European Commission

To what extent are Widening countries part of knowledge networks formed by the framework programmes?

Working paper supporting the interim evaluation of Horizon Europe (support study on Excellent Science)

Independent Expert Report

Research and Innovation

To what extent are Widening countries part of knowledge networks formed by the framework programmes? - Working paper supporting the interim evaluation of Horizon Europe (support study on Excellent Science)

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To what extent are Widening countries part of knowledge networks formed by the framework programmes?

Working paper supporting the interim evaluation of Horizon Europe (support study on Excellent Science)

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PPMI

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ABSTRACT

This paper investigates the integration and role of Widening countries within the collaborative networks established by the European Union's Framework Programmes, such as FP7, Horizon 2020, and the early stages of Horizon Europe. Through dynamic network analysis, it explores how these countries, characterized by lower participation rates in previous framework programmes, engage in research and innovation (R&I) collaborations across Europe. The analysis reveals the central role of major EU member states countries in steering consortia and setting research agendas, while also highlighting the evolving participation of Widening countries. These countries show an increasing trend in collaboration shares, indicative of the EU's policies' impact on fostering inclusivity. However, challenges remain for some Southeast European countries, with variations in participation levels and collaboration dynamics. The study also underscores the significance of shorter path lengths and the presence of 'bridge' countries in facilitating efficient knowledge exchange and enhancing the connectivity of Widening countries within the broader R&I network. The study finds that there are few influential organisations (network hubs) within Widening countries group. Following the Covid-19 pandemic, countries are more inclined to cooperate with others that are in close proximity and have similar strategic interests or socio-economic conditions. This also implies that Widening countries may not depend as heavily on Non-Widening countries to initiate collaborations. The paper contributes to understanding the complex dynamics of European research collaborations, with a particular focus on the inclusion of Widening countries and the strategic implications for future policy and program design.

1. Introduction

1.1. Importance of network analysis and previous research

Understanding collaboration patterns within the EU's Framework Programmes is crucial for maximising the benefits of collaborative research and innovation (R&I). Such collaborations are instrumental in generating spillover effects, knowledge sharing, and achieving the critical mass necessary to address global societal challenges. Studying collaborative networks allows for a better understanding of how research and development (R&D) activities are interconnected across different country groups, fostering a more comprehensive view of scientific collaboration (Roediger-Schluga and Barber, 2007).

This type of analysis helps identify patterns of participation among organisations involved in various EU R&D funding initiatives, providing insights into the dynamics of these collaborations and the impact they have on research outcomes (Scherngell et al., 2024). Previous results from the study on network analysis of the 7th Framework Programme participation have indicated that new participants who joined collaborative projects under FP7 experienced a significant positive impact on their innovation and the creation of new knowledge.[1] Inclusion of business enterprises, especially SMEs, in projects significantly increased the propensity of projects to introduce innovation, such as new products or processes. Furthermore, newcomers to the framework programmes who collaborated with more seasoned partners saw improvements in their research skills, acquired expertise in working on international projects, and were able to expand their own networks. The same study however pointed out that within the FP7 network, a core-periphery configuration was evident, in which a small number of key players, or hubs, positioned at the centre of the graphical representation, formed strong connections among themselves and weaker links with those on the periphery.

[1] Study on network analysis of the 7th Framework Programme participation – Methodological annex, Publications Office, 2015, https://data.europa.eu/doi/10.2777/739048

In 2018 the European Commission's Directorate-General for Research and Innovation (DG-RTD) published a study that aimed to analyse the collaborative networks. The study showed that comparing FP7 to H2020 there was a tendency for the EU-15 (those that were EU members before 2004) countries to open in cooperation with EU-13 countries (those that joined the EU in 2004 and after). However, EU-15 countries are still in general more central in the network compared to EU-13, associated countries, and third countries. Where being 'central' in a collaboration network means that nodes (participants) from a country have more direct connections or links to other nodes (participants) within the network. Some of the reasons claimed were cultural differences, geographical distances, and language barriers.

The EU-13 countries from the previous study are included in the Widening country group of the current study. The European Commission proposed the term of "Widening Countries",[2] for Horizon Europe as countries with low participation rates in FP7 and H2020 projects.[3] These are referred to as Widening Countries throughout the text. For FP7, we applied the H2020 categorisation.

In the H2020 framework programme, the Widening countries include Bulgaria, Croatia, Cyprus, Czechia, Estonia, Luxembourg, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, and all Associated Countries[4]. While for Horizon Europe (HE) framework programme, as indicated in the 2021-2022 work programme[5] Widening countries include Bulgaria, Croatia, Cyprus, Czechia, Estonia, Greece, Hungary, Latvia, Lithuania, Malta, Poland, Portugal, Romania, Slovakia, Slovenia, and all Associated Countries with equivalent characteristics in terms of R&I performance and the Outermost Regions[6]. In the HE Programme, Luxembourg is no longer classified as a Widening country. While, Greece has been introduced as the latest member of the Widening group.

This working paper aims to explore to what extent are Widening countries part of knowledge networks formed by the framework programmes. Using a dynamic collaborative network approach explores how Widening countries are involved in the R&I frameworks programmes through the prism of cross-country collaborations. The data employed comes from the monitoring data of Horizon Europe, Horizon 2020, and the Seventh Framework Programme for Research and Technological Development (FP7). The data regarding collaborative projects include the full implementation of FP7 and Horizon 2020, but also the first two years of implementation of Horizon Europe. The data was collected from the Common Research Data Warehouse (CORDA) and Horizon Dashboard. The categorization of countries into groups (such as Widening EU Member States (MS), Non-Widening EU MS[7], associated countries, and third countries) is determined based on their status within Horizon Europe.

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[2] Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0628&from=EN

[3] European Commission, European Research Executive Agency, Spreading excellence and widening participation impact report – H2020 results and outlook to Horizon Europe, Publications Office of the European Union, 2021, https://data.europa.eu/doi/10.2848/30035

[4] Widening Associated Countries: Albania, Armenia, Bosnia and Herzegovina, Faroe Islands, North Macedonia, Georgia, Moldova, Montenegro, Serbia, Tunisia, Turkey and Ukraine

[5] https://ec.europa.eu/info/funding-tenders/opportunities/docs/2021-2027/horizon/wp-call/2021-2022/wp-11-widening-participation-and-strengthening-the-european-research-area_horizon-2021-2022_en.pdf

[6] As indicated in the defined in the Art. 349 from Treaty on the Functioning of the European Union. http://data.europa.eu/eli/treaty/tfeu_2012/art_349/oj

[7] These are also referred through the text as "Non-Widening" country group and they represent the same countries. Non-Widening countries for HE are Austria, Belgium, Denmark, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Spain, Sweden

2. The current network of Horizon Europe: a comparison with H2020 and FP7

2.1. The evolution of the collaboration network from FP7 to Horizon 2020

The following figures represent cross-country collaboration networks within the context of the EU Framework Programmes for Research and Technological Development: FP7 and Horizon 2020.

The main method behind these representations is the MST (Minimum Spanning Tree) algorithm.[8] The application of MST and strongest connections is used to visualize the core structure of the network. It simplifies the complex structure of the network and can bring forward the main actors and their interactions. The upper plots were calculated using the participating countries as the nodes and projects as the edges (links). The thickness of the edges indicates the strength (number of projects) of the cooperation, while the size of the node indicates the eigenvector centrality. The eigenvector centrality takes into account the centrality of participants that the participant is connected to. A node which is connected to a few well-connected nodes may have a higher eigenvector centrality than a node which is connected to many poorly-connected nodes Newman (2008).[9]

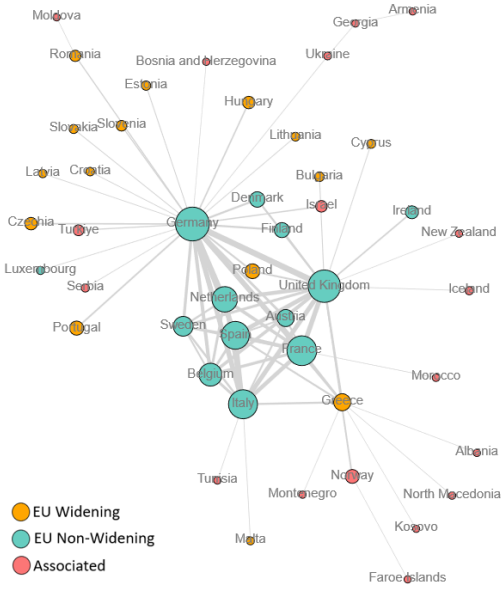

Figure 1. Cross-country collaborations network in FP7. Source: elaborated by the study team using eCorda data; June 2023 Corda data release

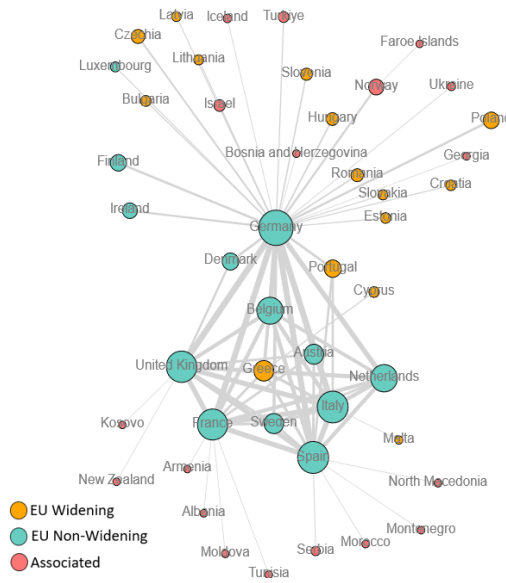

Figure 2. Cross-country collaborations network in H2020. Source: elaborated by the study team using eCorda data; June 2023 Corda data release

We can observe that between FP7 (Figure 1) and H2020 (Figure 2) still the most central nodes are the largest EU economies, high density of connections centred around a few

[8] The same method was also applied by Pierre-Alexandre Balland, Ron Boschma & Julien Ravet (2019) in a previous study.

countries, like Germany, France, the UK, Italy, and Spain that remain central, suggesting they are key hubs of research activity and collaboration. Their centrality implies they are leading many research consortia, receiving significant funding, and providing direction for research agendas, in both FP7 and H2020. However, there are subtle changes in the density of the connections between the two Framework Programmes which indicate evolving collaboration patterns.

In comparing the collaborative dynamics of countries in the FP7 and H2020 framework programmes, we observe notable shifts in partnership preferences and centrality. Specifically, the data reveal changes in how Associated countries select their EU partners. For example, comparing to FP7, in H2020 some Associated countries preferred to collaborate more with Spain or Germany than with Greece. Despite these changing preferences, Greece maintained its centrality in the network by expanding its collaborations with both Widening and Non-Widening countries. Portugal, another Widening EU MS became more connected but mostly with its neighbours Spain and Italy. We may associate the strength of the connections also with physical distance, also known as distance decay. Distance decay describes how the relationship between two countries generally gets weaker as the distance between them increases (Hasova and Wolf, 2022). Consequently, we should be cautious in using the term “opening up” to describe the expansion of collaborations among Widening and Non-Widening countries, since geographical proximity may be more important in initiation of these partnerships, rather than a deliberate decision to collaborate.

The methods used to visualize the plots, such as the Minimum Spanning Tree (MST) and the strongest links, are crucial for understanding patterns of inter-country collaboration. However, these methods may overlook less prominent but strategically significant connections. Smaller nodes and their connections might represent emerging country hubs which could be vital for understanding the complete network dynamics.

2.2. Comparing Horizon Europe with previous Framework Programmes

In the following collaboration network, we can see a representation of the first two implementation years of Horizon Europe. In this Framework Programme, the United Kingdom became an associated country. From FP7 to Horizon Europe, the number of collaborations between the United Kingdom and Widening countries, as well as associated countries, has gradually decreased. Similarly, France recently became one of the main partners mostly for small countries like Moldova, Armenia, Georgia but not much opening towards the Widening countries. Italy became one of the biggest partners for some associated countries such as Turkey, Albania, Marocco, but also for Romania as a Widening EU MS, meaning that we can see an opening up of Italy in the first years of Horizon Europe comparing to FP7 and H2020. From the Widening countries we can see that Greece continually had a core position in the collaboration networks. Poland was having a higher engagement in FP7 however it reduced its main collaborations to one important partner, Germany. Portugal gradually became more engaged but only with the main actors such as Germany, Italy and Spain.

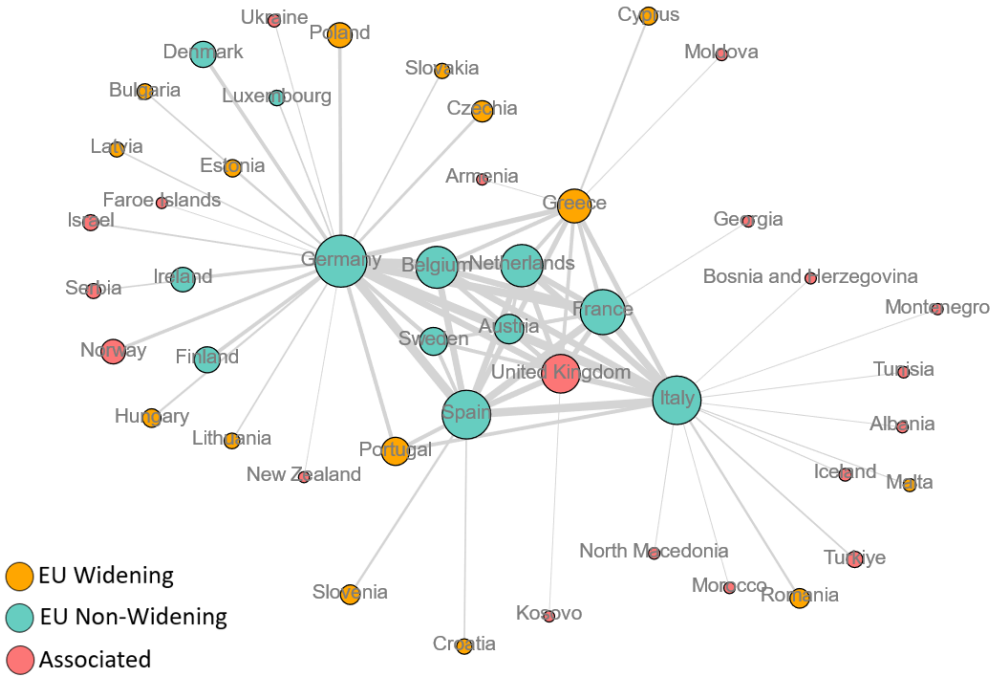

Figure 3. Cross-country collaborations network in Horizon Europe. Source: elaborated by the study team using eCorda data; June 2023 Corda data release.

2.3. Participation in the collaboration networks by framework programme and country

The following figure refers to the proportion of project collaborations that each country is involved in, within the entire network (including, Associated and Third countries) for each of the EU framework programs: FP7, Horizon 2020, and Horizon Europe. The EU Widening EU MS generally start with lower participation shares. Some of these countries show a notable increase from FP7 to Horizon Europe such as Greece, Portugal, Slovenia, which could reflect the impact of the EU's Widening participation policies aimed at improving research capabilities in these states. However, there are some Widening EU MS that don't show a significant upward trend such as Bulgaria, Poland, Romania and in the case of Hungary a decrease in engagement is observed.

Non-Widening EU MS maintain a consistent share across all programmes, indicating sustained, strong participation in EU research collaborations. However, a decreasing trend of influence in the network between the framework programmes was observed in the case of Germany, France, and Sweden. When comparing Widening EU MS with Non-Widening EU MS, Widening EU MS are still lagging in terms of participation in the collaboration network. The United Kingdom, as a recent associated country under HE, has a visible decrease in participation share from FP7 to Horizon 2020 and to Horizon Europe. This could be due to Brexit and the subsequent renegotiation of the UK's involvement in EU research funding programs.

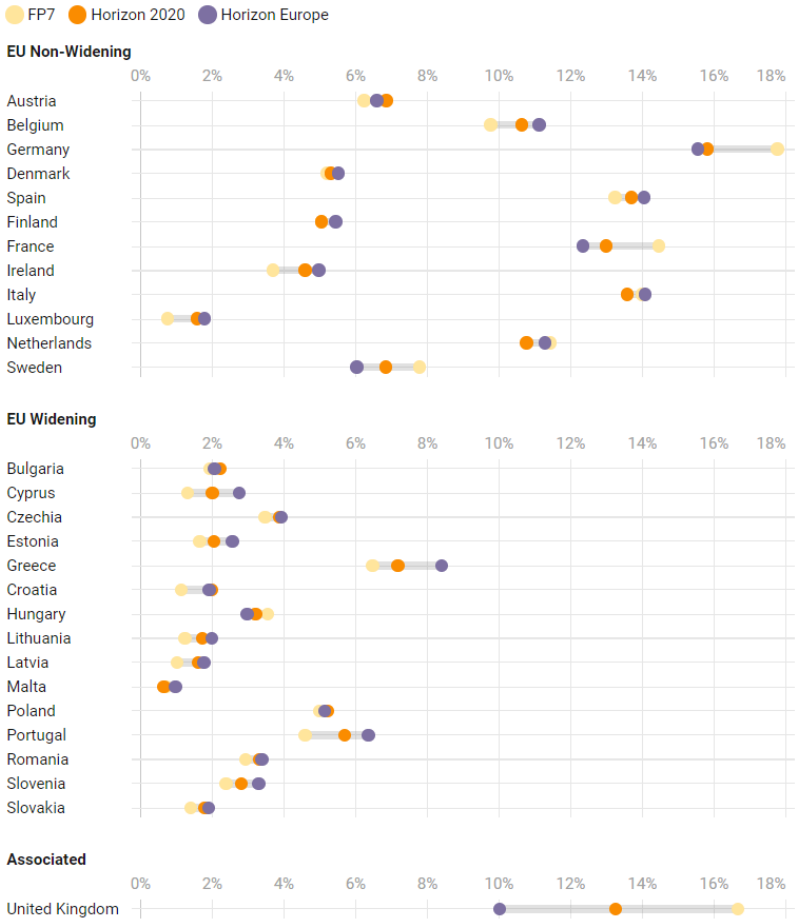

Figure 4. The share of connections within the entire collaboration network. Source: elaborated by the study team using eCorda data; June 2023 Corda data release

2.4. Evolution of the properties of the collaboration networks in different framework programmes

To observe the evolution of the collaboration network, Table 1 shows the set of dynamic network indicators for three different framework programs: FP7, Horizon 2020, and Horizon Europe. These indicators are designed to measure the characteristics of networks where nodes represent participating organisations and edges signify project collaborations.

According to Table 1 and the **average degree centrality**[10] measurement, during the period of FP7, each organisation engaged on average with approximately 48 other organisations,

[10] The average degree centrality indicates the average number of collaborations per participating organisation within the network. The network of participants is represented by an n × n matrix X = (xij), where xij represents the number of connections between participant i and participant j (i, j = 1, …, n). To calculate the average degree centrality, we first sum all connections for each organization, which involves adding up the entries in the matrix for each row (or column, as the matrix is symmetric in undirected networks). This sum gives the total number of connections for each participant. The average is then computed by dividing the total number of connections by the number of participants in the network.

illustrating a robust network of collaborations. This number increased to 54 by the Horizon 2020 period, indicating a significant expansion in the network's connectivity and collaborative activity. A high value of average degree centrality can be attributed to large research organisations in the network which elevate the overall degree average. However, a slight dip to 47.4 in the initial two years of Horizon Europe suggests a potential stabilization or shift in how collaborations are formed. It is important to note that the result may be influenced by the fact that we only have two years of data (2021 and 2022) for Horizon Europe, compared to the full seven years of data for the other Framework Programmes.

The measure of **assortativity** reflects the likelihood of organisations from several types of regions (Widening or Non-Widening) collaborating with each other. The positive assortativity values across all three programs suggest a preference for organisations to collaborate with others of a similar type. Notably, Horizon Europe has the highest assortativity at 0.129, indicating strengthened regional collaboration patterns.

Across the three programs, **inequality**[11] appears to increase in H2020 suggesting that the that few organisations have many connections, while most organisations have only a few, and then decrease from H2020 to Horizon Europe, suggesting a move towards a more balanced distribution of collaborations among organisations. However, this change is small and we need to mention again that for Horizon Europe we only account for the first two years of the framework programme implementation.

The **average path length**, both weighted and unweighted, remains stable across the programs, with slight variations. This metric indicates the number of steps required, on average, to connect any two organisations through their shortest path of collaboration. The consistent average path lengths imply that the efficiency of information spread through the networks has been maintained across different framework programs.

Table 1. Dynamic network indicators

Framework Programme	Average degree centrality	Assortativity of Widening and Non-Widening countries	Inequality	Average path length (unweighted)
FP7	47.6	0.106	0.68	2.78
Horizon 2020	54.0	0.113	0.70	2.75
Horizon Europe	47.4	0.129	0.62	2.75

Source: compiled by the study team using eCorda data; June 2023 Corda data release.

[11] Inequality is measured by the Gini coefficient of the network's degree distribution. A Gini coefficient of 1 would imply extreme inequality, where one node (organisation) is central to all connections. A coefficient of 0 indicates perfect equality, where each organisation has the same number of connections.

2.4.1 *Comparison of the degree distribution between framework programmes*

The degree distribution of the network shows how many times each node (in this case, a participating organisation) collaborated with another organisation on a project. From the following plot, we can observe that most organisations have a low degree of collaborations, as indicated by the peak towards the lower end of the degree axis. The plot shows two different distributions: one for Non-Widening countries and one for Widening countries. In the following calculations, Widening countries also include the associated countries. The Non-Widening countries exhibit a short distribution with a smooth decline in the number of degrees and a narrow, long tail. This suggests that there are many organizations with an average number of collaborations and only a few organizations with a high number of collaborations. But the distribution is much more equable than the one of the Widening countries. On the other hand, Widening countries show a higher distribution, with fewer collaborations per country overall and a steep decline, indicating that these countries have fewer organisations with a high degree of collaborations. The key takeaway here is that **Non-Widening countries have a wider range and a higher number of collaborations per organisation compared to Widening countries. The similarity in shape to previous Framework Programmes (FPs) suggests consistent collaboration patterns over time.**

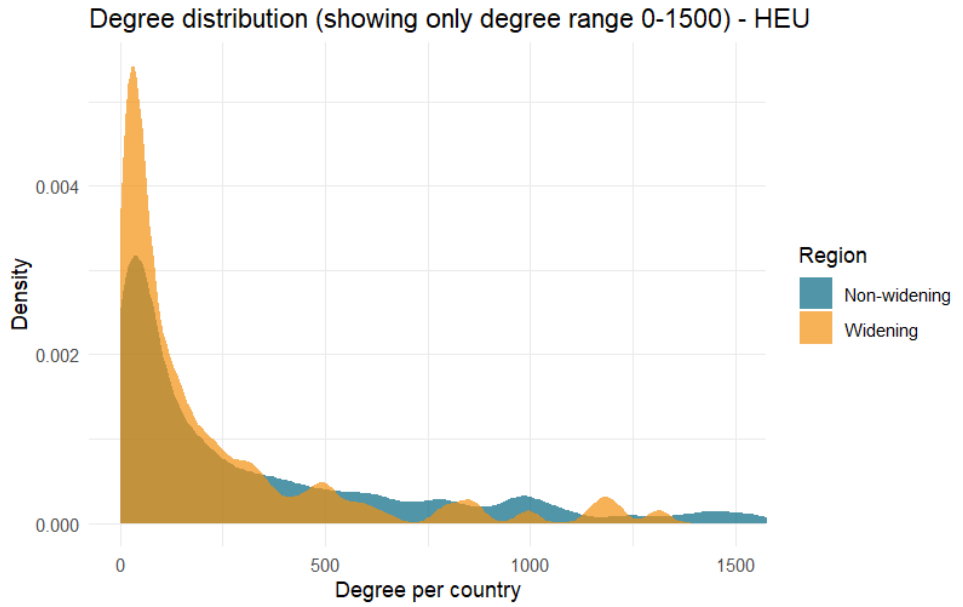

Figure 5. Degree distribution of the Horizon Europe collaboration network. Source: elaborated by the study team using eCorda data; June 2023 Corda data release

The average degree for Non-Widening countries shows a slight increase from FP7 to Horizon 2020. This trend is detailed in Table 2 and Table 3, followed by a small decrease in Horizon Europe, as seen in Table 4. Widening countries show a similar pattern but start with a lower average degree in FP7 and end with a slightly higher average degree in Horizon Europe compared to FP7. This suggests a convergence in the average number of collaborations between Non-Widening and Widening countries over time.

Table 2. Degree distribution for FP7

Region	Average	Median	Max
Non-Widening	50.9	17	7 571
Widening	45.1	18	1 789

Source: compiled by the study team using eCorda data; June 2023 Corda data release.

The median values, which represent the middle point of the data and are less affected by outliers, show less variability across the programmes for both region types. The medial values of Widening Countries are higher than those of Non-Widening countries across all Framework programmes. This might indicate that the typical (or median) organisation from Widening countries is involved in slightly more collaborations than their Non-Widening counterparts.

Table 1. Degree distribution for Horizon 2020

Region	Average	Median	Max
Non-Widening	56.7	20	8353
Widening	56.5	23	3765

Source: compiled by the study team using eCorda data; June 2023 Corda data release.

Maximum values, indicating the most collaborations by a single organisation within the dataset, are consistently higher for Non-Widening countries across all frameworks. This peak is higher in Non-Widening countries, suggesting that certain organisations in these countries are much more connected compared to the rest of the countries.

Table 4. Degree distribution for Horizon Europe

Region	Average	Median	Max
Non-Widening	50.1	21	3359
Widening	48.8	24	1921

Source: compiled by the study team using eCorda data; June 2023 Corda data release.

The most connected organisations in the Horizon Europe network are presented in Table 5. Degree centrality represents the number of connections that a particular organization (node) has to other organizations within the network. Notably, larger research organizations such as the Fraunhofer Society, CNRS, and CSIC demonstrate higher degree centralities, reflecting

their extensive collaborative networks. This prominence can be attributed to their broad research agendas, comprehensive funding access, and established international collaborations. Moreover, we can observe that many Greek universities rank among the most connected institutions from Widening countries. **Also, it is observed that organisations from Widening countries usually have lower degree centralities.**

Table 5. Most connected organisations in Horizon Europe

Non-Widening	Degree centrality	Widening	Degree centrality
Fraunhofer Society	3359	National Centre for Research and Development (Greece)	1921
Spanish National Research Council (CSIC)	2560	University of Ljubljana	1315
French National Centre for Scientific Research (CNRS)	2559	Aristotle University of Thessaloniki	1208
National Research Council (Italy)	2351	National Technical University of Athens	1183
Catholic University of Leuven	2080	Foundation for Research and Technology (Greece)	1183

Source: compiled by the study team using eCorda data; June 2023 Corda data release.

The Widening countries consistently show a marginally longer average path length across all frameworks, suggesting that they might occupy fewer central roles in the network or maintain fewer direct connections compared to their Non-Widening counterparts. Table 6 reveals a notable consistency in average path lengths across the FP7, Horizon 2020, and Horizon Europe frameworks for both Non-Widening and Widening countries. This uniformity suggests that the level of interconnectedness within the network has remained stable over time, without significant alterations from one Framework Programme to the next. Despite this stability, we see a slight variation between the Non-Widening and Widening countries.

Over time, there is a discernible but slight decrease in the average path lengths for both groups, indicating a potential increase in network density or efficiency. Organisations could be forming closer or more direct connections as the EU Framework Programmes evolve. Nonetheless, the minor differences in path lengths do not point to any significant shifts in collaboration patterns. Rather, the incremental decline may reflect a trend towards enhanced efficiency and greater interconnectedness within the network, possibly as a result of concerted EU initiatives aimed at fostering more robust collaboration among member states.

Table 6: Average path length comparison (unweighted)

Framework Programme	Non-Widening	Widening
FP7	2.771	2.798
Horizon 2020	2.739	2.754
Horizon Europe	2.737	2.758

Source: compiled by the study team using eCorda data; June 2023 Corda data release.

Also, we can look at the average path length measurement through prism of Watts' (1999) seminal work "Small Worlds" that provides an additional layer of understanding, particularly with his exploration of the 'small-world network' model. The model highlights the significance of shortcuts in networks—connections that bridge distant parts of the network, thereby reducing the average path length between any two nodes.

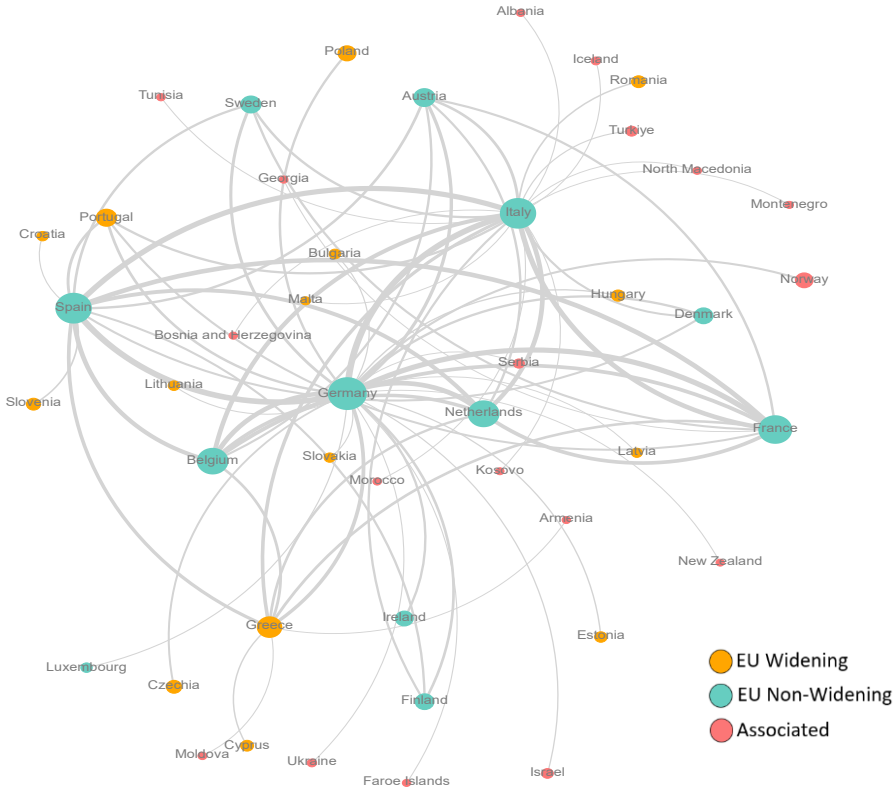

Figure 6. Small worlds representation of main collaborations in Horizon Europe. Source: elaborated by the study team using eCorda data; June 2023 Corda data release.

Even in a landscape marked by a core-periphery structure, where central (Non-Widening) and peripheral (Widening) countries are distinguished by their integration into the network,

the presence of 'shortcuts' between less connected, peripheral countries and the core can significantly enhance the network's overall connectivity and innovation potential. For example, as seen in Figure 6, Greece, Spain, Italy do serve as bridges between distinct parts of the network, so called “small worlds”. And the more bridging countries between Widening and Non-Widening exist the shorter the path length and the better the connectivity.

3. What are the patterns of collaboration between framework programmes and what the most related countries?

3.1. Patterns of collaboration between Widening and Non-Widening countries

The following analysis shadows the methodology outlined by Ravet and Balland (2018, p.12). The connections between two nodes (countries) are normalised by dividing the number of connections by the number that would be expected by chance. This controls for differing levels of participation and ensures that the connections shown are more likely to be meaningful. Only the top 4 edges (connections) for each country are kept, which helps to focus on the strongest relationships rather than all connections. The size of the nodes represents the eigenvector centrality. The layout of the graphs is Fruchterman-Reingold layout however it does not hold meaning. Therefore, the position of the countries on the graph is not relevant. Only the connections (edges) between countries are meaningful, which indicates patterns of collaboration. The colours of the edge represent the destination of the link.

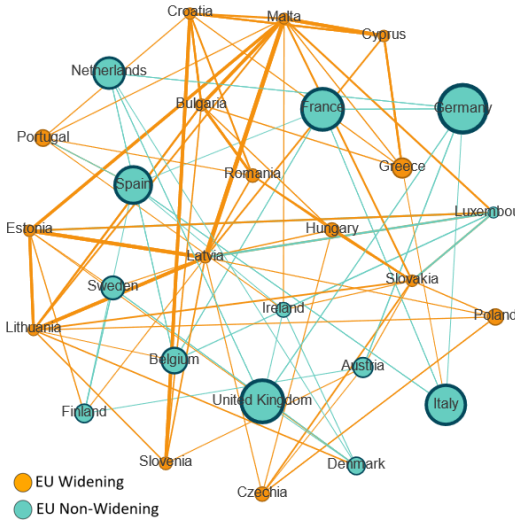

Figure 7. Most related countries and clusters in FP7. Source: elaborated by the study team using eCorda data; June 2023 Corda data release.

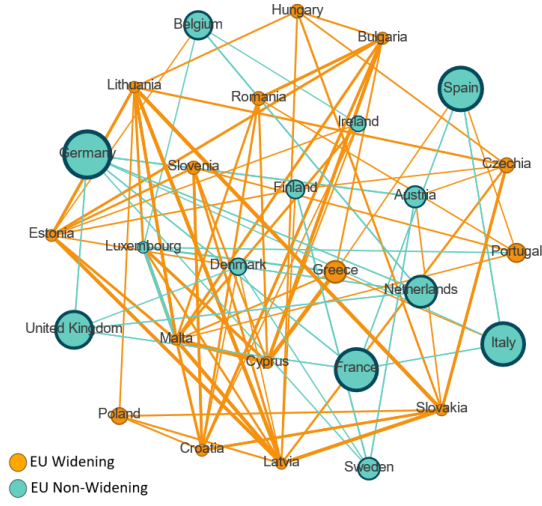

Figure 8. Most related countries and clusters in H2020. Source: elaborated by the study team using eCorda data; June 2023 Corda data release.

When we examine the four strongest connections of each country during FP7, discernible patterns of collaboration emerge. Notably, a significant cluster comprising Estonia, Lithuania, and Latvia indicates a robust regional collaborative network. Additionally, Malta, Estonia, and Latvia form a distinct collaborative triangle. This could be related to both geographical

(physical distance) and cognitive (similarity in knowledge bases and expertise) proximity.[12] Then, in Horizon 2020, new clusters appear, such as the one involving Lithuania, Slovakia, and Czechia, along with the traditional ties between Bulgaria and Romania, as well as the ongoing cooperation between Greece and Cyprus. Moreover, some Non-Widening countries are also collaborating with Widening countries, such as Portugal with Spain, Italy with Greece, and France with Czechia.

Figure 9, which includes data from the first two years of Horizon Europe implementation, reveals that these historical collaboration roots have become even more pronounced. This may be the result of strategic investment oriented towards a specific group of countries. For instance, the thickness of the link between Romania and Bulgaria in different Framework Programmes indicates that they have further strengthened their relationship. Additionally, Slovenia and Croatia are collaborating more extensively than in the past. Additionally, the traditional triadic closure is observed between Denmark, Finland, and Sweden, as well as between France, Italy, and Spain. This suggests that following the Covid-19 pandemic, countries are more inclined to cooperate with others that are in close proximity and have similar strategic interests or socio-economic conditions. **It also implies that Widening countries may not depend as heavily on Non-Widening countries to initiate collaborations.**

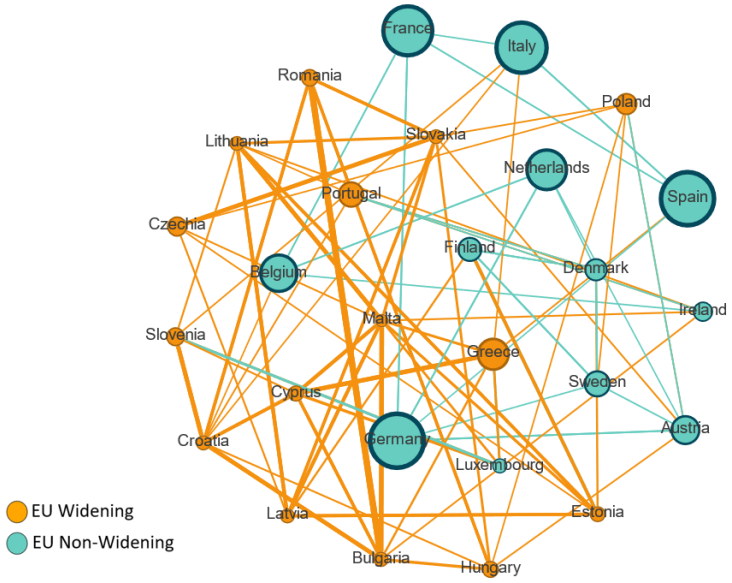

Figure 9. Most related countries and clusters in Horizon Europe. Source: elaborated by the study team using eCorda data; June 2023 Corda data release.

3.2. Network hub analysis

Hubs are organisations which are highly influential in the network. They are those organisations which are in the top 2% of both degree and eigenvector centrality rankings. This refers to the organizations that are within the top 2% in terms of connectivity in the network. In this context, connectivity is measured by both the number of direct links an organization has (degree centrality) and the significance of these links (eigenvector

[12] According to Boschma's (2005) framework there are five types of proximity: geographical, cognitive, social, organisational and institutional proximity.

centrality).[13] In other words, these organizations are not just connected to many others but are also connected to those that are themselves highly connected and influential. This position allows them to have a greater impact on the network, potentially influencing the direction of collaborations and the flow of information.

From the Table 7 we can see that in FP7 (Framework Programme 7), there were 67 "Widening" organisations that were among the top 2% in terms of network connectivity. In contrast, there were significantly more "Non-Widening" organisations in this top tier, with a total of 414.The Horizon 2020 programme shows an increase in the number of influential organisations in both categories: 88 "Widening" and 504 "Non-Widening" organisations. In the Horizon Europe programme, the number of top influential "Widening" organisations decreased to 47, while the number of "Non-Widening" organisations also decreased but remained higher at 214**. The data indicates that organisations from Non-Widening countries consistently played a more significant role within the network across all three Framework Programmes.** However, higher number of "Non-Widening" organizations inherently increases their likelihood of falling within the top 2% of most connected entities simply due to their greater volume. Additionally, there is a notable increase in the total number of influential organisations from FP7 to Horizon 2020, followed by a decrease in Horizon Europe, due to data availability.

Table 7: Network hub breakdown

Framework Programme	Widening	Non Widening
FP7	67	414
Horizon 2020	88	504
Horizon Europe	47	214

Source: compiled by the study team using eCorda data; June 2023 Corda data release.

The Widening country group, in Figure 10, represented by the orange area, has a peak at the lower end of the scale, indicating that most countries in this group have a small number of network hubs, most Widening countries host either zero or one network hub. **This implies few influential organisations within Widening countries group**. The distribution declines quickly and shows that very few countries have many hubs. The shape of the distribution in Figure 10 is similar for previous FPs.

The "Non-Widening" country group, shown in blue, has a broader and flatter distribution. This suggests that countries in this group have a more varied number of network hubs. There is a peak at a lower number like the "Widening" country group, but there are also countries with a higher number of hubs extending towards the right part of the graph. Non-Widening countries tend to have more network hubs than Widening countries overall.

[13] As explained by Ravet and Balland (2018), Network hub is calculated as a dummy variable (0/1) that takes the value 1 if a participant belongs to the top 2% of both the degree and eigenvector centrality distribution.

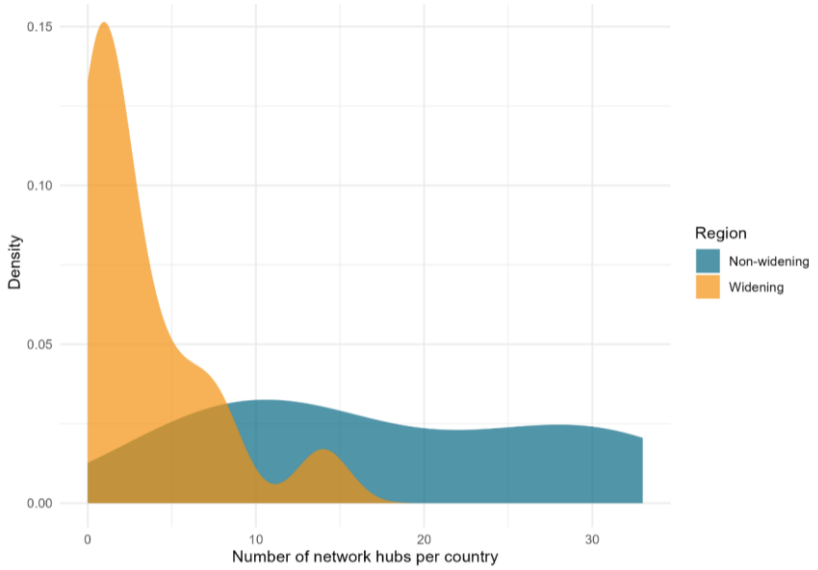

Figure 10. Network hub distribution for Horizon Europe. Source: elaborated by the study team using eCorda data; June 2023 Corda data release.

3.3. Are Non-Widening countries opening up to Widening countries?

This section examines the extent to which Non-Widening countries are increasing their collaborations with Widening countries. In Figure 11 we can observe a more detailed image of the collaborations between Widening countries and Non-Widening countries (orange).

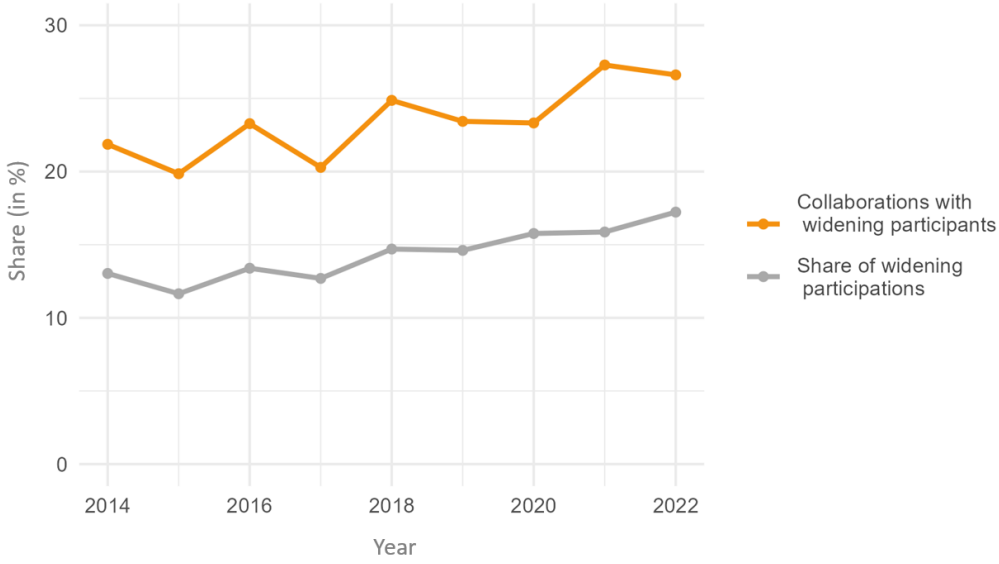

Figure 11. Collaborations of widening countries with Non-Widening countries. Source: elaborated by the study team using eCorda data; June 2023 Corda data release.

This was calculated for each year, where the total number of collaborations between Widening and Non-Widening countries was divided by the total number of collaborations that

Non-Widening countries engaged in. While in grey we can observe the participation of Widening countries as a share of all participations.

It is visible that the trend is stable and increasing over the years. This indicates a **gradual rise in collaborations and an opening up of Non-Widening countries to Widening countries.** The grey line tracks the percentage of all participations from Widening countries, showing a pattern that is relatively steady without significant fluctuations. Over the long term, both trends show a gradual increase, suggesting that increased participation is likely followed by increased collaboration.

4. Has the centrality position of country groups changed in different Framework programmes?

Eigenvector centrality is the measure of the influence of a node in a network. It not only considers the number of connections a node has (degree centrality) but also the number of connections their connections have. In other words, having connections to highly connected nodes contribute more to a node's score than equal connections to less influential nodes.

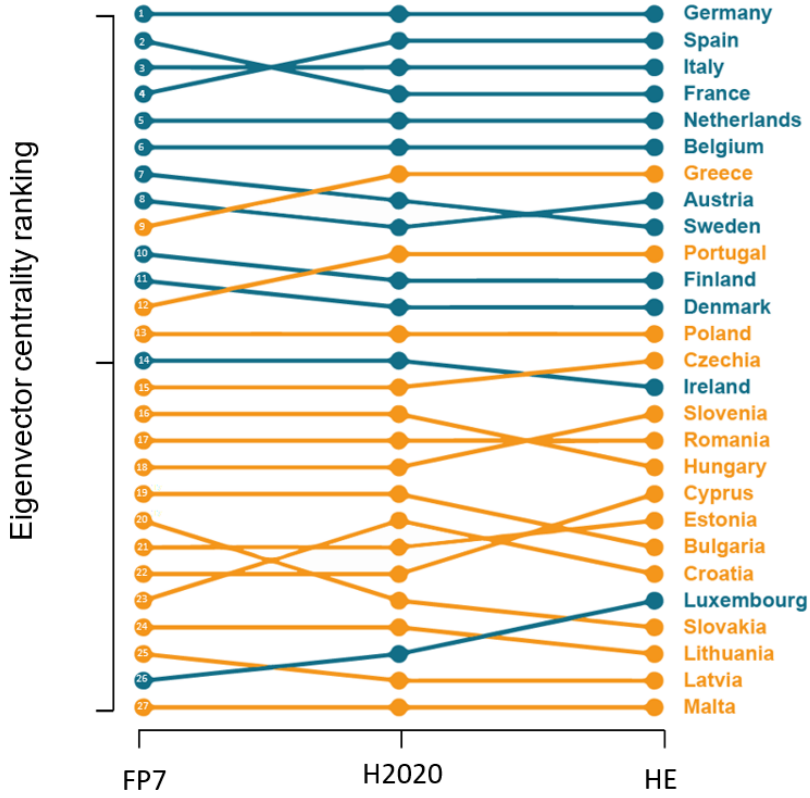

Figure 12. Country position by eigenvector centrality. Source: elaborated by the study team using eCorda data; June 2023 Corda data release

The lines in Figure 12 represent countries, and their positions on the horizontal axes correspond to their eigenvector centrality rankings within each framework programme. The leftmost point is the ranking in FP7, the middle in H2020, and the rightmost in HE (Horizon

Europe). For instance, some countries show a steep trend upwards or downwards, indicating a meaningful change in their centrality from one programme to the next.

A few countries, from the “Non-Widening countries” (in blue) maintain higher eigenvector centrality rankings than “Widening countries” (in orange), indicating they are more central in the network. Countries such as Germany, Italy, Netherlands, Spain, maintain a stable and high centrality across all programmes, indicating their sustained influence within the network. Countries like Luxembourg, Slovakia, Lithuania, and Latvia have low centrality rankings across all programmes, suggesting they are less central in the network. There are notable shifts for some countries, such as Greece, Portugal, Slovenia, Luxemburg which has moved from the lower centrality in FP7 to a higher ranking in HE. This could indicate a growing influence or integration within the research network. However, these changes could also reflect their evolving participation status, with Greece changing from a Non-Widening to a Widening country, and Luxembourg moving from Widening to the Non-Widening country group.

In the following figure however, when normalised by population, the positions of some countries have changed compared to the non-normalised rankings. For instance, smaller countries with high eigenvector centrality scores may rank higher on the normalised plot, reflecting a greater level of connectivity per capita. **Normalising by population size gives a more equitable basis for comparison among countries, as it reduces the bias that** can occur due to larger countries naturally having more connections or resources simply because of their size.

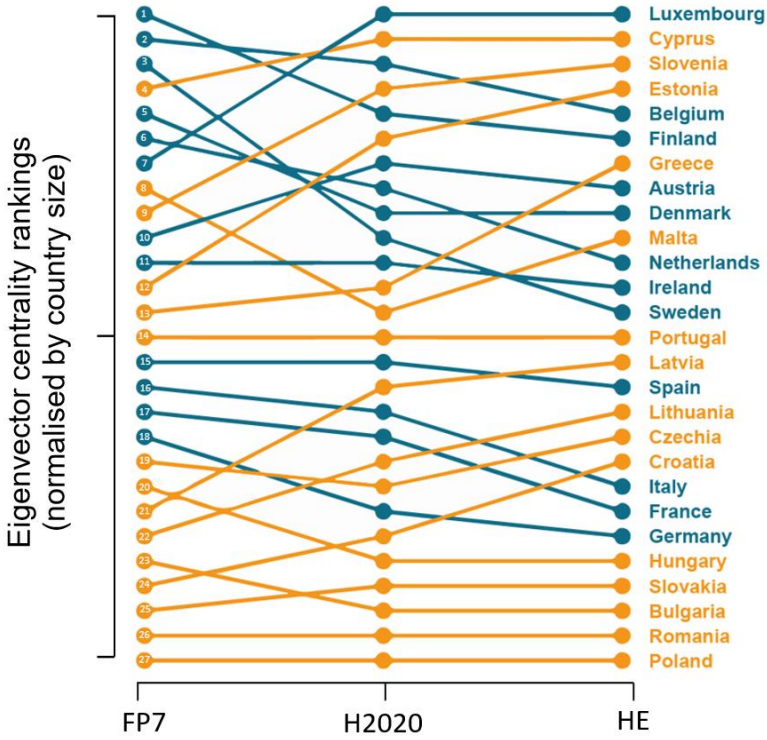

Figure 13. Country position by eigenvector centrality (normalised by population). Source: elaborated by the study team using eCorda data; June 2023 Corda data release.

Smaller countries hold better positions in the normalised ranking, potentially showing that they are more active or efficient in their connections relative to their size, compared to larger countries. It is visible that the impact of normalisation may be more significant for Widening countries (orange), if they have smaller populations, potentially elevating their relative centrality in the plot. Estonia for example, Latvia, Lithuania, Greece, have much higher centrality when normalised by population. Also, in this normalised plot Belgium and Finland, Austria became less active in the number of collaborations per capita.

5. Conclusion

This paper reveals insights into the evolving landscape of research and innovation collaboration, spotlighting particularly the role and integration of Widening countries within the knowledge networks formed by the Framework Programmes.

The analysis underscores the pivotal role of big EU Non-Widening countries as constant, central nodes within the network across FP7, Horizon 2020, and the nascent stages of Horizon Europe. Their sustained centrality not only signifies their leading positions in steering research consortia and setting research agendas but also highlights their capacity for generating significant spillover effects through knowledge sharing. However, the slight shifts in network density and the evolving configurations of collaborations signal a dynamic landscape where new patterns of partnership and interaction are emerging.

Particularly noteworthy is the evolving participation of Widening countries within these networks. While the initial lower participation shares point to the challenges faced by these countries in integrating into established research networks, the subsequent increase in their collaboration shares reflects the gradual but tangible impact of the EU's policies, as evidenced by the increased involvement of countries such as Greece, Portugal, and Slovenia. However, the Widening countries from Southeast and East Europe are still having modest participation within the collaboration networks. Hungary has seen a decrease in the collaboration share between Framework Programmes. Meanwhile, Poland, Romania, and Bulgaria remain low but constant in participation shares. An increase in collaboration between Romania and Bulgaria was observed, an orientation towards Greece as a bridge to the core of the network could benefit all three countries. Greece has relatively well-developed research infrastructure and has participated in EU framework programmes for a longer period, which makes it also more experienced with EU policies and frameworks compared to Bulgaria and Romania. The bridge position of Greece would make it possible for Bulgaria and Romania to easier connect with partners from Non-Widening countries. Similarly, a strong and persistent regional cooperation of Baltic countries was noted.

Notably, the analysis of network dynamics reveals the presence of shorter path lengths in the collaboration networks involving Widening countries. Shorter paths within a network are indicative of more direct connections between nodes (in this case, countries, or institutions), which can facilitate faster and more efficient dissemination of knowledge and resources. This is particularly significant for Widening countries as it suggests these countries are moving closer to the core of the research network, thereby potentially gaining better access to collaborative opportunities and the accompanying benefits in terms of knowledge exchange, innovation, and research capacity building. However, this may also be the result of so-called bridges that connect the periphery to the network core, such as **Italy**, **Spain**, **Greece**, **Germany**.

Moreover, the working paper notes a nuanced evolution in the collaborations of Non-Widening countries, suggesting a gradual **'opening up'** to partnerships with Widening countries. However, we see that countries that are more far away collaborate less, therefore

geographical distance may remain one of the motives for little collaboration between Widening and Non-Widening countries. Important insights for Widening countries are seen in the network hub distribution which shows a peak at lower degrees of collaboration, implying that there are few highly influential organizations within these countries, where most Widening countries host either zero or one network hubs. This suggests that these countries contain **fewer influential organizations** capable of initiating extensive collaborations.

Emerging trends in the data from the first two years of Horizon Europe further underscore some collaboration shifts, revealing that historical collaboration roots have become even more pronounced, potentially fuelled by strategic investments aimed at reinforcing regional ties. The enhanced connectivity between **Romania and Bulgaria**, along with increased collaboration between Slovenia and Croatia, exemplifies this trend. Traditional collaborative groups like the triadic closure observed between Denmark, Finland, and Sweden, as well as between France, Italy, and Spain, suggest that following the Covid-19 pandemic, countries are more inclined to cooperate with others that are in **close proximity** and have similar strategic interests or socio-economic conditions. This also implies that Widening countries may not depend as heavily on Non-Widening countries to initiate collaborations.

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This paper complements the study on Excellent Science under Horizon Europe. The analysis investigates the integration and role of Widening countries within the collaborative networks established by the European Union's Framework Programmes, such as FP7, Horizon 2020, and the early stages of Horizon Europe.

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