The Pandemic's Effects: Trade, Digitalization and Energy Transitions

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Abstract. *The COVID-19 pandemic has greatly impacted the world changes in economy, trade, energy consumption, digital technologies and market behavior. This paper will analyze 10 indicators of 41 European countries from 2015 to 2023 trying to determine their influence by the pandemic. Previous studies dealt with these issues separately; however, this paper takes an integrative approach relating to several indicators. The study uses exploratory data analysis, principal component analysis and cluster analysis. Results show that under this crisis, the integration of digitalization with more thrust to ICT has been further accelerated. The sustainability transformation has also led to even greater inequalities across countries. This paper contributes to existing literature by taking a longer period, employing different variables, and offering comparative perspectives on European economies pre-pandemic, during the pandemic, and post-pandemic.*

Keywords: COVID-19 pandemic, principal component analysis, cluster analysis, trade disruptions, digitalization.

Introduction

The crisis impacted several economic sectors, particularly international trade, energy use, and the environment.

The main steps that were taken comprised closing borders, restriction of movement, and a travel ban. These variations have ultimately resulted in huge declines in output and transformations in the patterns of trade and energy (Hayakawa & Mukunoki, 2021).

During the lockdown, of course, both greenhouse gases and energy consumption took a great fall. The leading sectors were transport and industrial. Besides a more than 50% reduction in aviation fuel consumption, European regions reported NO_2 emissions quite drastically (Patino-Artaza et al., 2024). As brief as it was, the pandemic laid bare the weaknesses of the world energy system and brought into sharp focus the urgent need for long-term sustainable transformations (Aktar et al., 2021).

This aided the quick turn to using digital tools in other areas by letting people work from home and sell online. It also offered help Companies in Europe that moved quickly to use the tech

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showed more ability. However, the digital gap between all wealthy and poor countries has become bigger (Dyba & Di Maria, 2024).

Others set economic and technological trade-offs on how COVID-19 impacted global trade, energy consumption, and greenhouse gas emissions (Lahcen et al., 2020).

This paper tries to evaluate economic, digital, and ecological transformations in 41 European countries from 2015 until 2023 with close attention to how extreme fluctuations in trade, rapid virtualization, energy use, and changes in working conditions post-COVID-19 shock really impact these states. Ten indicators from different fields can give a comprehensive and wider picture that is relevant. This paper takes a very long-term view of the evolution of this period that can be split into three parts: pre-pandemic, during-pandemic, and post-pandemic. Thus, Europe was looked at on a country basis, plus Romania separately.

Literature review

The impact of the pandemic on international trade

Trade was largely affected by the pandemic. In 2020, during the first half of the year, both exports and imports decreased (Hayakawa & Mukunoki, 2021).

Countries with strong economic and digital infrastructures cushioned their losses largely through digital trade and diversification in their supply chains (Mena et al., 2022).

This led to a very steep drop in trade, and Romania was able to maintain its trade relations quite stable due to the better imports of medical products (Tudorache & Nicolescu, 2023).

The pandemic pushed the need for new business models and strategies on supply chain diversification and digital trade that can support economic recovery (Saif et al., 2021).

Similarly, the pandemic has revealed that logistics mainly stabilize trade. For example, a 1% rise in the efficiency of logistics may lead to a 9.7% increase in international trade (Rehman Khan et al., 2022).

Energy consumption and environmental impacts of the pandemic

Lockdowns caused a huge fall in energy use since one of the sectors is transport. It fell by 23.6% in Italy and 15.4% in Spain, and energy prices were demand-driven (Strielkowski et al., 2021).

In 2020, total emissions for Europe dropped by 17%, the aviation sector took a 63% nosedive, and road transport went down by 26%. It showed how vulnerable the Energy Transport Sector is (Rodríguez-Sánchez et al., 2022). However, these cuts were short-lived; as soon as the limits were relaxed, emissions started rising again (Ray et al., 2022).

Results led to a claim that the pandemic has a direct influence on economic cycles; therefore, it was realized that energy consumption, hence demand for energy, is the main indicator of economic crises (Kufel et al., 2022).

It occurred when lockdowns temporarily cleaned the air over big cities in Europe. For more than one year, NO_2 emissions fell by 20-30% in metro areas, which clearly showed how fast human actions are impacting nature (Muhammad et al., 2020).

Digitalization and changes in the job market sped up

This resulted in fundamental shifts in operations and accelerated digital transformation. Many companies have adopted virtual HR and AI tools for the recruitment and management of employees (Boiko et al., 2024).

For Romania, it was essential to continue working on the digital transformation of the construction sector because those companies that embraced technologies such as BIM and Cloud Computing were able to minimize their losses during the shutdown (Leontie et al., 2022).

Dutch firms adopted digital tools more quickly than Romanian firms, reflecting their better DESI score in going digital (Thierry et al., 2021). Challenges in going digital were evident in both Romania and the Netherlands; the latter adapted much better. The major areas were customer interaction, business process change, and company internal workings. But still, the country's infrastructure and past states of the digital economy affect results and how strong business setups are.

The pandemic has once more overtaken the reorganization of logistics along with the rapid development of supply chains, automation, IoT, and blockchain. Technologies have made transport easier and secure (Zondervan et al., 2022).

A large number of Romanian universities went almost at breakneck speed into adopting digital platforms for education. They faced many challenges because they did not have enough money and also had inadequate infrastructure (Hudrea et al., 2023).

The policies on economic recovery and sustainability

To have the economy rebound in the long run, some long-term policies had to be adopted that would enable the economy to regenerate after the pandemic's effects. Among them is support for renewable energy and energy efficiency (Lahcen et al., 2020).

This led to investment in sustainable infrastructure and emission constraints, which are important not only for the economy but also for future environmental issues (He & Zhang, 2022).

Other studies have indicated the role of energy consumption in economic cycles and sustainable development policies of Europe and Romania (Soava & Mehedintu, 2023).

Methodology

The research questions were discovered and intuited at that moment.

The research questions were discovered and intuited at that moment. They were: (1) what indicators have been principal in Europe? (2) What would the role of the COVID-19 pandemic be in accelerating or changing these transformations? (3) How have the European economies evolved, and what has weighed on their resilience or volatility? Finally, we identified and reviewed data availability and all preparatory work regarding the topic. The interest evoked by the theme made it necessary to cite some of them in the corpus of literature. In the next step would come the methodology’s setting and the techniques that may be a requisite for adequately answering the research questions. Finally, an examination of results and evaluation were conducted to create study conclusions, yet discussions of future research could be undertaken.

Descriptive statistics shall be used for the selected variables under study. The mean comparison shall be made among three periods: pre-pandemic, pandemic, and post-pandemic. The data will be analyzed using techniques such as principal component analysis and cluster analysis. The procedure started with collecting, checking, cleaning, and transforming the database into a suitable format.

Principal component analysis was used in this study to reduce the dimension of the data set by giving information about the few components that explain most of the variation in the data.

This paper sorts of European countries into clusters based on socio-economic indicators.

This paper is going to find out which countries are alike and how much they differ regarding economic growth, labor market, and digitalization.

We got the results in this work using both Microsoft Excel and R.

Results and discussions

Exploratory data analysis

The data for the analysis was collected from The World Bank Group, and it comprised the following set of indicators along with their measurement units: Population (total persons), trade balance (percentage points of GDP), primary energy (% of total final energy consumption), renewable energy (% of total final energy consumption), total greenhouse gas emissions (% change), mobile subscriptions (total subscriptions) individuals using the Internet (% of population) ICT trade balance (percentage points of total goods), GDP growth (annual %), employment to population ratio (total %). The table below gives these indicators and their codes.

Table 1. Variable code and variable name of indicators

Variable code	Variable name
X_1	Population
X_2	Trade Balance
X_3	Primary energy
X_4	Renewable energy
X_5	Total greenhouse gas emissions
X_6	Mobile
X_7	Internet
X_8	ICT Trade Balance
X_9	GDP
X_{10}	Employment-to-population

Source: Authors' own research.

Factors considered in the study are supply shocks, energy use, natural capital, and CO2 emissions in a pandemic context. When these two measures were looked at individually, there was a strong positive correlation, and some information overlapped. Due to this trade balance, export values were calculated as minus import values.

Analysis period 2015-2023 for 41 countries. The table below shows the complete list of these countries and their associated codes.

Table 2. Countries and codes

Country	Code
Albania	ALB
Austria	AUT
Belarus	BLR
Belgium	BEL
Bosnia and Herzegovina	BIH
Bulgaria	BGR
Croatia	HRV
Cyprus	CYP
Czechia	CZE
Denmark	DNK
Estonia	EST
Finland	FIN
France	FRA
Georgia	GEO
Germany	DEU
Greece	GRC

Country	Code
Hungary	HUN
Iceland	ISL
Ireland	IRL
Italy	ITA
Latvia	LVA
Lithuania	LTU
Luxembourg	LUX
Malta	MLT
Moldova	MDA
Montenegro	MNE
Netherlands	NLD
North Macedonia	MKD
Norway	NOR
Poland	POL
Portugal	PRT
Romania	ROU
Serbia	SRB
Slovakia	SVK
Slovenia	SVN
Spain	ESP
Sweden	SWE
Switzerland	CHE
Türkiye	TUR
Ukraine	UKR
United Kingdom	GBR

Source: Authors' own research.

Comparison of periods

Analysis was carried out by looking at each indicator individually to see whether statistical differences occurred across the three periods.

A t-test was run first to check for inter-group differences, and since it flagged some differences among groups for certain indicators, the next step was to ascertain whether the data followed a normal distribution (using the Shapiro-Wilk test). It appeared that at least one of the groups did not follow a normal distribution; therefore, the analysis proceeded with an appropriate test for when data does not follow the normal distribution- Kruskal-Wallis. This serves here as a non-parametric alternative to ANOVA for comparing medians across three or more groups. However, since this test does not pinpoint exactly between which groups differences exist, an appropriate post hoc test-Dunn test- was applied.

The table shows a very significant difference between internet use during the pandemic and pre-pandemic periods. The pandemic impacted strongly by causing increased internet use (working from home, online education, increased consumption of digital content, etc.). There is also a very significant statistical difference between post-pandemic and pre-pandemic periods. The pandemic is over, but the usage of the internet remains unchanged. Thus, it can be stated that, in general, new technologies and digitalization have been adopted in the long term. For the ICT trade balance, all three periods are statistically significant. ICT trade balance went up during the pandemic compared to the pre-pandemic period, probably due to the high demand for technology, software, telecommunication, and digital services. The post-pandemic ICT trade balance went down compared to the pandemic period, but not very strongly. The ICT trade balance is still much higher than before the pandemic, so it can be said that the ICT sector had a lasting effect from the pandemic crisis. The only statistically significant period for the employment/population ratio was post-pandemic to pre-pandemic. This ratio increased after the pandemic than before, which implies that employment got better after the pandemic; this could be due to economic recovery or new employment opportunities.

There is a very statistically significant difference between internet use in the pandemic vs. pre-pandemic periods. The pandemic was impacted by the strong increase in internet use (work from home, online education, consumption of digital content). There is also a very statistically significant difference between post-pandemic and pre-pandemic periods. The pandemic is over, but internet usage has held constant. So, it can be said that, on average, new technologies and digitalization have been adopted in the long term. For the ICT trade balance, all three periods are statistically significant. It went up during the pandemic compared to pre-pandemic, probably because technology, software telecommunication, and digital services were in high demand. Post-pandemic ICT trade balance went down compared to the pandemic period, but not very strongly. The ICT trade balance is still way above pre-pandemic levels; thus, it can be asserted that the ICT sector got a lasting effect from the pandemic shock. The only statistically significant period for the employment/population ratio was post-pandemic to pre-pandemic. This ratio increased after the pandemic than before; therefore, one could assume that employment got better after the pandemic, maybe due to economic recovery or new employment opportunities.

Table 3. Comparison of periods

Variable code	Comparison	p.adj
X_8	Pandemic – Post - pandemic	0.064
	Pandemic – Pre - pandemic	1.785E-05
	Post – pandemic – Pre - pandemic	1.028E-12
X_9	Pandemic – Post - pandemic	0.041
	Pandemic – Pre - pandemic	1.765E-05
	Post – pandemic – Pre - pandemic	2.333E-13
X_{11}	Pandemic – Post - pandemic	0.453
	Pandemic – Pre - pandemic	1
	Post – pandemic – Pre - pandemic	0.038

Source: Authors' own research.

Principal Component Analysis

The PCA was carried out between 2015 and 2023, thereby recognizing four general kinds of European economies. These groups have very opposite characteristics in terms of economic growth, level of digitalization, and labor market organization.

All the biplot graphs are in Appendix B.

Name this quadrant "Advanced and Digitalized Economies" as it includes countries with solid digital infrastructure and service-based economies that are hydra-angled into international trade chains. These are the kinds of economies where innovation, technology, and highly globalized trade can be sustained. Such economies include Belgium, Luxembourg, Netherlands, and Switzerland. Having already good economic infrastructure available is required to quicken the digital transformation and stay competitive. Examples would be France, Italy, Poland, Turkey, and Ukraine. Albania, Bosnia and Herzegovina, Bulgaria, Croatia, Georgia, Hungary, Malta, Moldova, Portugal, Serbia, and Romania (except for 2021 and 2023) fall in the fourth quadrant, labelled "Innovation & Sustainability Leaders." This means orientated towards sustainability plus renewable energy and technological innovation with balanced growth, which is also resilient. These are countries that prioritize the green transition plus sustainable development.

Between 2015 and 2023, however, the great repositioning of European nations changing quadrants was very much in between. It showed the differences in their economies, methods of digitalization, and sustainability practices. Also, former leaders in economic and digital modelling, Germany and the UK, have slid into a more industrial model because of restraints from the energy crisis and Brexit, respectively. In a staggered, upwardly mobilizing economy and industrialization, Romania, the Czech Republic, and Slovakia gradually but steadily found their footing in the European economy while still clinging onto manufacturing, just the opposite of what Spain followed. This industrialized to a digitalized economy made itself more competitive, and new technologies were developed at a fast pace.

At the same time, Nordic countries—Denmark and Slovenia—balanced the seesaw of digitalization with sustainability, prioritizing either development or transformation into a green economy. Slovenia had a very brief, highly increased digital insertion, which later swung back to the sustainable model. Austria, Cyprus, and Latvia made very big changes either by turning themselves in a more lasting way or by changing their economies to meet new digital needs.

The indicators that changed their position between the four groups were primary energy, GDP, and employment-to-population. Trade balance, total greenhouse gas emissions, people using the Internet, and ICT trade balance remain static in Quadrant 1; population and mobile subscriptions remain static in Quadrant 2; and renewable energy remains static in Quadrant 4.

Primary energy used to be associated with digitalized and industrialized economies (Quadrant 1), but it shifted to Quadrant 4 in 2018.

Wavy GDP growth was first associated with very digitized economies (Quadrant 1) in 2015-2016 and then later moved towards Quadrants 3 and 4.

From this movement, it seems that economic growth is more related to developing countries and long-term plans for expansion than to digitalization and high technology.

The employment/population ratio took a giant leap in 2017 from Quadrant 1(the countries that have digitized and developed their economies) to Quadrant 4 and has remained there until 2023.

This, in our view, shows that employment rates nowadays relate more to economies with sustainability, innovation, and restructuring of the labor market than to digitalized economies as a leading indicator.

Cluster analysis

After cluster analysis, these countries were grouped into three clusters.

Refer to all dendrogram graphs in the figures in Appendix C.

The first group is termed "developed and stable countries," comprising Austria, Belgium, etc.; these are countries that did not shift to any other group during the years under review; they have high significant values for trade balance, primary energy, renewable energy, total greenhouse emissions, individuals using the Internet, ICT trade balance, and the employment-to-population ratio where the economy is advanced digitalization and high employment rate.

Cluster 2 represents the emerging and transition countries, including France, Germany, Spain, Italy, Poland, Turkey, and Ukraine. Large populations in these countries reflect big economies and strong industrial sectors; hence, it is marked. Low renewable energy and total greenhouse gas emissions are below the mean possible structural issues in human capital development. The employment/population ratio is moderately low. It is lower than that of Cluster 1 but is on an increasing trend.

The final category is that of developing and economically lagging countries. It includes Albania , Bulgaria, Croatia, Georgia, Greece, Moldova, Montenegro, North Macedonia, Romania, Serbia, Latvia, Lithuania, Slovakia, Slovenia and Portugal. The indicator was low for mobile subscriptions, internet users, and ICT trade balance, which means their economy is not digitalized or technologized. It has the lowest value for the employment/population ratio of all the groups; therefore, it has a low value for employment rate and possible economic sturdiness issues.

Albania, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, France, Georgia, Germany, Greece, Italy, Moldova, Montenegro, North Macedonia, Portugal, Romania, Serbia, Spain, Turkey, and England are the only repositioned countries in the years under review.

The other countries, not in that initial stable group, have moved in years of these occurrences.

Conclusion

This paper considers economic, digital, and environmental changes in 41 European countries from 2015 to 2023. It mainly discusses the effects of the issues related to trade flows, energy use, and labor market conditions.

This paper has already identified the economic and structural changes by undertaking principal component analysis and hierarchical clustering. It will now describe long-term trends and the shock of the COVID-19 pandemic -- using four major economic groups: advanced and digitalized economies, industrialized nations and those in the digital transition, emerging countries, and nations at the frontier of innovation and sustainability. All these countries in the sample followed different trajectories of digitalization, trade sustainability, and employment under imbalanced regulations.

Three groups were returned by the cluster analysis. The first group was composed of Austria, Belgium, Denmark, Estonia, Finland, Iceland, Luxembourg, the Netherlands, Norway, Sweden, and Switzerland—very high trade balances and high levels of digitalization and the labor market. The second economic group included the mature and dynamic inject nations, such as France, Germany, Spain, Italy, Poland, Turkey, and Ukraine—big industries and relatively slower renewable energy employment growth. The third group summarized all countries—Albania, Bosnia, Bulgaria, Croatia, Georgia, Greece, Moldova, Montenegro, North Macedonia, Romania, Serbia, the Baltic States, and Slovenia—Low digitalization, low use of tech, and weak employment-to-population ratios. All indicate rapid economic volatility of economic adjustments. After a thorough examination, the divergence in the indicators is attributed to the COVID-19 pandemic. During the pandemic, there was much more internet use, so the ICT trade balance saw a big increase.

These changes were mostly because of the high demand for digital services and working from home. These days, a lot of learning happens on the internet. These styles were seen and kept long after the disease had spread. This type of change was very easy for some and quite hard for others. The changes in the rules on how to make something digital and green had helped change the money status of many lands at that time. For instance, while Germany and the UK leaned more toward the first direction, Spain moved toward a digital economy. Romania, the Czech Republic, and Slovakia swung between the farming spheres; closeness to the European economic plan was wanted, but parts of the old regime stayed. It shows the policies that should allow for digitalization in the economic recovery and sustainable growth henceforth.

Therefore, more digital-infrastructure countries should invest more in reducing the gap while introducing stability for running labor-market-oriented policies and efforts to bridge the gap between technological and industrial transformation. This will also be energy transition-related policies because the energy systems from a low cleaner environment are among the most dominant sources in the mix for a wide range of emissions. Therefore, post-pandemic economic evolution will press countries to monitor such actions in due time to support their competitiveness and stability. Another future research avenue should be an in-depth study to assess the weight of digitalization in each sector and workforce automation in the different economies, as well as a much more fine-grained analysis at the regional level.

This paper informs about the economic reformation of the European states from 2015 to 2023. The study looks at selected indicators of trade, digitalization, energy, and employment; therefore, its results should be taken with a wider set of indicators for each sign that should be taken up in future research to provide a clearer view. The regional disparities between the countries should be considered to note any specific change.

Further external shocks should be political tension, and climate policy and should also be integrated into models of long-term economic transformation. Studies should establish the extent of automation and AI on employment, the relationship between digitalization and the green agenda, and international policy cooperation in economic recovery. This provides a roadmap for further research to consider that openings are proffered in how economies recalibrate in a changing world.

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Appendix

Appendix A: Evolution of Indicators

This section provides a detailed trend analysis for each indicator, comparing Romania with the European average across the pre-pandemic (2015-2019), pandemic (2020-2021), and post-pandemic (2022-2023) periods.

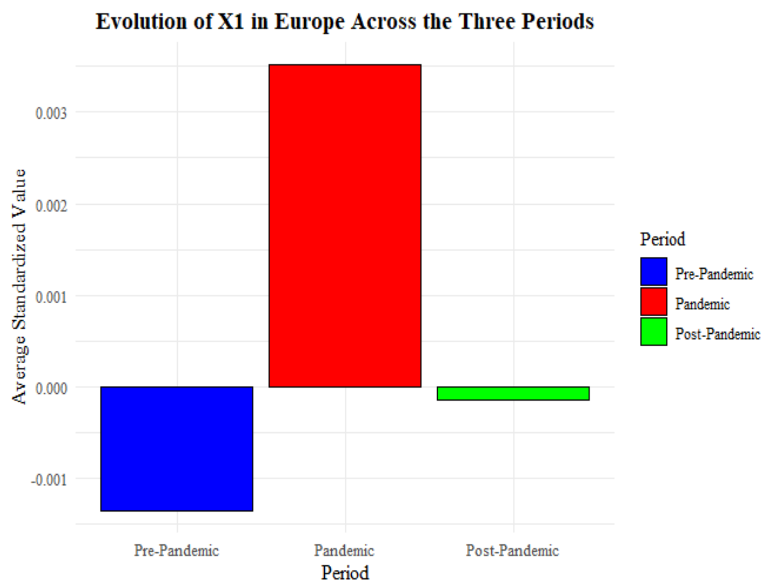

Figure 1. Europe evolution for X_1

Source: Authors' own research.

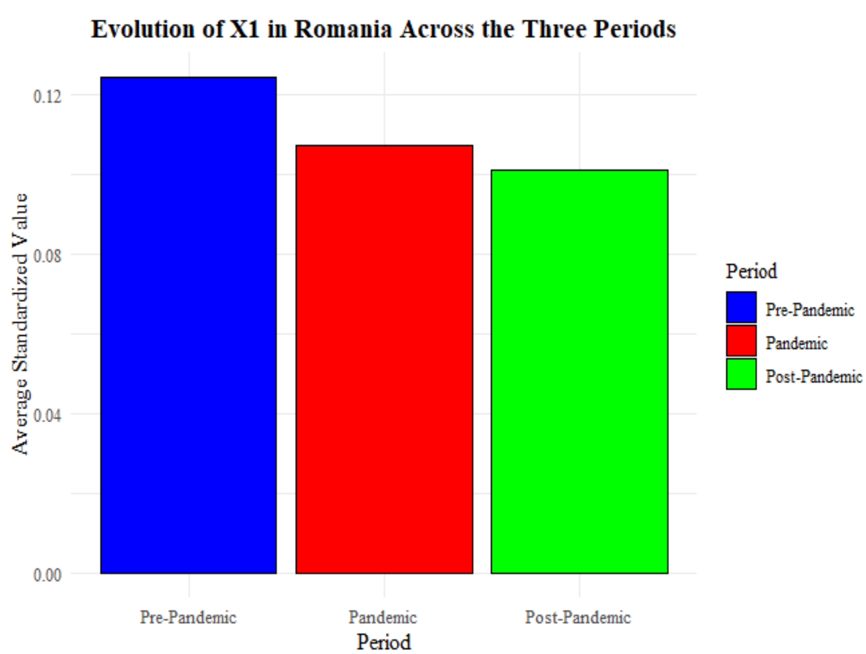

Figure 2. Evolution of X_1 in Romania

Source: Authors' own research.

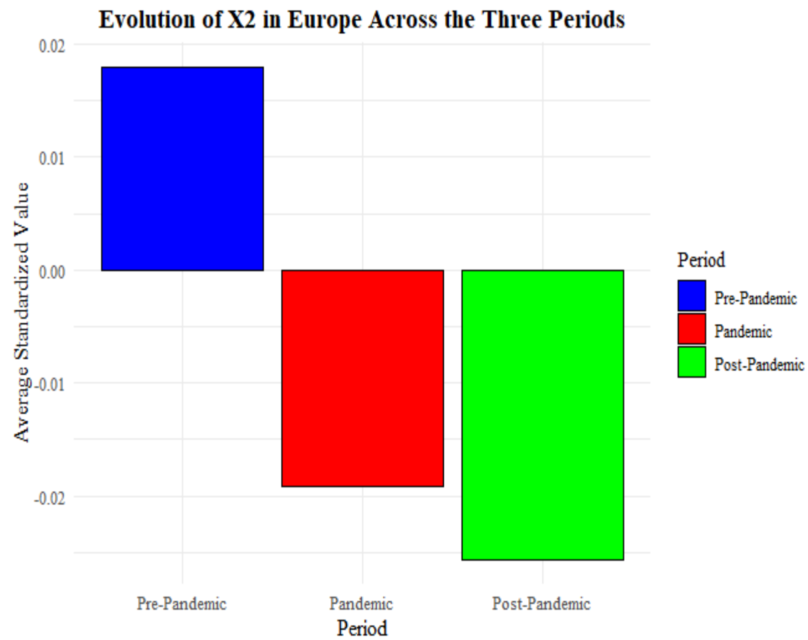

Figure 3. Europe evolution for X_2

Source: Authors' own research.

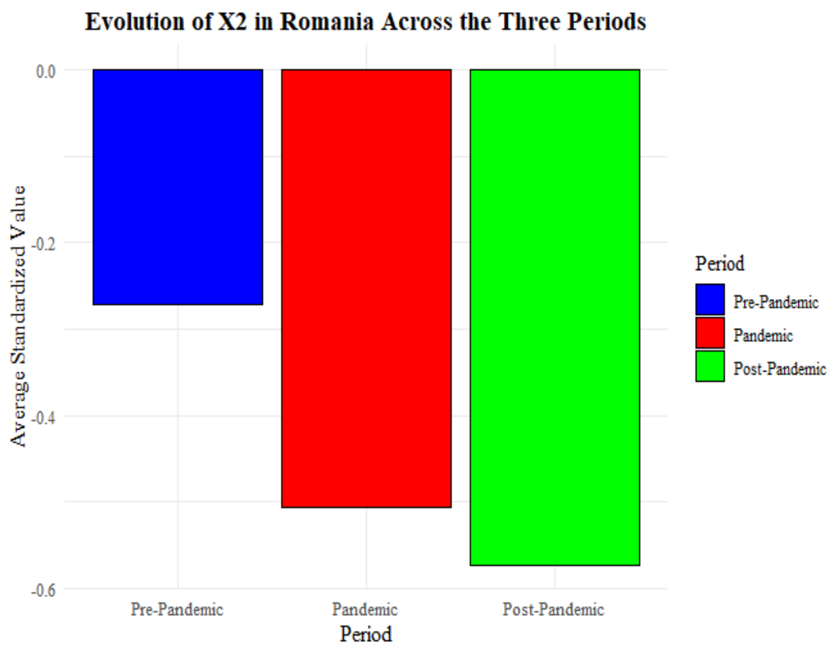

Figure 4. Evolution of X_2 in Romania

Source: Authors' own research.

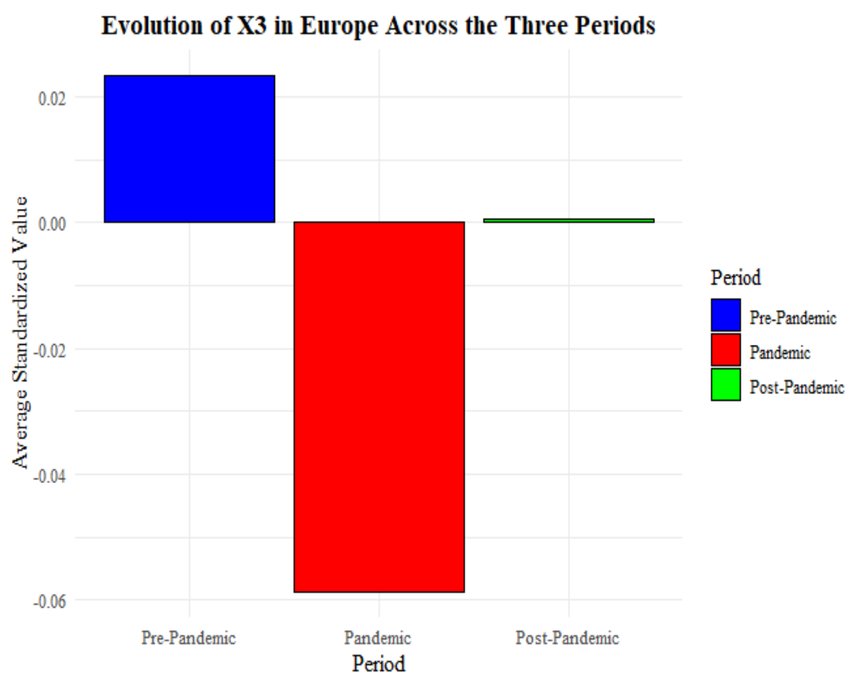

Figure 5. Europe evolution for X_3

Source: Authors' own research.

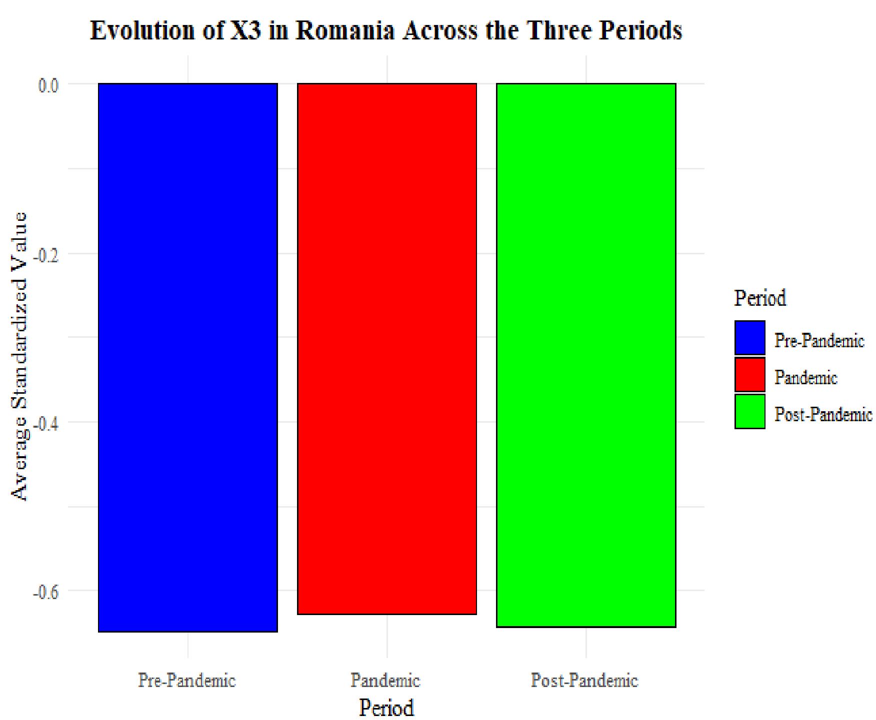

Figure 6. Trends of X_3 in Romania

Source: Authors' own research.

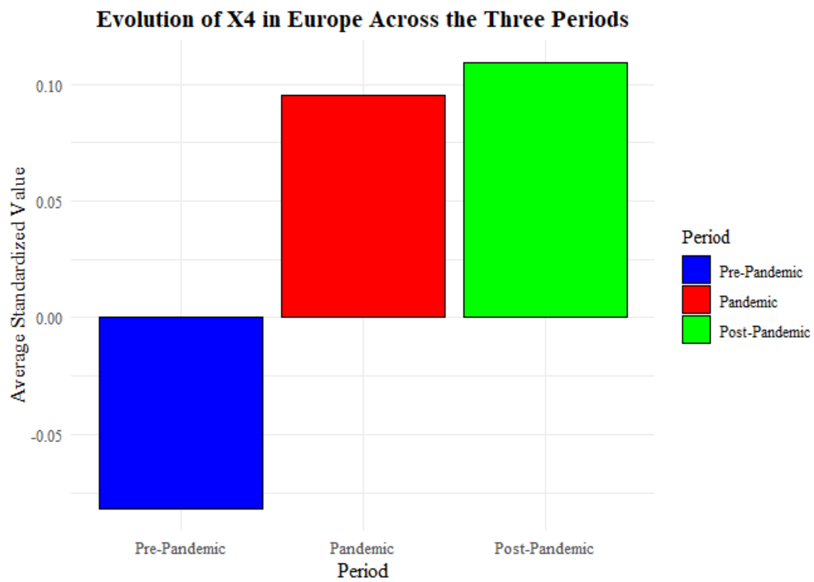

Figure 7. Europe evolution for X_4

Source: Authors' own research.

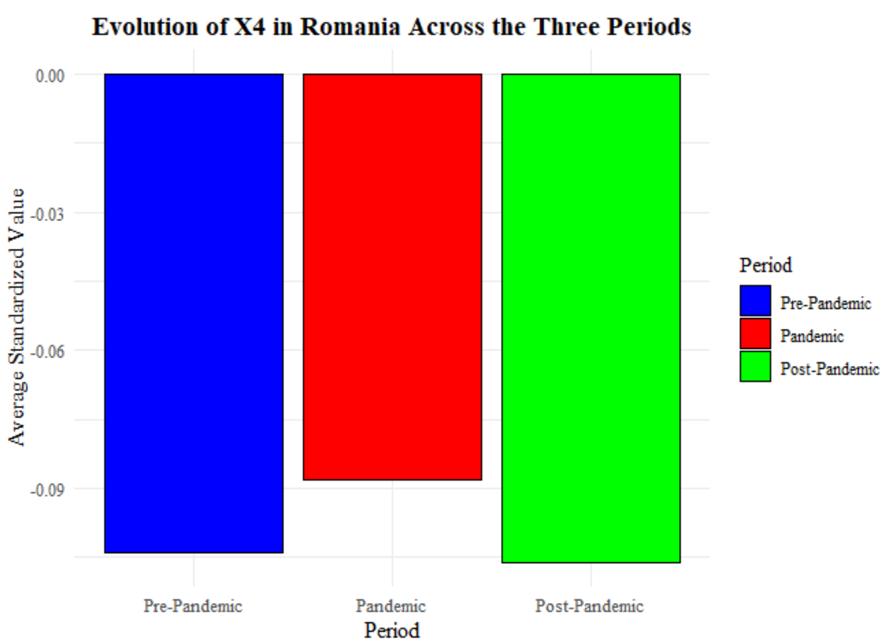

Figure 8. Trends for X_4 in Romania

Source: Authors' own research.

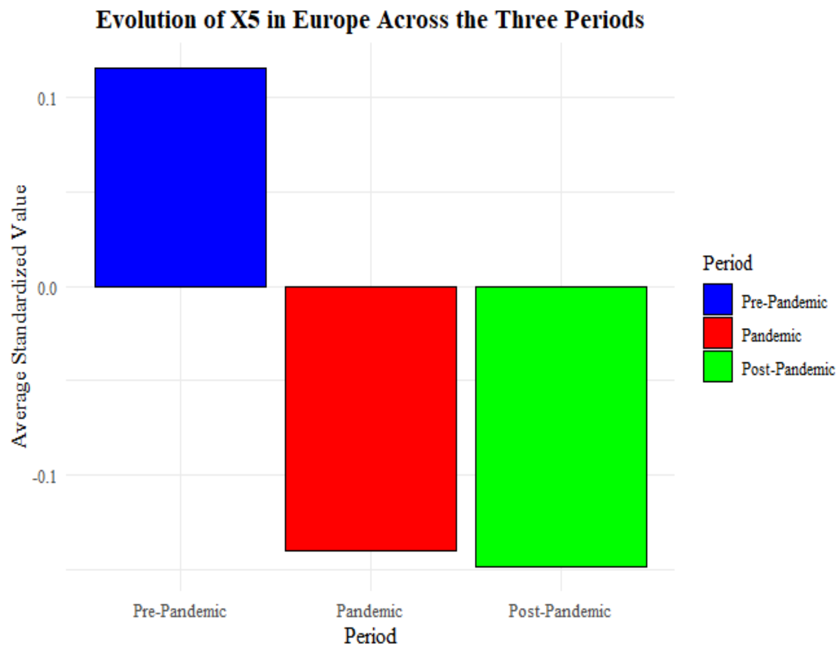

Figure 9. Europe evolution for X_5

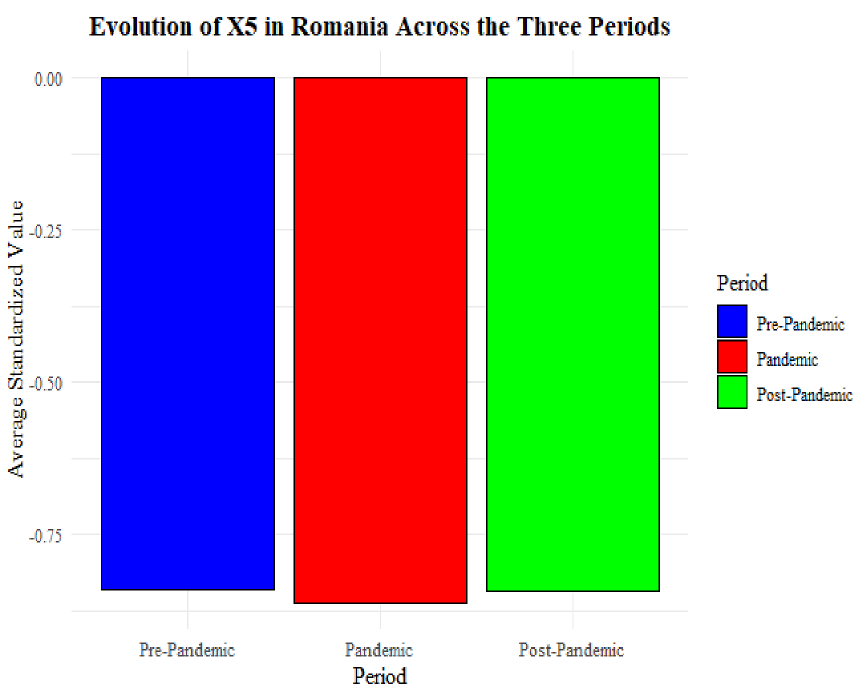

Figure 10. Evolution of X_5 in Romania

Source: Authors' own research.

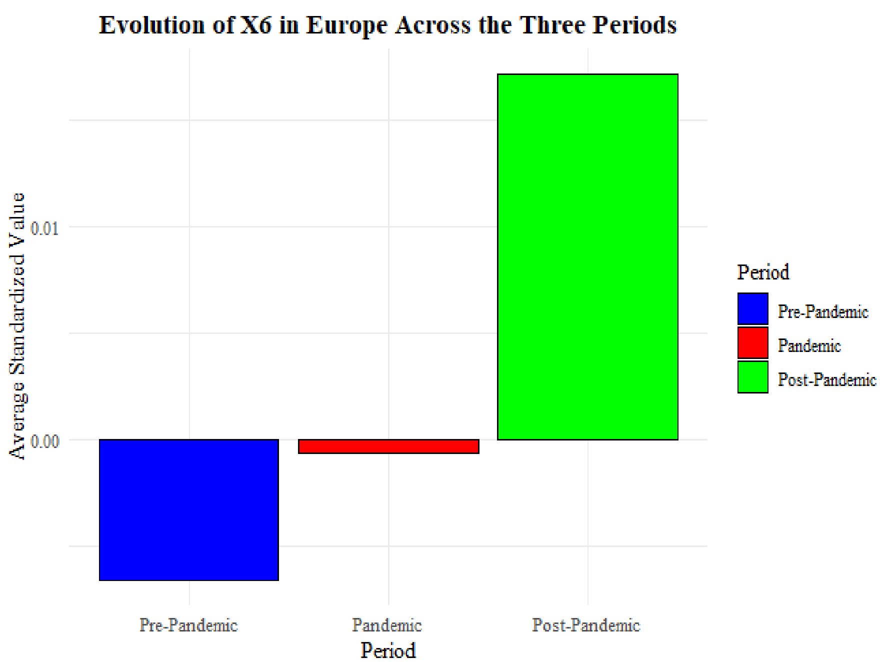

Figure 11. Europe evolution for X_6

Source: Authors' own research.

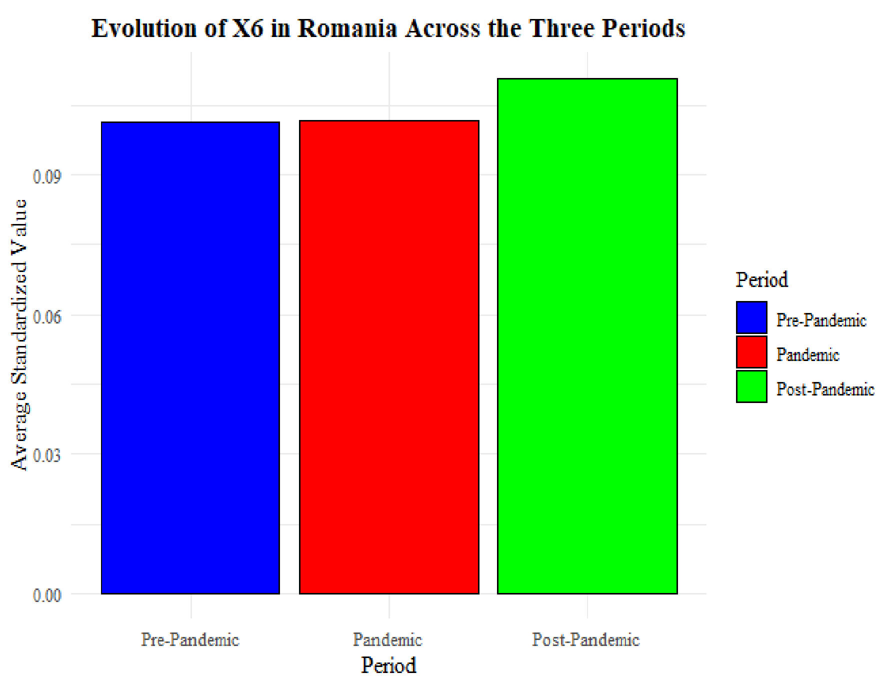

Figure 12. Evolution of X_6 in Romania

Source: Authors' own research.

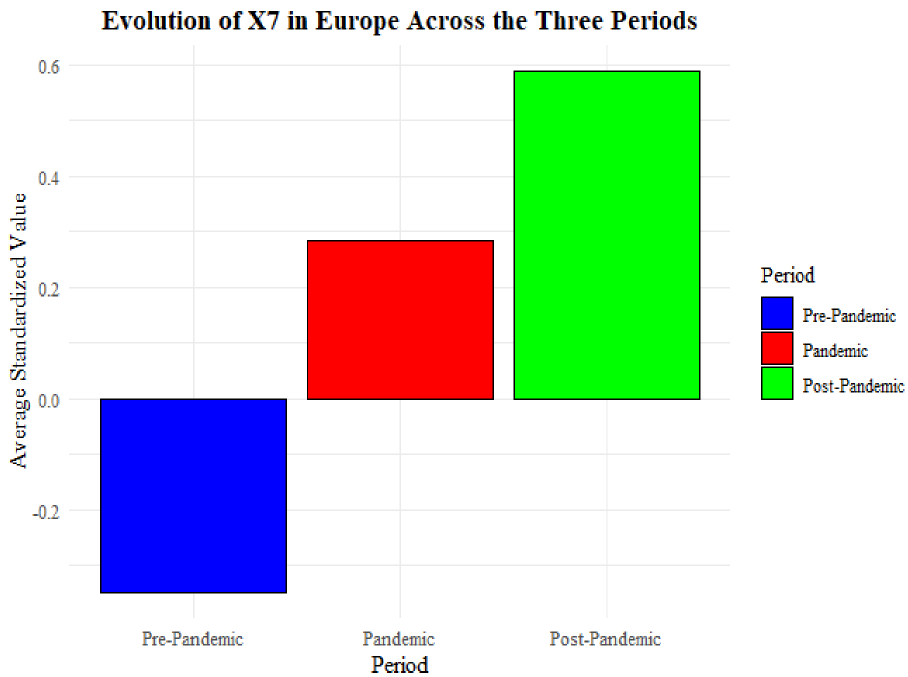

Figure 13. Europe evolution for X_7

Source: Authors' own research.

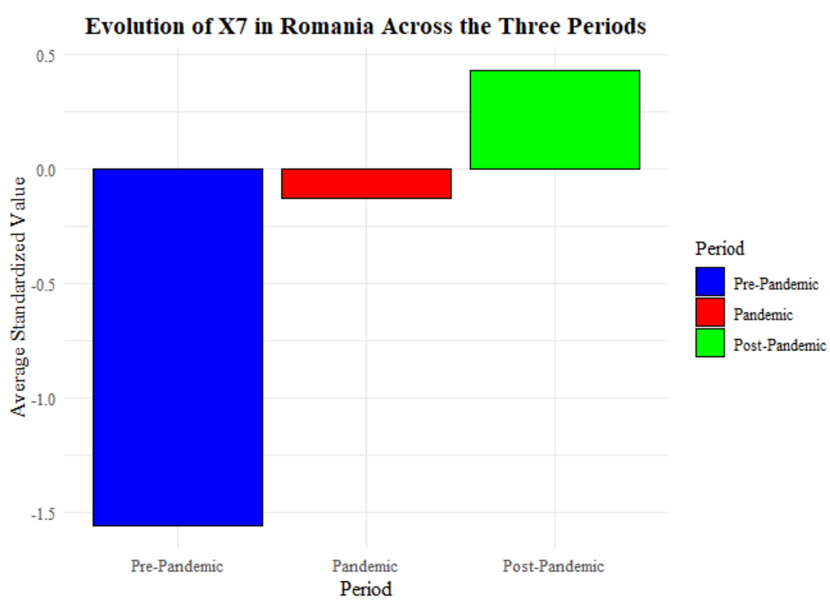

Figure 14. Evolution of X_7 in Romania

Source: Authors' own research.

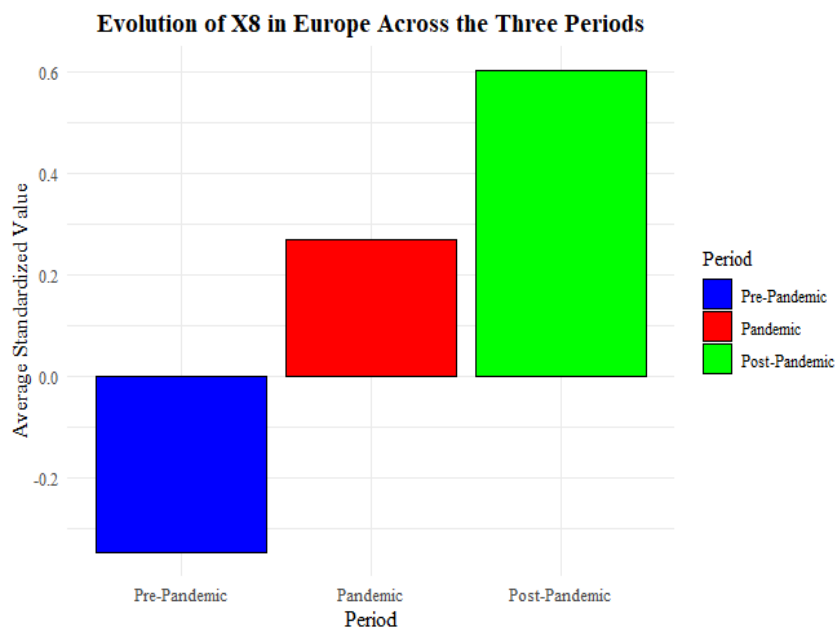

Figure 15. Europe evolution for X_8

Source: Authors' own research.

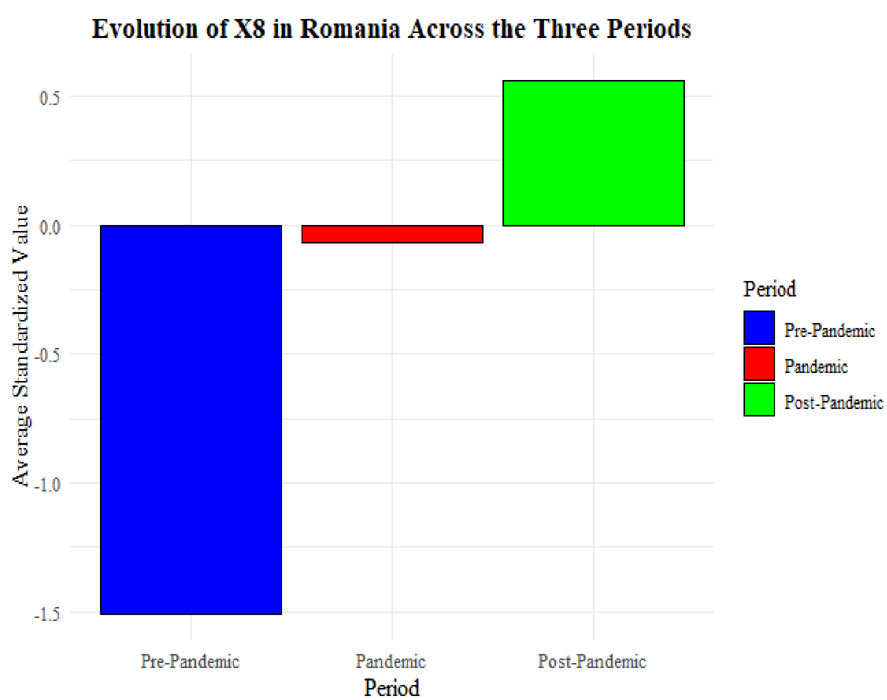

Figure 16. Evolution of X_8 in Romania

Source: Authors' own research.

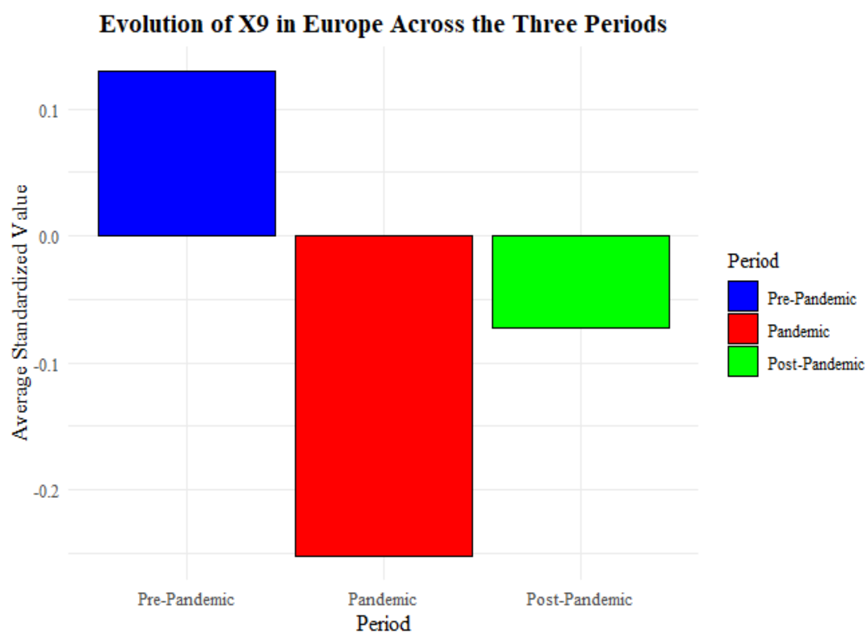

Figure 17. Europe evolution for X_9

Source: Authors' own research.

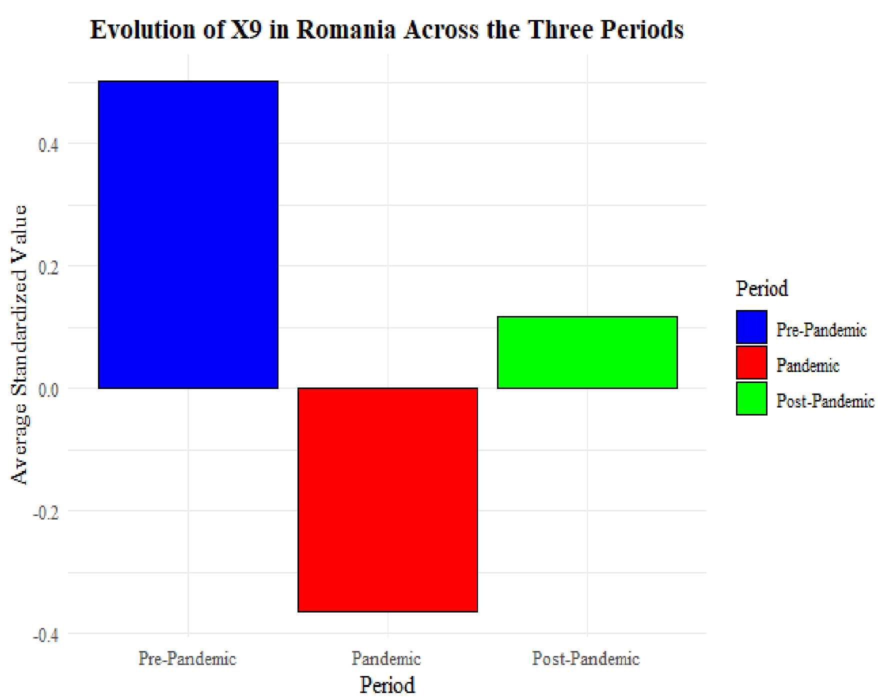

Figure 18. Evolution of X_9 in Romania

Source: Authors' own research.

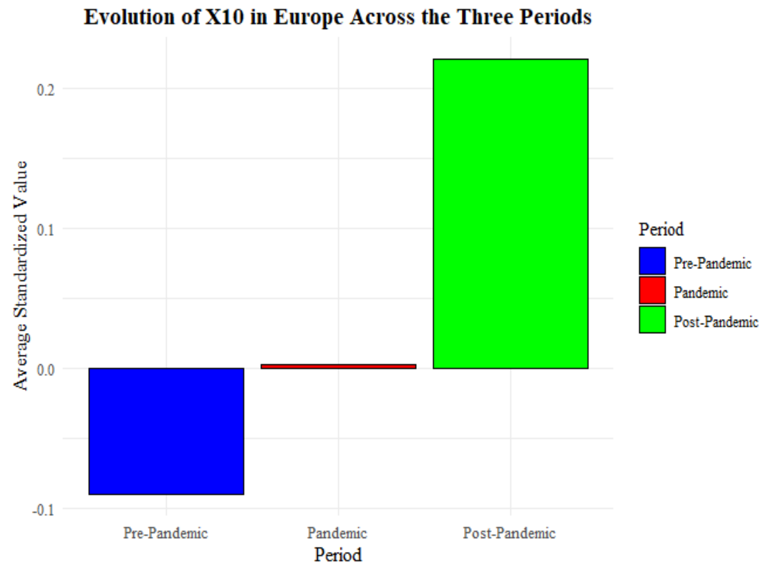

Figure 19. Europe evolution for X_{10}

Source: Authors' own research.

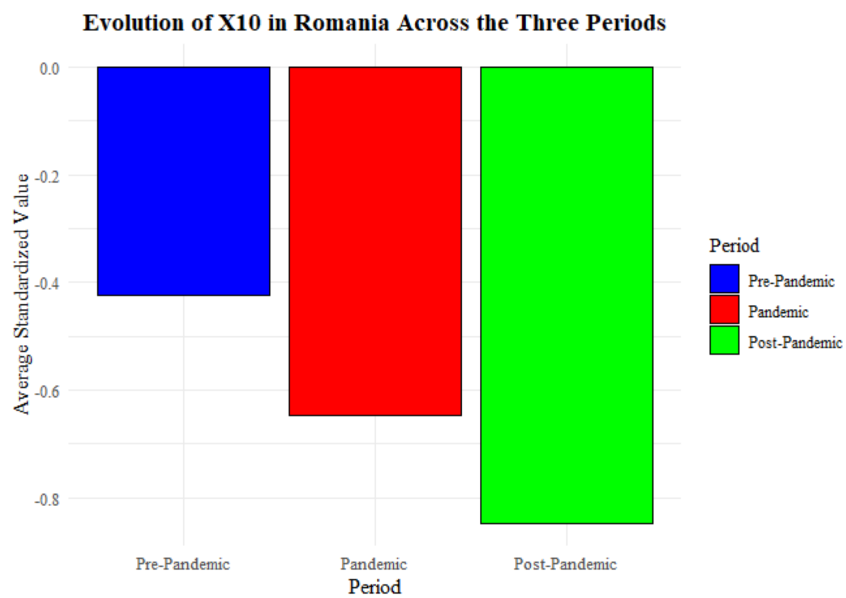

Figure 20. Evolution of X_{10} in Romania

Source: Authors' own research.

Appendix B: PCA Biplots

This section presents the Principal Component Analysis (PCA) biplots for each year from 2015 to 2023, illustrating the structural evolution of economic indicators over time. These figures complement the main analysis discussed in the "Results and Discussion" section.

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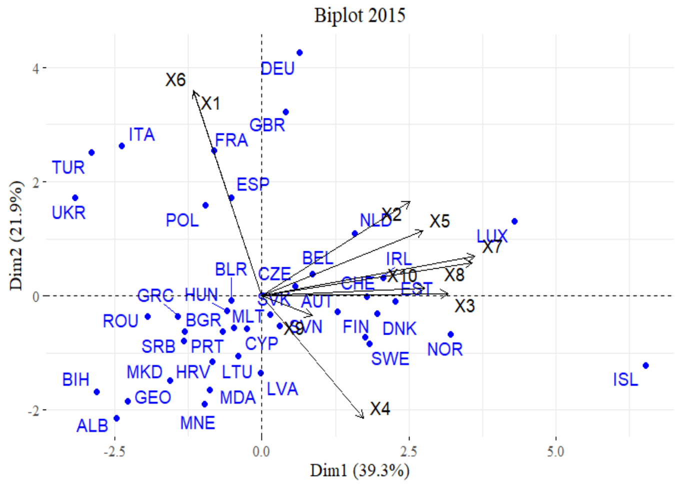

Figure 21. Biplot 2015

Source: Authors' own research.

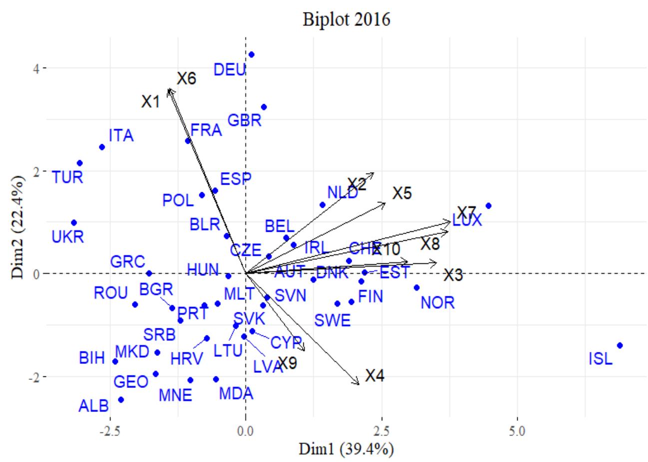

Figure 22. Biplot 2016

Source: Authors' own research.

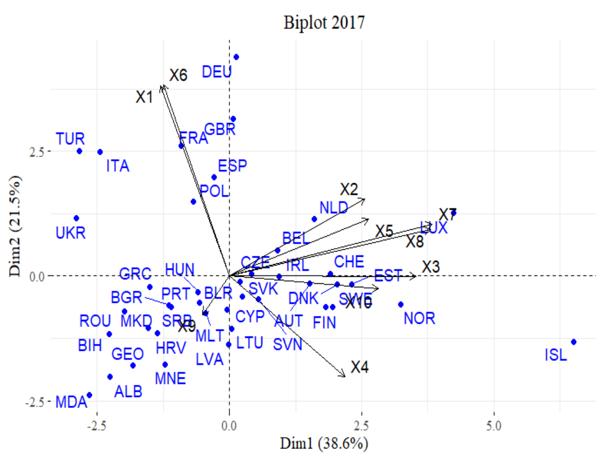

Figure 23. Biplot 2017

Source: Authors' own research.

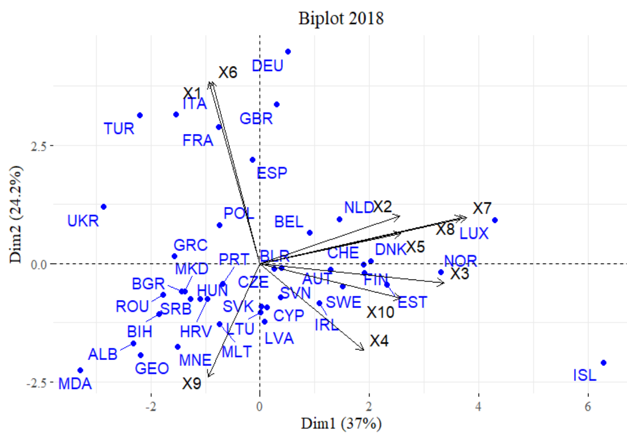

Figure 24. Biplot 2018

Source: Authors' own research.

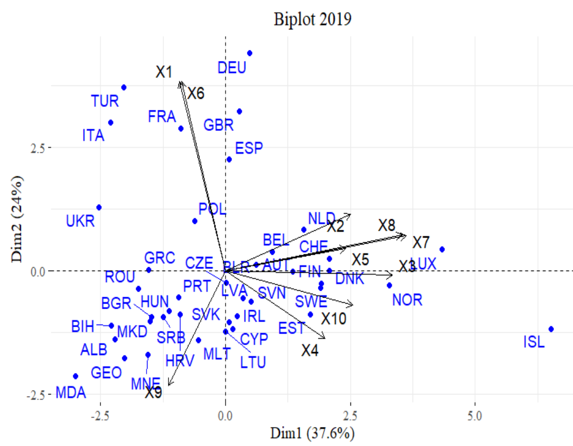

Figure 25. Biplot 2019

Source: Authors' own research.

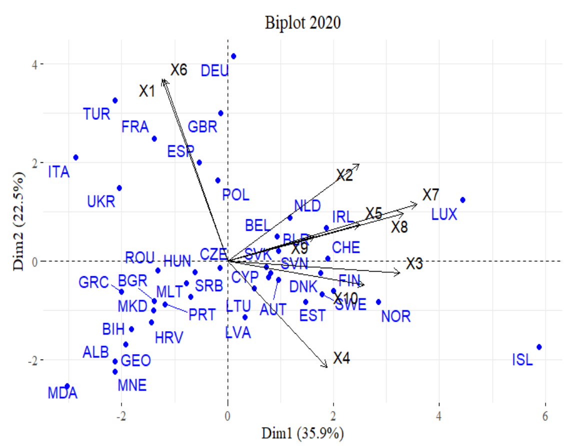

Figure 26. Biplot 2020

Source: Authors' own research.

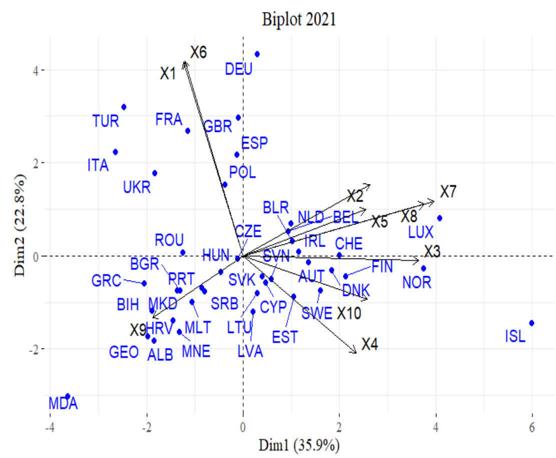

Figure 27. Biplot 2021

Source: Authors' own research.

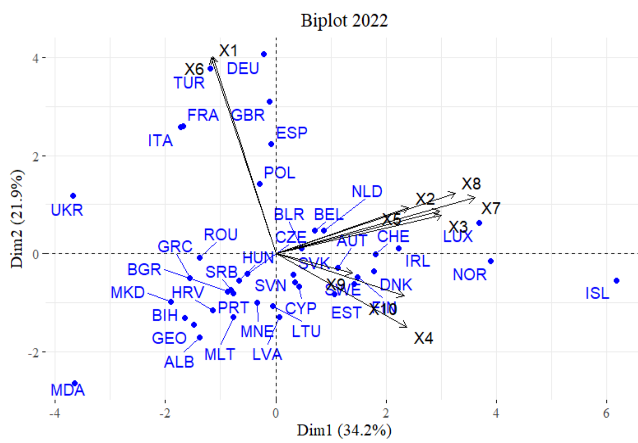

Figure 28. Biplot 2022

Source: Authors' own research.

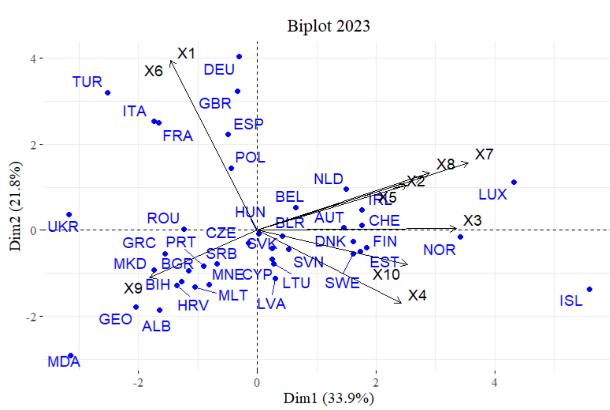

Figure 29. Biplot 2023

Source: Authors' own research.

Appendix C: Hierarchical Clustering Dendrograms

The following dendrograms illustrate the results of hierarchical clustering for each year, highlighting the evolution of economic groupings across European countries.

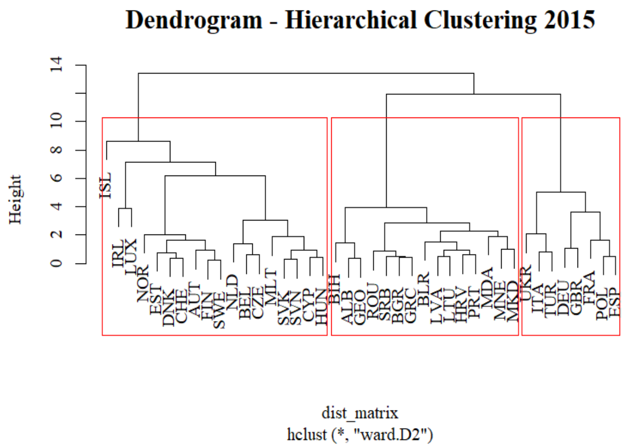

Figure 30. Dendrogram 2015

Source: Authors' own research.

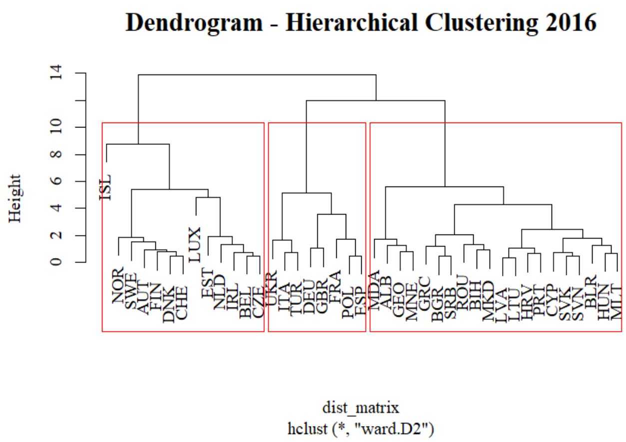

Figure 31. Dendrogram 2016

Source: Authors' own research.

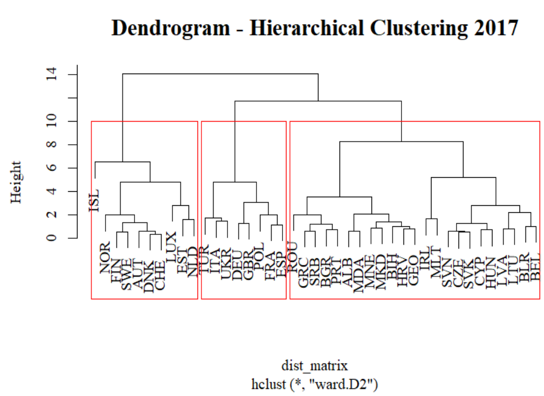

Figure 32. Dendrogram 2017

Source: Authors' own research.

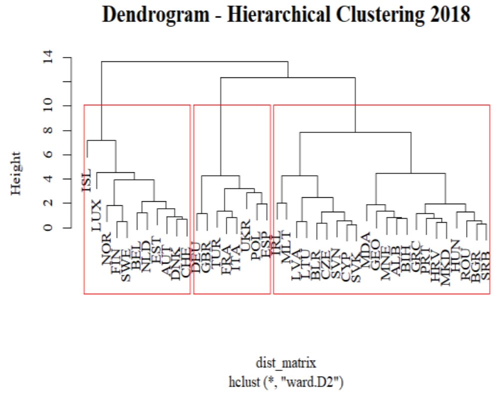

Figure 33. Dendrogram 2018

Source: Authors' own research.

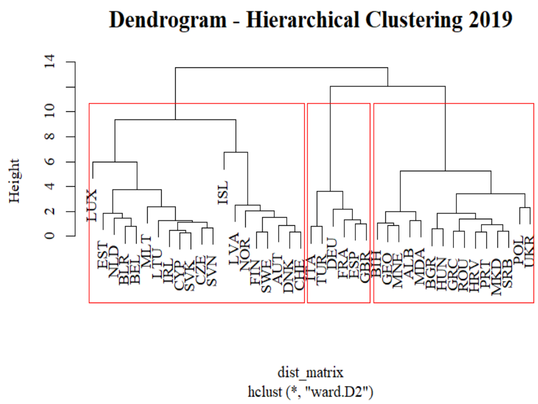

Figure 34. Dendrogram 2019

Source: Authors' own research.

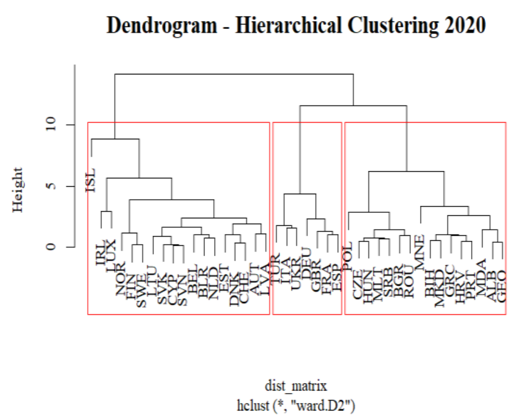

Figure 35. Dendrogram 2020

Source: Authors' own research.

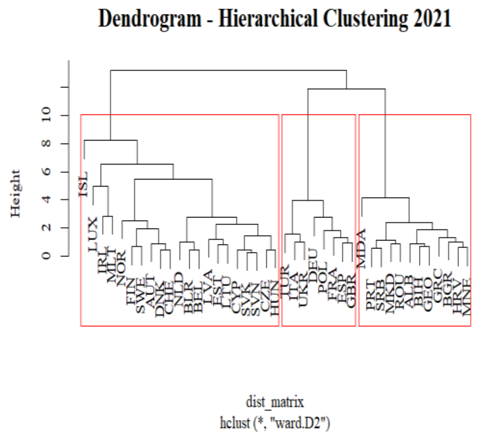

Figure 36. Dendrogram 2021

Source: Authors' own research.

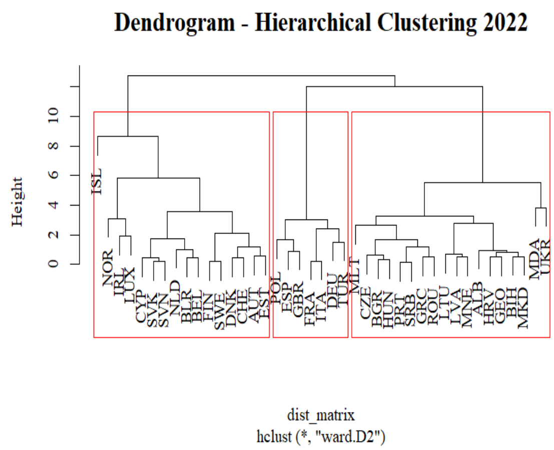

Figure 37. Dendrogram 2022

Source: Authors' own research.

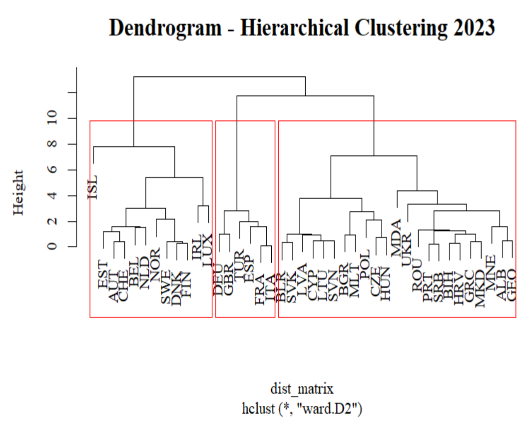

Figure 38. Dendrogram 2023

Source: Authors' own research.