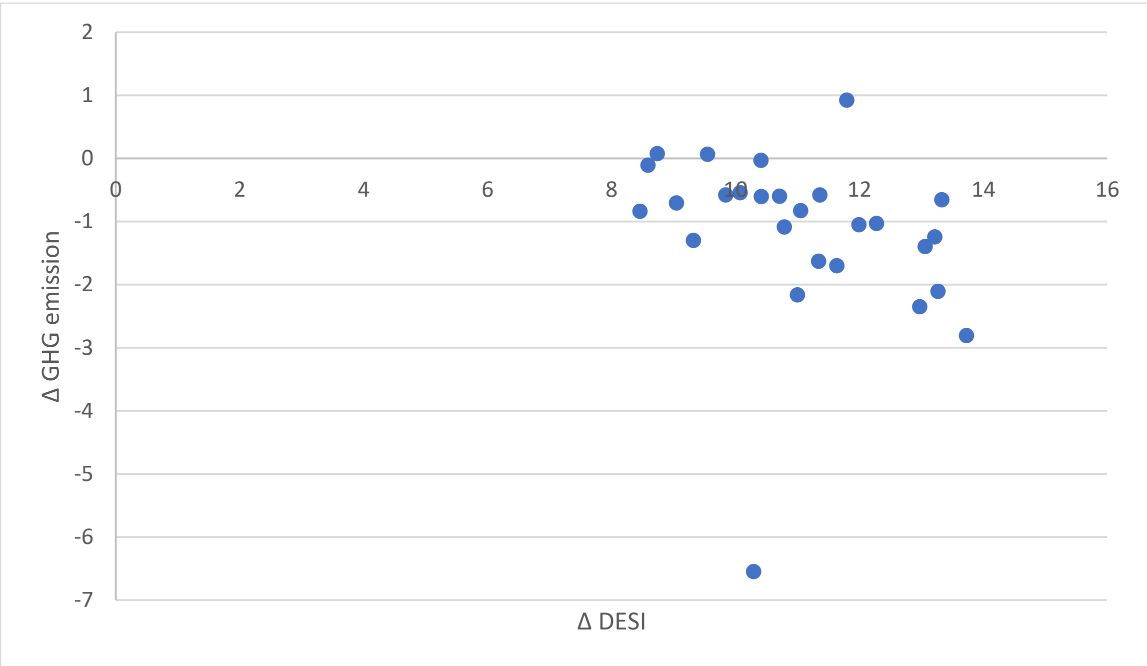


**Fig. 5.** Scatterplot **change** of DESI and GHG emissions in 2016–2020 (EU-27)

*Source:* Based on Table 2.

**Appendix H**

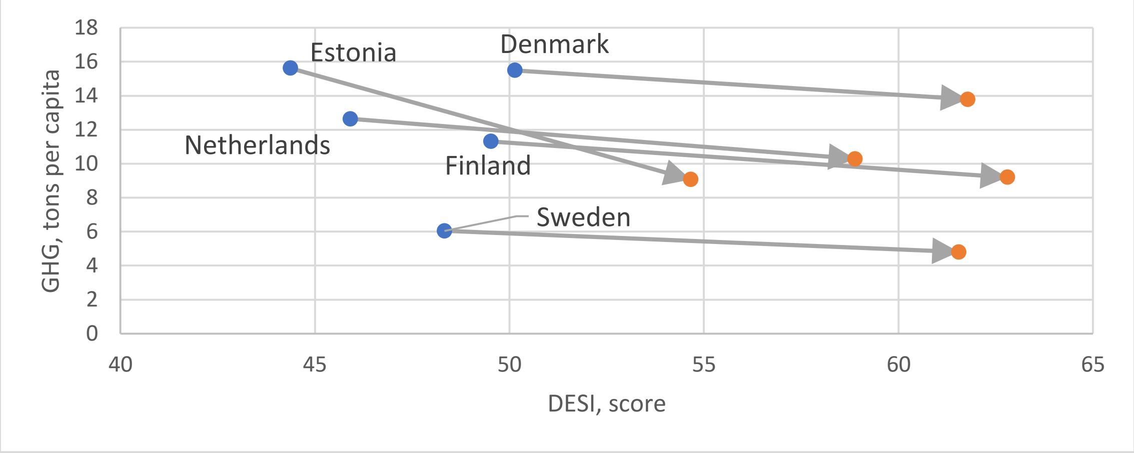


**Fig. 6.** Change DESI and GHG emission TOP-5 countries in 2016-2020

*Source:* Constructed by the authors based on Table 1.

**Appendix K**

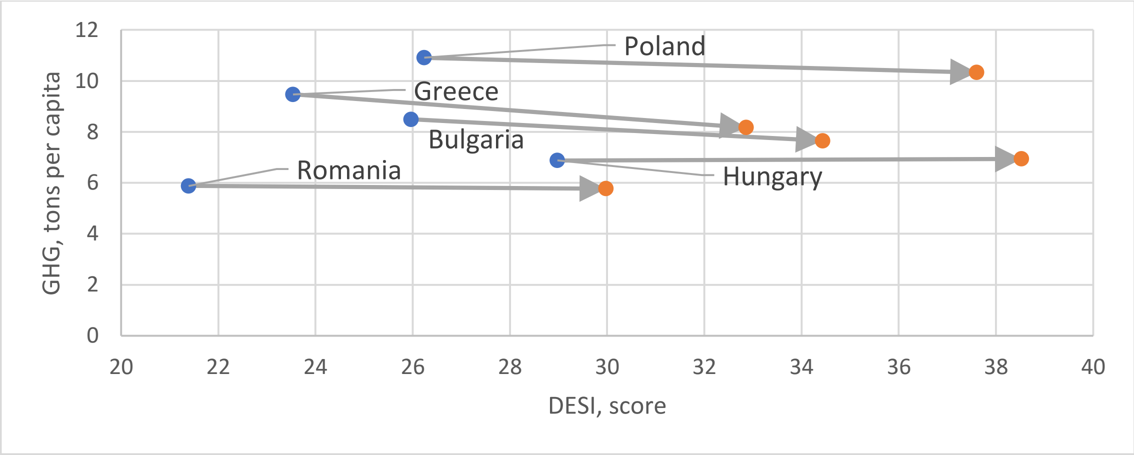


**Fig. 7.** Change DESI and GHG emission **BOTTOM**-5 countries in 2016-2020

*Source:* Constructed by the authors based on Table 1.

**Appendix L**

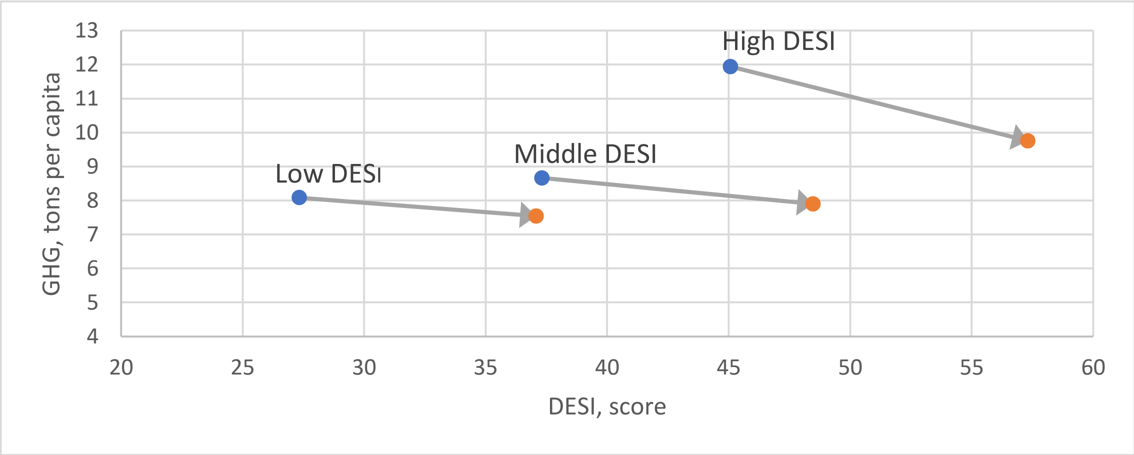


**Fig. 8.** Change DESI and GHG emissions **in** 2016-2020 with law, middle and high DESI level in 2016

*Source:* Constructed by the authors based on Table 1.

**Appendix M**

**Table 3.** Various regression options where DESI is the independent variable ($X_t$) and GHG emission is the dependent variable ($Y_t$)

| Characteristic | $Y_{2016}=b_0+b_1X_{2016}$ | $Y_{2017}=b_0+b_1X_{2017}$ | $Y_{2018}=b_0+b_1X_{2018}$ | $Y_{2019}=b_0+b_1X_{2019}$ | $Y_{2020}=b_0+b_1X_{2020}$ | $Y_{2020}=b_0+b_1X_{2019}$ | $Y_{2020}=b_0+b_1X_{2018}$ | $Y_{2020}=b_0+b_1X_{2017}$ | $Y_{2020}=b_0+b_1X_{2016}$ | $dY=b_0+b_1dX$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
| R | 0.4086 | 0.3765 | 0.3598 | 0.3229 | 0.2883 | 0.2640 | 0.2811 | 0.3047 | 0.2950 | 0.2524 |
| R^2 | 0.1670 | 0.1418 | 0.1294 | 0.1043 | 0.0831 | 0.0697 | 0.0790 | 0.0928 | 0.0870 | 0.0637 |
| Adjusted R^2 | 0.1336 | 0.1075 | 0.0946 | 0.0684 | 0.0464 | 0.0325 | 0.0422 | 0.0565 | 0.0505 | 0.0263 |
| F(1.25) | 5.0108 | 4.1302 | 3.7173 | 2.9102 | 2.2659 | 1.8722 | 2.1456 | 2.5583 | 2.3827 | 1.7011 |
| p-value | 0.0343 | 0.0529 | 0.0653 | 0.1004 | 0.1448 | 0.1834 | 0.1554 | 0.1223 | 0.1352 | 0.2040 |
| $b_0^{(1)}$ | 3.0967 | 3.5193 | 3.5062 | 4.1421 | 4.2686 | 4.6580 | 4.5143 | 4.3605 | 4.6850 | 1.2357 |
| $b_1^{(2)}$ | 0.1768 | 0.1582 | 0.1455 | 0.1138 | 0.0867 | 0.0842 | 0.0926 | 0.1031 | 0.1015 | -0.2172 |
| $b_1^{*\,(3)}$ | 0.4086 | 0.3765 | 0.3598 | 0.3229 | 0.2883 | 0.2640 | 0.2811 | 0.3047 | 0.2950 | -0.2524 |
| Std.Error of $b_1$ | 0.0790 | 0.0779 | 0.0755 | 0.0667 | 0.0576 | 0.0615 | 0.0632 | 0.0644 | 0.0658 | 0.1666 |
| t(25) for $b_1$ | 2.2385 | 2.0323 | 1.9280 | 1.7059 | 1.5053 | 1.3683 | 1.4648 | 1.5995 | 1.5436 | -1.3043 |

*Notes:* $^{(1)}$ – intercept (constant); $^{(2)}$ – regression coefficient; $^{(3)}$ –standardized regression coefficient.

*Source:* Based by the authors.

**Appendix N**

**Table 4.** Characteristics of regression of type $Y_t=b_0+b_1X_t+b_2Y_{t-1}$

| Characteristic | $Y_{2017}=b_0+b_1X_{2017}+b_2Y_{2016}$ | $Y_{2018}=b_0+b_1X_{2018}+b_2Y_{2017}$ | $Y_{2019}=b_0+b_1X_{2019}+b_2Y_{2018}$ | $Y_{2020}=b_0+b_1X_{2020}+b_2Y_{2019}$ |
|---|---|---|---|---|
| R | 0.9963 | 0.9972 | 0.9696 | 0.9838 |
| R^2 | 0.9925 | 0.9943 | 0.9402 | 0.9678 |
| Adjusted R^2 | 0.9919 | 0.9938 | 0.9352 | 0.9651 |
| F(2.24) | 1597 | 2099 | 189 | 361 |
| Std. Error of estimate | 0.3064 | 0.2643 | 0.7715 | 0.5123 |
| $b_0$ | 0.8252 | -0.0247 | 0.9794 | 0.9366 |
| $b_1$ | -0.0172 | 0.0017 | -0.0046 | -0.0188 |
| $b_2$ | 1.0006 | 0.9837 | 0.8768 | 0.9085 |
| $b_1^*$ | -0.0410 | 0.0042 | -0.0131 | -0.0625 |
| $b_2^*$ | 1.0125 | 0.9956 | 0.9741 | 1.0039 |
| t(24) for $b_1$ | -2.1175 | 0.2554 | -0.2466 | -1.5983 |
| t(24) for b(2) | 52.3158 | 60.4301 | 18.3183 | 25.6866 |
| p-value for $b_1$ | 0.0448 | 0.8006 | 0.8073 | 0.1231 |
| p-value for $b_2$ | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

*Source:* Compiled by the authors based on the data in Table 1.

# 以欧盟成员国为例评估数字化对温室气体排放的影响

**關鍵詞**
数字化
数字经济与社会指数
温室气体排放
欧洲绿色协议
经验分析

**摘要**
数字化和气候中和是欧盟成员国的发展重点。这引起了对描述这些过程的广泛科学和实践兴，包括它们的相互影响。在这种情况下，数字化是一个因素，而气候中和（主要以温室气体排放为特征）就是答案。因此，本研究的目的是以欧盟成员国为例，评估数字化对温室气体排放的影响。所得结果的科学新颖性在于假设的提出，其证明将使我们能够使用经济和数学工具估计数字化过程对欧盟成员国人均温室气体排放量的影响程度。数字化对温室气体排放水平的直接影响不能被认为具有显着性和统计学意义，这是有道理的。尚未确定数字化对延迟 1 至 4 年减少温室气体排放过程的影响。考虑到温室气体排放与数字化水平之间的相关回归依赖性较低，可以假设（1）其他因素具有显着影响（列表），或（2）观测范围仅被“捕获”由库兹涅茨曲线的一部分，它对应于下降部分抛物线。因此，所进行的分析表明，有充分的理由相信数字化不是减少温室气体排放的主要（主导）因素。这需要进一步研究，在模型中包含广泛的变量（与监管政策、税收政策、投资政策、消费文化有关）。