Journal of Engineering Faculty

The Effect of the Coronavirus Pandemic on the Human Development Index of EU Countries: An Analysis Using Machine Learning Methods

Yusuf Kahreman[1,a],*, Abdulkadir Şeker[2,b]

[1] The Department of Banking and Finance, Zara Veysel Dursun School of Applied Sciences, Sivas Cumhuriyet University, Sivas, Türkiye
[2] The Department of Computer Engineering, Faculty of Engineering, Sivas Cumhuriyet University, Sivas, Türkiye
*Corresponding author

Research Article

ABSTRACT

The Human Development Index (HDI) is a pivotal indicator in gauging the extent of development and living standards across countries. However, the global pandemic of the Coronavirus disease 2019 (Covid-19) is believed to exert a deleterious influence on these indices. It is therefore important to understand the effects of the pandemic on HDI and how HDI would be shaped in a scenario without the pandemic. In this context, the HDI data for the years 1995-2019 were subjected to linear regression analysis, and the HDI values for 2020, 2021 and 2022, when the effects of the pandemic were observed, were estimated. Furthermore, the original HDI indicators were compared for these years. The study demonstrates that in the absence of the pandemic, the HDI values of the countries would continue the upward trajectory observed in previous years. Furthermore, despite the initial negative effects, the Netherlands and Portugal have reached the simulated HDI values by 2022, indicating that they have been able to overcome the significant slowdown or decline in HDI caused by the pandemic. The original HDI values of Austria, Croatia, Cyprus, Denmark, Finland, France, Greece, Ireland, Italy, Spain, Sweden and Sweden were only approximated by the simulated HDI values by 2022. In other EU countries, it is observed that the effects of the pandemic on HDI are long-lasting. In the analysis, Sweden is a notable exception.

Keywords: HDI, COVID-19, Linear Regression, Forecasting.

COVID-19 Pandemisinin AB Ülkelerinin İnsani Gelişmişlik Endeksi Üzerindeki Etkisi: Makine Öğrenmesi Yöntemleriyle İnceleme

ÖZ

İnsani Gelişmişlik Endeksi (HDI), ülkelerin gelişim düzeyini ve yaşam standartlarını belirlemede kritik bir gösterge iken COVID-19'un ülkelerin bu göstergelerini olumsuz etkilediği düşünülmektedir. Bu nedenle, pandeminin HDI üzerindeki etkilerini ve pandeminin olmadığı bir senaryoda HDI'nin nasıl şekilleneceğini anlamak önemlidir. Bu bağlamda, 1995-2019 yıllarına ait HDI verileri doğrusal regresyon yöntemiyle analiz edilerek pandeminin etkilerinin görüldüğü 2020, 2021 ve 2022 yıllarındaki HDI değerleri tahmin edilmiş, ayrıca orijinal HDI göstergeleri bu yıllar için karşılaştırılmıştır. Çalışmada, pandeminin yaşanmadığı bir senaryoda ülkelerin HDI değerlerinin önceki yıllardaki artış eğilimini sürdüreceğini ortaya koymaktadır. Buna ek olarak, COVID-19'un HDI üzerinde belirgin bir yavaşlama veya düşüşe yol açtığı anlaşılmakla birlikte, Hollanda ve Portekiz'in başlangıçtaki olumsuz etkilenmelere rağmen 2022 itibarıyla simüle edilen HDI değerlerine ulaştıkları görülmüştür. Avusturya, Hırvatistan, Kıbrıs, Danimarka, Finlandiya, Fransa, Yunanistan, İrlanda, İtalya, İspanya ve İsveç'in orijinal HDI değerlerinin simüle edilmiş HDI değerlerine ancak 2022 yılı itibariyle yaklaştıkları gözlemlenmiştir. Diğer AB ülkelerinde ise COVID-19'un HDI üzerinde kalıcı bir etkisinin olduğu görülmektedir. Analizde, İsveç için ise özel bir durum söz konusudur. Çalışma, pandeminin insani gelişmişliğe sürdürülebilirlik açısından oluşturduğu tehditlerin anlaşılmasına katkı sağlayarak literatüre önemli bir bakış açısı sunmaktadır.

Anahtar Kelimeler: İnsani Gelişmişlik Endeksi (HDI), COVID-19, Doğrusal Regresyon, Tahminleme.

[a] ✉ ykahreman@cumhuriyet.edu.tr   ⬡ ORCID 0000-0001-5968-5081   [b] ✉ aseker@cumhuriyet.edu.tr   ⬡ ORCID 0000-0002-4552-2676

Introduction

The Human Development Index (HDI) occupies a significant position within the field of international development studies, serving as a comprehensive indicator that assesses and evaluates the development levels and living standards of countries in accordance with objective criteria. Developed and updated on an annual basis by the United Nations Development Programme (UNDP), the HDI is calculated based on three principal dimensions: education level, life expectancy and per capita income level [1]. These components facilitate a comprehensive evaluation of human development that extends beyond mere economic indicators, offering a holistic assessment of a country's social and economic structure [2]. The HDI provides a comprehensive measure of a country's welfare level and quality of life, extending beyond mere economic growth to encompass social factors such as education and health.

As a consequence of this structure, the HDI is employed as a significant data source for the comparison of the welfare level of numerous countries and the formulation of long-term development policies [3], [4], [5]. The annual updating of this index enables the monitoring of development trends in countries and the observation of the effects of social policies. However, the change in HDI over time may be affected by sudden developments on a global scale. For example, unexpected global events, such as the COVID-19 pandemic, can have short- and long-term impacts on human development [6].

In this context, when we consider HDI values as a time series data set, machine learning methods can be employed to predict future values of the index [7]. In the context of time series analysis, techniques such as linear regression are frequently employed to predict future trends based on past data. In the case of a multicomponent indicator such as HDI, these methods facilitate the modelling of the effects of the pandemic and the simulation of potential future changes through the analysis of data from each year. Consequently, a model developed based on past data will be capable of examining how HDI might trend in a scenario where there is no pandemic [8]. It follows that a model developed on the basis of past data will be capable of examining the potential trajectory of HDI in the absence of a pandemic.

In formulating a future trajectory for HDI, it is crucial for policymakers to comprehend the underlying natural progression, distinct from the exceptional influences precipitated by pandemic circumstances. It is anticipated that the effects of the pandemic will be observed not only in the field of health but also in the fundamental components of HDI, including education and economic welfare. The implementation of budgetary constraints in the field of education, the weakening of health systems and the occurrence of income losses during the pandemic may result in a deceleration or even a decline in HDI. Modelling the trajectory of HDI values in the absence of the pandemic will facilitate the formulation of effective inferences regarding long-term development goals at the country level. In order to gain a deeper understanding of the impact of the COVID-19 pandemic on human development, it is essential to construct a model that depicts the trajectory of the HDI in the absence of the pandemic. The objective of this simulation is to provide long-term projections on the human development process of countries by enabling an examination of the natural trends of HDI independent of deviations induced by the pandemic. In accordance with the aforementioned objective, the present study seeks to forecast the manner in which the HDI values will be constituted in 2020, 2021 and 2022 in a scenario devoid of the pandemic. To this end, a simulation has been conducted based on the historical trends of HDI values, with the effects of the COVID-19 pandemic being disregarded.

In this study, the HDI data for the period 1995-2019 were modelled using the linear regression method, and HDI forecasts were made for the period 2020-2022 under the assumption that there is no pandemic. The time series models, created for each country separately, facilitate comprehension of the direct impact of the pandemic on HDI and provide a comprehensive analysis of the effects of the pandemic on socioeconomic sustainability. Consequently, this study is regarded as a valuable contribution to the literature, offering crucial insights for the formulation of sustainability strategies through the examination of economic and social indicators of HDI divergence among countries.

Literature Review

A review of the literature reveals a multitude of studies investigating the impact of the ongoing pandemic on social and economic indicators. Palamim et al. conducted an analysis examining the relationship between case fatality rates associated with the novel coronavirus in Brazil and a range of socioeconomic indicators, including the HDI. Their findings indicate that mortality rates are higher in regions with lower HDI [9]. A further study demonstrates that the incidence of cases and deaths resulting from the novel COVID-19 infection, along with the number of tests conducted, is higher in countries with a high HDI. However, there is a negative correlation between HDI and both the case fatality rate (CFR) and the recovery rate. This indicates that more advanced reporting and monitoring systems may also be effective in countries with a high HDI [6].

In his study, Sareminia concluded that the level of education has a greater impact on mortality rates associated with the COVID-19 than environmental and health factors. He also found that knowledgeable societies are more successful in crisis management [10]. In this paper, the level of social development plays a critical role in reducing the impact of crises. The findings of this study indicate that the incidence and mortality of the COVID-19 in southeastern Brazil is influenced to a limited extent by factors such as population size, gross domestic product (GDP), and HDI. However, higher mortality rates have been observed, particularly in cities with high population density, medium GDP, and high HDI [11]. Another study

indicates that the number of confirmed cases of the COVID-19 is higher in countries with a high Human Development Index (HDI) compared to countries with a low HDI. This is attributed to the greater capacity of countries with a high HDI to conduct more tests. The study suggests that this finding can inform international cooperation in the fight against the pandemic and the development of prevention methods [12].

Artificial intelligence and machine learning methods are employed to analyse HDI and other socioeconomic indicators in real time, with the objective of predicting future trends. In their study, Kavuran et al. investigate the impact of the pandemic on HDI using AI techniques such as Deep Convolutional Neural Network (DCNN) and Support Vector Machine (SVM). They demonstrate that these methods can accurately identify the relationship between HDI and pandemic-related variables [13]. A further study demonstrates that the utilisation of machine learning techniques to investigate the correlation between economic advancement and human capital enhances the precision of Support Vector Machines (SVM) and Gaussian Process Regression (GPR) models, particularly those optimised by the Bayesian method. The BT-GPR model exhibits the most accurate predictive capacity [14]. A further study examined the efficacy of quality of life (QoL) prediction systems utilising data from the World Happiness Index, employing machine learning algorithms. The findings revealed that Lasso Regression, Multiple Linear Regression and Long Short-Term Memory (LSTM) algorithms exhibited the highest accuracy for the 2021 QoL indicator [15].

Despite the existence of numerous studies examining the relationship between HDI and the ongoing pandemic, no research has yet explored how the HDI values of countries might evolve in the absence of a pandemic. In light of this gap in the literature, this study was designed to address this gap and contribute new insights to the field.

Materials and Methods

In this section, within the scope of the purpose of the study, firstly, how HDI real data is calculated will be explained and then the application steps of the study will be explained.

The Official HDI Calculation method (UNDP)

The Human Development Index (HDI) is calculated by a formula that includes three basic components: Life Expectancy Index, Education Index and Income Index. HDI is calculated by taking the geometric mean of these three components. The HDI formula is as follows level [1];

Step 1: Calculation Of Life Expectancy Index

The life expectancy index is calculated by normalizing a country's life expectancy by the minimum (20 years) and maximum (85 years) life expectancy set by UNDP. This calculation is performed by the following Equation (1).

$$Life\ Expectancy\ Index = \frac{(Life\ Expectancy - 20)}{(85 - 20)}$$

Step 2: Calculation Of Education Index

The education index is a combination of two sub-indices: expected years of education and average years of education. The expected years of education index is calculated as in Equation (2), assuming a UNDP maximum expected years of education of 18 years. The average years of education index is calculated as in Equation (3), assuming a maximum average years of education of 15 years. As can be seen in Equation (4), the education index is obtained by taking the arithmetic average of these two sub-indices. Expected years of schooling and Mean years of schooling.

$$Expected\ years\ of\ schooling = \frac{Years\ of\ schooling}{18} \quad (2)$$

$$Mean\ years\ of\ schooling = \frac{Years\ of\ schooling}{15} \quad (3)$$

$$Education\ Index = \\ \frac{Expected\ years\ of\ schooling + Mean\ years\ of\ schooling}{2} \quad (4)$$

Step 3: Calculation Of Income Index

The income index is calculated with the help of Equation (5) using the Gross National Income (GNI) per capita data. The income index is normalised between the minimum ($100) and maximum ($75,000) income values determined by UNDP.

$$Income\ index = \frac{\log(per\ capita\ GNI) - \log 100}{\log(75000) - \log(100)} \quad (5)$$

Step 4: Calculation Of Human Development Index

Finally, the life expectancy, education and income indices calculated above are combined by taking the geometric mean. The HDI is calculated by taking the cube root of the product of these three indices.

$$HDI = \sqrt[3]{\begin{array}{c} Life\ Expectancy\ Index \times \\ Education\ Index \times \\ Income\ Index \end{array}} \quad (6)$$

The Dataset

Within the scope of the study, the performances of countries in various indicators (e.g. education, life expectancy) by years were obtained from UNDP reports. EU countries were filtered from this report and the data containing the indicators to be used for the calculation of HDI components (Expected Years of Schooling (years), Gross National Income Per Capita (2017 PPP$), Life Expectancy at Birth (years), Mean Years of Schooling (years) were selected.

The Forecasting Model

Linear regression is a basic statistical method used to model the linear relationship between a dependent variable and one or more independent variables, and is often preferred to predict future values based on past data. In this study, the life expectancy index, the education index and the income index, which make up the HDI value, were estimated with 3 different models. The model was trained with data from 1995-2019 and the years 2020-2022 were estimated. The parameters of the linear regression model are as follows;

- fit_intercept (default=True) ;The model is estimated in the form y = mx + b (b is the value of the intercept).
- normalise (default=False) ;The independent variables are not normalised.
- copy_X (default=True) ;Guarantees that the original data will not be changed.

- n_jobs (default=None) ;The number of processors to use in the calculation is set to 1.

Results

In this section, the findings obtained within the scope of the research are examined in detail and the results of the analyses are presented in a systematic manner.
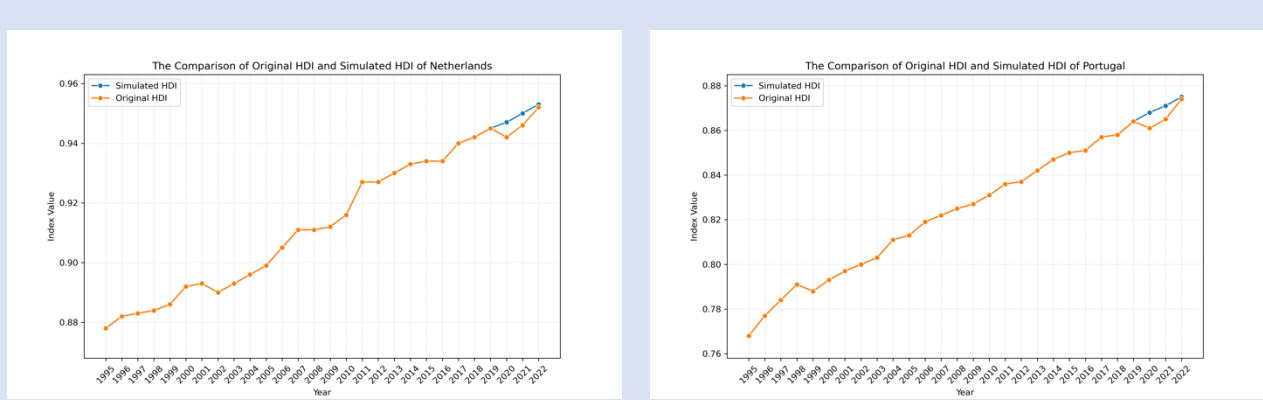
Figure 1. The HDI Graphics of Netherlands (a) and Portugal (b)

In the Netherlands and Portugal, although there was a significant decline HDI values at the beginning of the COVID-19 pandemic, it was found that the simulated HDI levels of the no-pandemic scenario were reached by 2022. Analyzing Fig 1, it can be seen that both countries experienced a decline in their initial HDI values during the transition period from 2019 to 2020, but immediately after this decline they showed a more pronounced upward trend.
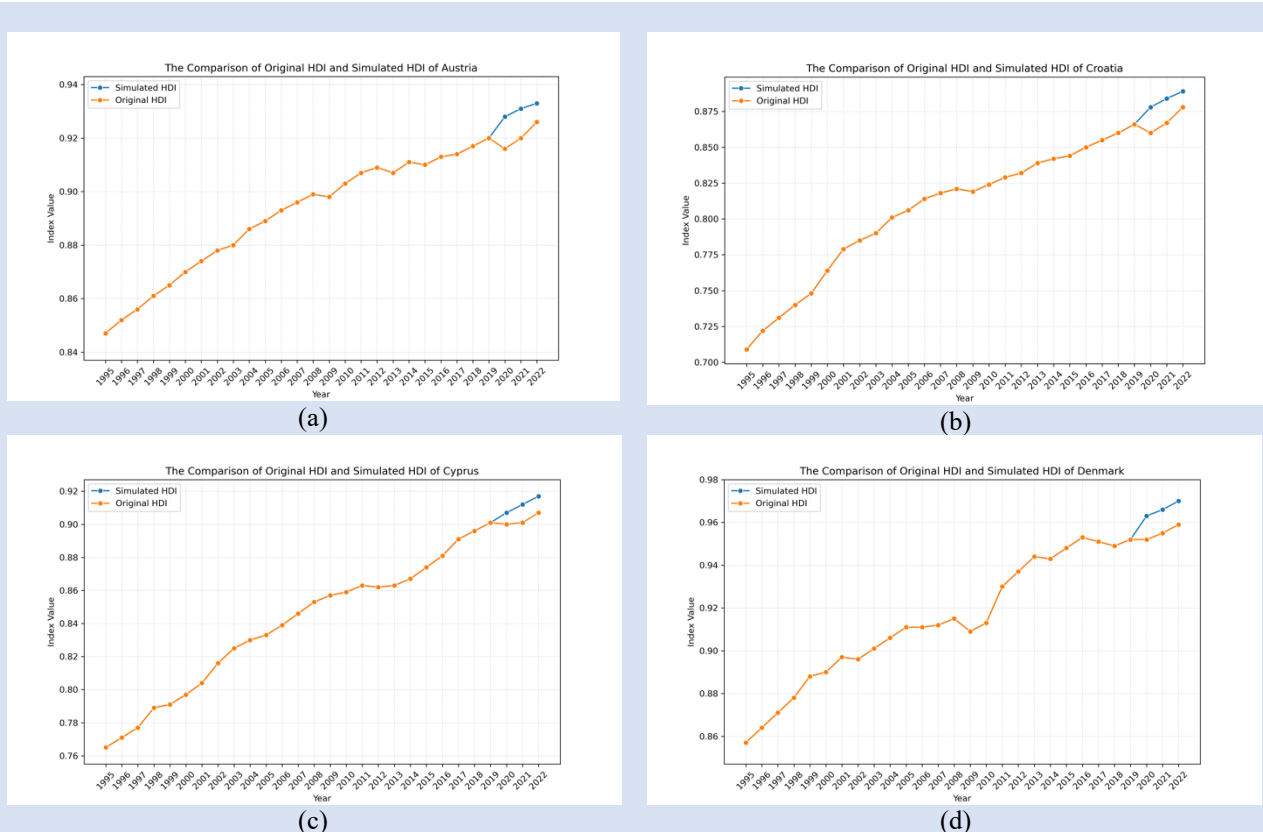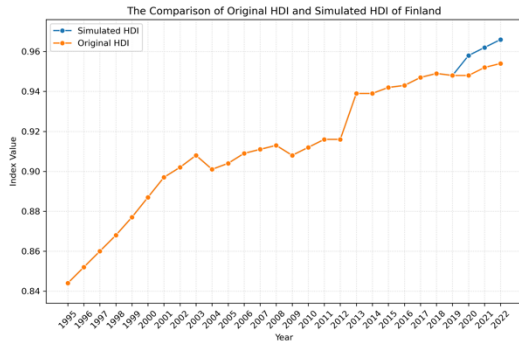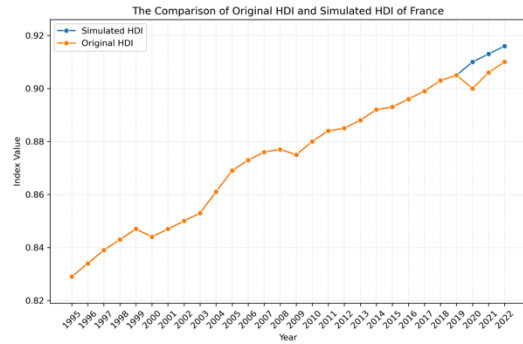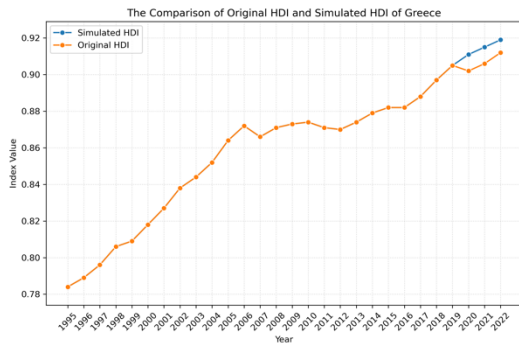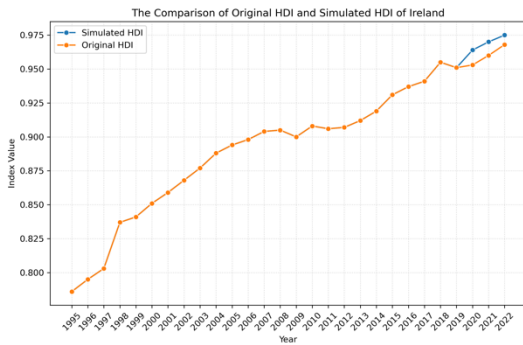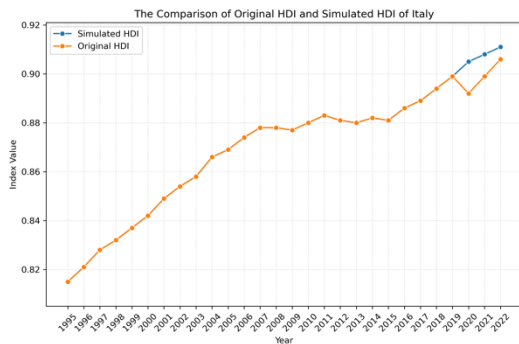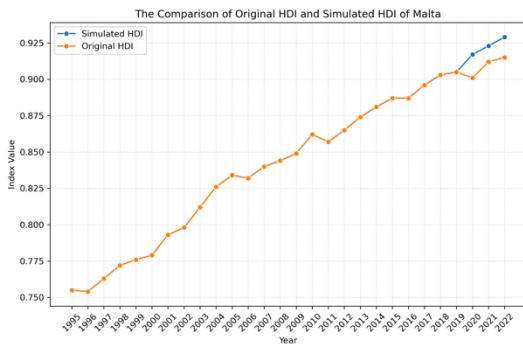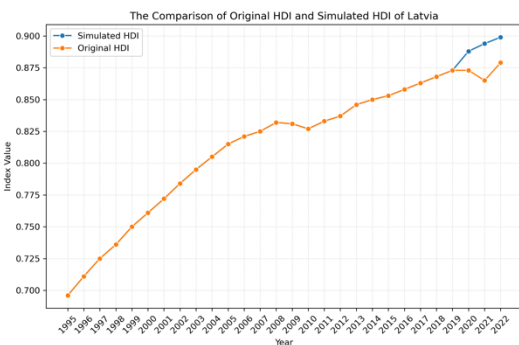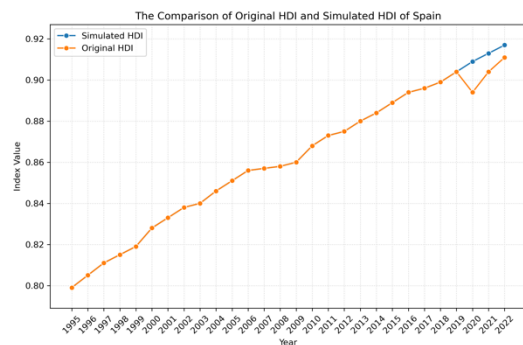
Figure 2. The HDI Graphics of Austria, Croatia, Cyprus, Denmark, Finland, France, Greece, Ireland, Italy, Malta, Latvia, Italy, Malta, Latvia and Spain.

The HDI values of Austria, Croatia, Cyprus, Denmark, Finland, France, Greece, Ireland, Italy, Malta, Latvia, Italy, Malta, Latvia and Spain were significantly closer to the simulated levels by 2022, indicating that the effects of the pandemic have lasted to a limited extent. Analysis of Fig 2 reveals that in most o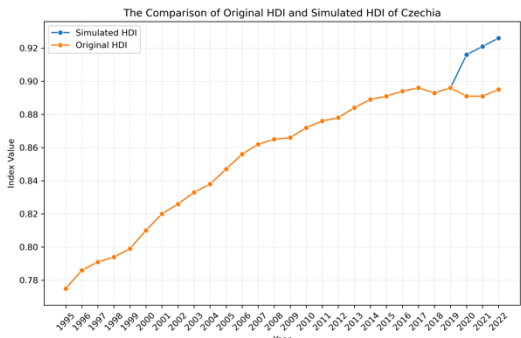f these countries, the COVID-19 pandemic caused a direct decline in HDI, followed by a clear upward trend in the original HDI values. Cyprus and Ireland, in particular, were able to reach simulated HDI levels more quickly, as the effects of the pandemic on the original HDI were more limited.
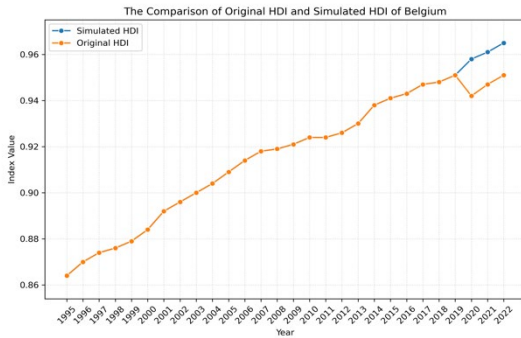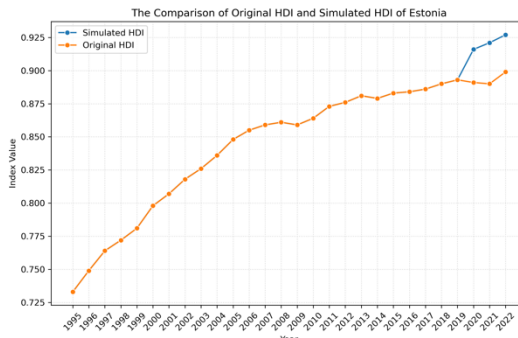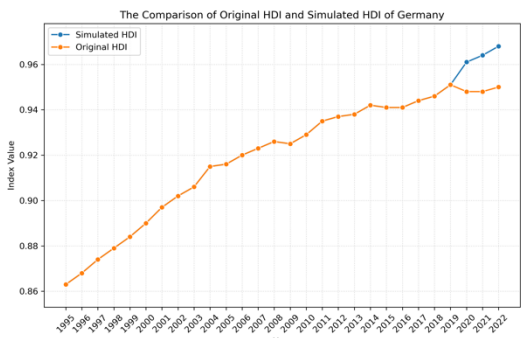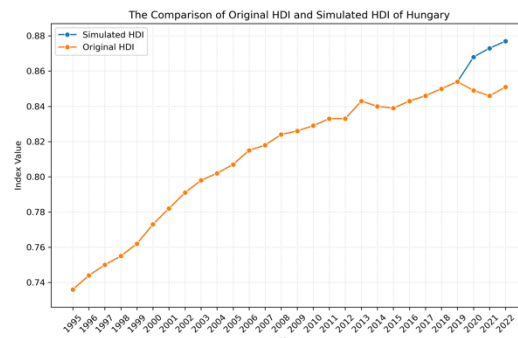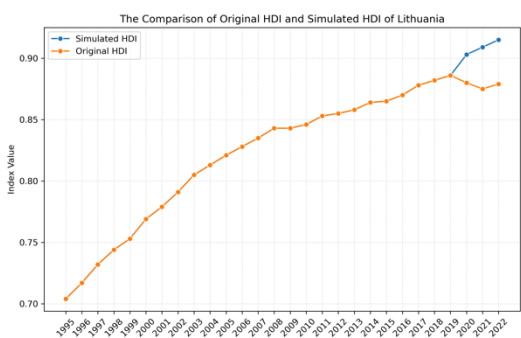
(a)
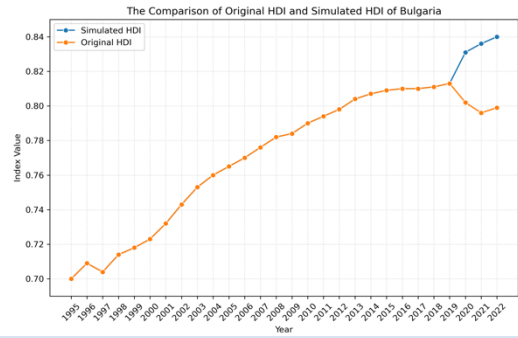
(b)

(c)

(d)

(e)

(f)

(g)
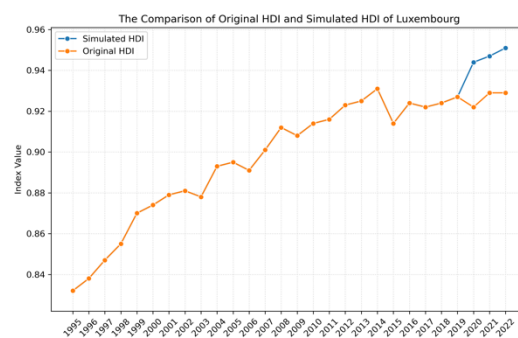
(h)

(i)

(i)

(j)

(k)

Figure 3. The HDI Graphics of Belgium, Bulgaria, Czech Republic, Estonia, Germany, Hungary, Lithuania, Luxembourg, Romania, Slovakia, Slovenia and Poland

In Belgium, Bulgaria, the Czech Republic, Estonia, Germany, Hungary, Lithuania, Luxembourg, Romania, Slovakia, Slovenia, Luxembourg, Romania, Slovakia, Slovenia and Poland, the negative impact of the pandemic has had a more lasting impact on HDI and the r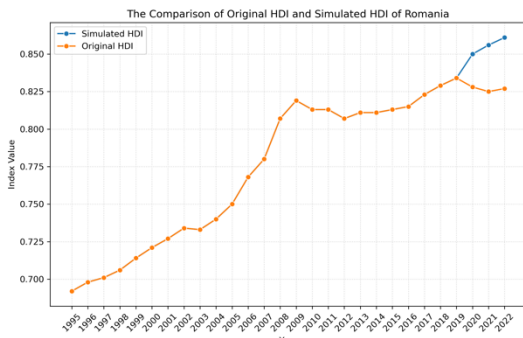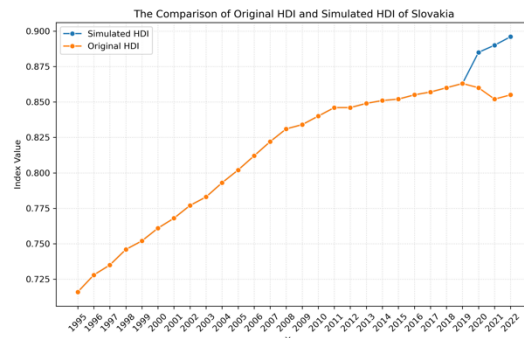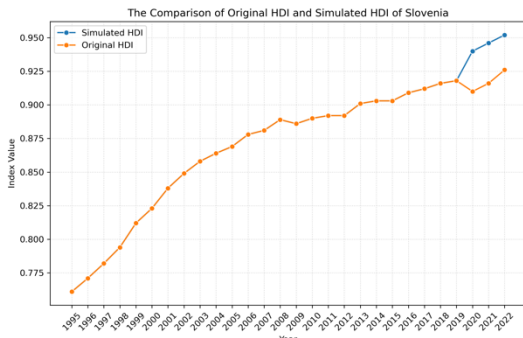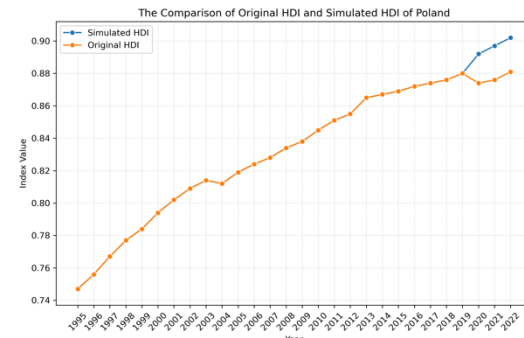ecovery process has not yet gained sufficient momentum. These countries have not fully recovered from the decline in HDI at the beginning of the pandemic and have difficulties in reaching the simulated HDI levels.
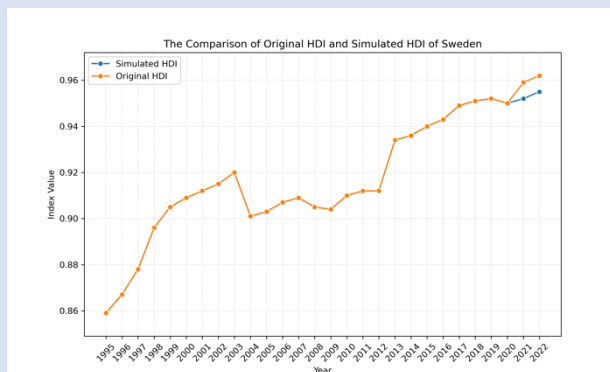
Figure 4. The HDI Graphic of Sweden.

When the effects of the COVID-19 pandemic on the HDI for Sweden are analyzed, it is found that the pandemic has produced some positive results. After the pandemic year, it was observed that the original HDI showed an above-normal increase, which is thought to have caused the simulated HDI to remain below the original HDI.

Conclusion

The Netherlands and Portugal experienced a significant drop in Human Development Index (HDI) values at the onset of the COVID-19 pandemic, but both countries have shown a strong recovery, returning to the HDI levels estimated in a no-pandemic scenario by 2022. This recovery is largely attributed to both countries' rapid

and effective government interventions, health policies, high immunization rates and financial assistance from the European Union. The Netherlands' strong health infrastructure and economic diversification, and Portugal's recovery trends that quickly overcame the economic downturn, are projected to have enabled a rapid improvement in human development indicators in both countries. The reasons behind this recovery are predicted to be that successful management strategies in health and economic policies will allow the HDI to show sustainable growth in the long run, regardless of the pandemic.

In countries such as Austria, Croatia, Cyprus, Denmark, Finland, France, Greece, Ireland, Italy, Malta, Latvia, Italy, Malta, Latvia and Spain, the fact that the negative impacts of COVID-19 only approached the simulated HDI values by 2022 suggests that the recovery trend observed in these countries may be a result of the long-lasting effects of the pandemic in education, health and economic areas. The pandemic's economic contractions, disruptions in health systems and disruptions in the education sector may have had longer-lasting negative effects on certain components of the HDI (especially health and education) in these countries. In addition, although the financial and health assistance received in EU member states has led to a limited recovery in some countries, factors such as economic vulnerabilities, long-term labor force loss and unemployment, and disruptions in education, especially in low-income countries, may have prevented the HDI from fully recovering. In addition, post-pandemic social and economic recovery processes may have been faster in countries with stronger health and education infrastructure, whereas in countries with less developed economies, this recovery process may have taken longer, leading to lower HDI values than in the no-pandemic scenario. While these countries have experienced a reacceleration of economic growth, improved labor markets, and restructuring in the education sector, it suggests that more time will be needed for the negative post-pandemic effects of the HDI to fully dissipate.

During the pandemic, EU countries such as Belgium, Bulgaria, Czech Republic, Estonia, Germany, Hungary, Lithuania, Luxembourg, Romania, Slovakia, Slovenia, Luxembourg, Lithuania, Luxembourg, Romania, Slovakia, Slovenia and Poland have experienced lasting negative impacts on HDI. These countries have faced a range of problems, including capacity limitations of their health systems, disruptions in education and labor force losses. Germany, despite having a strong health system, has been slower to recover due to high morbidity and mortality rates during the pandemic. Similarly, high mortality rates and labor force losses in countries such as Belgium and Luxembourg led to lower HDI values compared to the no-pandemic scenario. In Central and Eastern European countries such as Poland, the Czech Republic, Slovakia and Hungary, pressures on health care and major disruptions in education led to persistent negative changes in the HDI. In lower-income EU countries, such as Romania and Bulgaria, the pandemic had deeper and longer-lasting

effects due to inadequacies in health and education systems. In these countries, economic difficulties and infrastructure deficiencies during the pandemic led to a decline in HDI values and the recovery process was limited. The Baltic countries of Estonia and Lithuania have similarly failed to show a significant improvement in HDI values due to deficiencies in health and education. These countries felt the negative effects of the pandemic for a long time, as they were economically weaker and tried to recover after the pandemic with limited resources.

In the analysis, there is a special case for Sweden. When the effects of COVID-19 on the Human Development Index (HDI) are analyzed, it is observed that the pandemic has led to certain positive outcomes. In particular, Sweden, which has a highly developed healthcare system and education infrastructure, has increased social welfare by digitizing and strengthening these structures during the pandemic, resulting in a positive impact on HDI values. Strengthening the healthcare system and accelerating the digital transformation in the education sector led to improvements in HDI, regardless of the pandemic-specific negative effects of COVID-19. However, in a scenario without the pandemic, these improvements could have been expected to occur over a longer timeframe and at a slower pace. Moreover, economic growth and social welfare gains, which gained momentum with the impact of COVID-19, would have been more limited without the pandemic. In this context, while Sweden's HDI values are likely to have fallen to lower levels compared to the projected estimates in a non-pandemic situation, the impact of COVID-19 contributed to the country's higher HDI values.

Acknowledgements

References

[1]   UNDP, "Human Development Report 2023-24," 2024.

[2]   C. V. Joana Carolina, R. G. Gabriela, and M. C. Ismael, "Effect of the economic, social and technological factors on sustainable entrepreneurship over time," *J Bus Res*, vol. 173, p. 114457, Feb. 2024, doi: 10.1016/J.JBUSRES.2023.114457.

[3]   A. Goswami, H. Roy, and P. Giri, "Does HDIs level sustainable during 1999/2018 across cross-nations? An application of bootstrap quantile regression approach," *Sustainable Operations and Computers*, vol. 2, pp. 127–138, Jan. 2021, doi: 10.1016/J.SUSOC.2021.06.001.

[4]   C. A. Mbouteu Megaptche, S. Waita, H. Kim, P. M. Musau, and B. Odhiambo Aduda, "Multi-dimensional analysis in optimal sizing of hybrid renewable energy systems for green energy growth in Garoua, Cameroon: From techno-economic and social models to policies," *Energy Convers Manag*, vol. 315, p. 118804, Sep. 2024, doi: 10.1016/J.ENCONMAN.2024.118804.

[5]   K. Tong, "Urbanization moderates the transitional linkages between energy resource use, greenhouse gas emissions, socio-economic and human development: Insights from subnational analyses in China," *J Clean*

Prod, vol. 476, p. 143776, Oct. 2024, doi: 10.1016/J.JCLEPRO.2024.143776.

[6] A. Mirahmadizadeh *et al.*, "Correlation between human development index and its components with COVID-19 indices: a global level ecologic study," *BMC Public Health*, vol. 22, no. 1, pp. 1–8, Dec. 2022, doi: 10.1186/S12889-022-13698-5/FIGURES/1.

[7] R. P. Masini, M. C. Medeiros, and E. F. Mendes, "Machine learning advances for time series forecasting," *J Econ Surv*, vol. 37, no. 1, pp. 76–111, Feb. 2023, doi: 10.1111/JOES.12429.

[8] F. B. Khan and A. Noor, "Prediction and Classification of Human Development Index Using Machine Learning Techniques," in *2021 5th International Conference on Electrical Information and Communication Technology, EICT 2021*, Institute of Electrical and Electronics Engineers Inc., 2021. doi: 10.1109/EICT54103.2021.9733645.

[9] C. V. C. Palamim, M. N. Boschiero, F. E. Valencise, and F. A. L. Marson, "Human Development Index Is Associated with COVID-19 Case Fatality Rate in Brazil: An Ecological Study," *Int J Environ Res Public Health*, vol. 19, no. 9, p. 5306, May 2022, doi: 10.3390/IJERPH19095306/S1.

[10] S. Sareminia, "Upgrading the Human Development Index (HDI) to control pandemic mortality rates: A data mining approach to COVID-19," *Journal of AI and Data Mining*, vol. 10, no. 3, pp. 345–360, Jul. 2022, doi: 10.22044/JADM.2022.11503.2307.

[11] M. F. Groppo, F. C. Groppo, S. R. Figueroba, and A. C. Pereira, "Influence of Population Size, the Human Development Index and the Gross Domestic Product on Mortality by COVID-19 in the Southeast Region of Brazil," *Int J Environ Res Public Health*, vol. 19, no. 21, p. 14459, Nov. 2022, doi: 10.3390/IJERPH192114459/S1.

[12] M. H. Heo, Y. D. Kwon, J. Cheon, K. B. Kim, and J. W. Noh, "Association between the Human Development Index and Confirmed COVID-19 Cases by Country," *Healthcare 2022, Vol. 10, Page 1417*, vol. 10, no. 8, p. 1417, Jul. 2022, doi: 10.3390/HEALTHCARE10081417.

[13] G. Kavuran, Ş. Gökhan, and C. Yeroğlu, "COVID-19 and human development: An approach for classification of HDI with deep CNN," *Biomed Signal Process Control*, vol. 81, p. 104499, Mar. 2023, doi: 10.1016/J.BSPC.2022.104499.

[14] E. Ozden and D. Guleryuz, "Optimized Machine Learning Algorithms for Investigating the Relationship Between Economic Development and Human Capital," *Comput Econ*, vol. 60, no. 1, pp. 347–373, Jun. 2022, doi: 10.1007/S10614-021-10194-7/FIGURES/4.

[15] A. Jannani, N. Sael, and F. Benabbou, "Predicting Quality of Life using Machine Learning: case of World Happiness Index," *2021 4th International Symposium on Advanced Electrical and Communication Technologies, ISAECT 2021*, 2021, doi: 10.1109/ISAECT53699.2021.9668429.