SOCIAL NETWORK ANALYSIS OF ENERGY PROJECTS IN THE EU 7TH FRAMEWORK AND HORIZON 2020 PROGRAMMES

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ABSTRACT

SOCIAL NETWORK ANALYSIS OF ENERGY PROJECTS IN THE EU 7TH FRAMEWORK AND HORIZON 2020 PROGRAMMES

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This dissertation investigates the social network dynamics of energy projects funded under the EU's 7th Framework Programme (FP7) and Horizon 2020, using Social Network Analysis (SNA) to examine the evolution of collaboration networks and their impact on innovation. The study aims to identify significant changes in the characteristics of these projects, assess the influence of network structures on innovation outcomes, and evaluate the efficacy of the EU's top-down approach to innovation policy. By comparing SNA results with conventional statistical analyses, the research provides a comprehensive understanding of how collaborative efforts within energy projects contribute to achieving the EU's ambitious renewable energy and efficiency targets. The findings highlight the importance of adapting policy frameworks to better address regional and sector-specific challenges, offering methodological insights for future research and policy design.

Keywords: Social Network Analysis, EU Framework Programmes, Energy Projects, Innovation Policy, Structural Holes, Brokerage Roles

ÖZ

AB'NİN 7. ÇERÇEVE VE HORIZON 2020 PROGRAMLARINDAKİ ENERJİ PROJELERİNİN SOSYAL AĞ ANALİZİ

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Bu tez, AB'nin 7. Çerçeve Programı (FP7) ve Horizon 2020 kapsamında finanse edilen enerji projelerinin sosyal ağ dinamiklerini araştırmakta ve Sosyal Ağ Analizi (SNA) kullanarak işbirliği ağlarının evrimini ve bunların yenilik üzerindeki etkilerini incelemektedir. Çalışmanın amacı, bu projelerin özelliklerindeki önemli değişiklikleri belirlemek, ağ yapıların yenilik sonuçları üzerindeki etkisini değerlendirmek ve AB'nin yukarıdan aşağıya yenilik politikasının etkinliğini ölçmektir. SNA sonuçlarını geleneksel istatistiksel analizlerle karşılaştırarak, araştırma enerji projelerindeki işbirlikçi çabaların AB'nin iddialı yenilenebilir enerji ve verimlilik hedeflerine ulaşmasına nasıl katkıda bulunduğuna dair kapsamlı bir anlayış sunmaktadır. Bulgular, politika çerçevelerinin bölgesel ve sektörel zorlukları daha iyi ele alacak şekilde uyarlanmasının önemini vurgulamakta ve gelecek araştırmalar ile politika tasarımı için metodolojik içgörüler sunmaktadır.

Anahtar Kelimeler: Sosyal Ağ Analizi, AB Çerçeve Programları, Enerji Projeleri, Yenilik Politikası, Yapısal Delikler, Aracılık Rolleri

To my family

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As I look forward to continuing my academic journey, I am eager to contribute to the literature and am hopeful that the comprehensive research presented in my thesis will make a meaningful impact in the field of social network analysis and energy project development.

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LIST OF ABBREVIATIONS

EU: European Union
FP: Framework Programmes
ERA: European Research Area
SNA: Social Network Analysis
STI: Science, Technology and Innovation
NUTS: Nomenclature of territorial units for statistics
RDI: Research -Development -Innovation
TRL: Technology Readiness Level

CHAPTER 1

INTRODUCTION

The pursuit of innovation has been a cornerstone of socio-economic and technological advancement, aiming to provide solutions to complex socio-economic and technical challenges. In the context of the European Union (EU), innovation has been strategically aligned with ambitious policy objectives to drive progress across various sectors, particularly energy. This chapter sets the stage for an in-depth analysis of the social network dynamics of energy projects funded under the EU's 7th Framework Programme (FP7) and Horizon 2020. It explores how these collaborative networks have evolved and their consequent impact on innovation, with a specific focus on the EU's energy policy.

The European Union has delineated robust energy policy targets to address the pressing challenges of climate change, energy security, and sustainability. By 2030, the EU aims to source at least 32% of its energy from renewable sources, enhance energy efficiency by at least 32.5%, and reduce greenhouse gas emissions by at least 40% compared to 1990 levels (European Commission, 2019). Achieving these targets necessitates significant advancements in energy technologies and systemic innovation within the energy sector. The alignment of innovation policies with these targets is critical, as innovative research and development (R&D) efforts are essential for meeting the EU's energy and sustainability goals.

The EU's Framework Programmes (FPs) have been instrumental in promoting collaborative research and innovation across member states. Initiated in 1984, the FPs have progressively evolved, with FP7 (2007-2013) and Horizon 2020 (2014-2020) being particularly significant in terms of budget allocation and strategic focus. These programmes have aimed to enhance the competitiveness of the European Research Area (ERA) by funding collaborative projects involving a diverse array of participants, including universities, research centers, public bodies, and private companies

(European Commission, 2021).

The FPs have sought to address the innovation lag between the EU and its global competitors by fostering strong collaborative networks. The core philosophy underpinning these programmes is the belief that multidisciplinary, multinational, and multi-institutional consortia can drive significant advancements in various sectors, including energy. This top-down, competitive funding approach is designed to catalyze innovation, ensuring that the EU remains at the forefront of technological development and sustainability.

This dissertation focuses specifically on energy projects funded under FP7 and Horizon 2020. The energy sector is a critical area of analysis due to its direct relevance to global environmental issues such as climate change and its sensitivity to regional and geopolitical dynamics. By examining the social network dynamics within these projects, this study aims to provide insights into the effectiveness of the EU's innovation policies in the energy sector and identify potential areas for improvement.

Social Network Analysis (SNA) is employed in this research to investigate the collaboration networks within energy projects funded by FP7 and Horizon 2020. SNA allows for the systematic examination of the structure and dynamics of these networks, identifying key actors, their roles, and the overall impact of network structures on innovation outcomes. By integrating SNA with conventional statistical analyses, this research offers a comprehensive understanding of how collaborative efforts within energy projects contribute to achieving the EU's energy policy objectives. The primary objective of this research is to explore the evolution and impact of network structures in energy projects under FP7 and Horizon 2020. By investigating the social network dynamics of energy projects within the EU's Framework Programmes, this dissertation aims to contribute to a deeper understanding of how innovation policies can be designed and implemented to effectively address regional and sector-specific challenges, thereby supporting the EU's energy and sustainability goals

In this introductory chapter we present the subject we shall investigate in this dissertation. **Section 1.1** comprises a short bibliographic analysis of the technological innovation concept and the introduction of the innovation lag problem between the

European Union (EU) and its competitors, as seen by the European Commission. The Section also introduces the Framework Programmes (FPs) approach experienced in the last 40 years by the European Commission as a remedy to reduce the observed innovation lag. The main part of this section will present a review of different analyses and critics of the EU FPs - and insist in particular on some of its global hypotheses such as those assuming the applicability of the European Commission recipes indistinctively to all science-technology-innovation areas and to all European countries and regions.

Based on this section, **Section 1.2** clarifies the aims and the significance of our work organized around two main research questions, which are, first, whether there are major evolutions between the global characteristics of Energy projects in FP7 and Horizon 2020 programmes and, second, whether the analysis may gain in explanatory power when SNA is combined with descriptive statistical analysis and with some micro-level analysis both qualitative and quantitative. To this end, we compared SNA results with those of the more conventional descriptive statistical analyses. Finally, **Section 1.3** presents the general organization of the thesis manuscript.

1.1. Statement of the problem

Innovation is one of the key words in our world. It has several meanings depending on the concerned area but in general, it means generation and organization of new knowledge to propose solutions to socio-economic and technical problems or challenges (Freeman 1982; Nelson 1993; Freeman 2003; Foray 2004; Metcalfe 2005). According to the Oslo Manual, innovation is "a new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)". The Frascati Manual further defines research and experimental development (R&D) as "creative and systematic work undertaken in order to increase the stock of knowledge – including knowledge of humankind, culture, and society – and to devise new applications of available knowledge".

These definitions underscore the importance of innovation in addressing the EU's ambitious targets within its Framework Programmes (FPs), such as Horizon 2020 and

FP7. The European Union has set forth specific energy policy targets which include sourcing at least 32% of its energy from renewable sources by 2030, improving energy efficiency by at least 32.5%, and reducing greenhouse gas emissions by at least 40% compared to 1990 levels. The alignment of innovation policies with these targets is critical, as innovative R&D is essential for achieving these goals. The Framework Programmes are designed to foster such innovation, supporting projects that advance renewable energy technologies, enhance energy efficiency, and contribute to the reduction of greenhouse gas emissions.

Most of the early studies, but even today, refer to the classical works of Joseph Schumpeter (1942, 1947), Vannevar Bush (1945), Rupert Maclaurin (1950), Simon Kuznets (1951), Walt Rostow (1952), Richard Nelson (1959), Jacob Schmookler (1966) and others. These classical works contributed to the emergence of immense literature around the concept of technological innovation (Godin, 2008; Kashani and Roshani, 2019).

Innovation is indeed strongly dependent on scientific and technological knowledge but not only; organizational aspects also matter, such as the route from invention to innovation, market penetration, its social acceptance, etc. (Brozen, 1951; Ruttan, 1959; Ames, 1961; Scherer, 1965; Utterback, 1974; Hughes, 1982; Forrest, 1991; Edgerton, 2004; Godin, 2006; Jackson, 2011; Oh et al., 2016). How innovation or the process from invention to innovation should be accelerated is a capital question today in developed countries as well as developing ones (Lundwall, 1992; 2009). How the innovation ecosystem should be organized and financially supported by public authorities but also by private companies? What are the relations between the knowledge ecosystem and the innovation process? The question arises as to whether authorities can influence the configuration of the Research-Development-Innovation (RDI) system. Specifically, can they enhance the cycle from Research to Innovation, thereby making it more virtuous? The aim would be to accelerate the transition from new knowledge generation, or the organization of existing knowledge in novel ways, to the development of commercially viable products.

A crucial aspect of this process is the avoidance of "Death Valleys"—points at which

innovations fail to progress from conception to market. By effectively managing this cycle, authorities can address societal challenges and positively impact the socio-economic and environmental conditions of a nation or region.

This perspective is supported by extensive research, including seminal works by Edquist (1997), Sorenson (2006), Chaminade and Edquist (2010), Berrone et al. (2013), and Calvo-Gallardo et al. (2022). These studies underscore the importance of a well-structured RDI system in fostering innovation and development.

An important question is whether there are universal strategies to accelerate innovation, or if innovation is inherently context-dependent, shaped by historical, geographical, cultural conditions, and specific application domains.The European Union has been experimenting with a general and global approach to strengthen the innovation process within EU member states through its Framework Programs (FPs) since 1984 (Farole et al., 2011; Hazir et al., 2016; European Commission, 2017; 2018). Since its inception 40 years ago, the global philosophy of the FPs has not changed much and is a collaborative projects-based funding system approach. The idea is to develop strong collaborative programs between various partner types (universities, research centers, public bodies, and private sector companies of all sizes). There are also rules for building eligible projects consortia such as the presence of participants from at least 3 member states (or associated states). The idea is therefore to increase the competitivity of the European Research Area (ERA) and of the associated innovation system, both at the EU level and at the member states levels. So, the European Commission message seems to be: work together at a pre-competitive level, increase the coherence of the global EU Innovation system and close the gap with our main competitors, such as the USA, China, Japan, and others, and you will be funded (European Commission, 2021).

The selection of the projects in FPs is based on a top-down approach managed by successive calls for proposals where the RDI call topics are identified by the European Commission, following some consultations with the main stakeholders, especially from industry. The submitted eligible projects are evaluated by a panel of experts, appointed by the European Commission. The competition for funding is harsh between

projects' consortia for the same topic as the success rate is around 10% on average (Wanzenböck et al., 2020).

After the first 7 FPs, between 1984 and 2013 (lasting each 4 years), the EU moved to the Horizon 2020 program between 2014 and 2020 and is now progressing through the Horizon Europe program for the period 2021 to 2027. Each FP budget experienced successive and important increases and is equal to 95.5 billion Euros for the Horizon Europe programme (Figure 1.1 FPs).

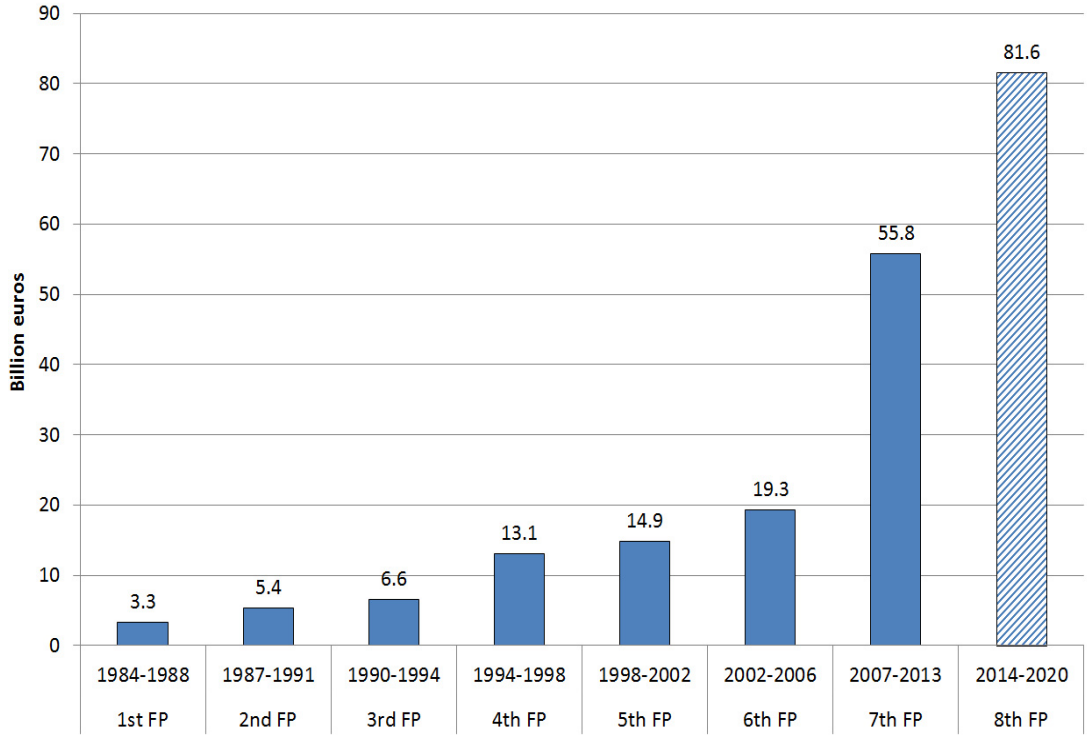


Figure 1.1: FP's Budgets

Source: European Commission; https://www.sbfi.admin.ch/sbfi/en/home

There are some differences between FPs' focus points, especially for those after FP6, namely in terms of their emphasis on knowledge generation or on problem solving by innovation, but the main philosophy is an unchanged belief that the European RDI system needs to be better organized along globally competitive, multidisciplinary, multi-national and multi-institutional consortia or excellency centers.

For example, the European Commission explains as below the important characteristics of FP7 and H2020 programs where the stronger emphasis on innovation

in H2020 appears clearly.

FP7 (2007–2013)

The European Commission's FP7 program aimed to integrate the research activities of member states, associated countries, and the private sector into the European Research Area (ERA). To support this goal, the Commission increased joint project funding, such as coordinating efforts between different member states through ERA-NETs and ERA-NET+ (European Research Area networks). Additionally, it promoted the alignment of national funding programs to create a sustainable transnational R&D support program and introduced Joint Programming Initiatives (JPIs) to address major European societal issues through coordinated EU-level research programs. The program also fostered public-private partnerships through initiatives like the transformation of European Technology Platforms (ETP) into Joint Technology Initiatives (JTI), enabling collaboration among industry, researchers, and government agencies (European Commission, 2007) .

Horizon 2020 (FP8) (2014–2020)

Building on FP7's integration of European research, Horizon 2020, with a budget of EUR 81.6 billion, continued to reduce thematic program funding from 59% to 53%, while increasing support for fundamental research from 13.7% to 17% and introducing the Access to Risk Finance program (3.7%). Horizon 2020 also established the European Institute of Innovation and Technology (EIT), akin to a European MIT. It replaced some FP7 instruments, such as Integrated Projects and Networks of Excellence, with Future and Emerging Technologies (FET) Flagships, each funded with half a billion Swiss francs over ten years, based on matching funds from member states, associated countries, and the private sector. Public-Public Partnerships (P2P) and expanded Joint Programming Initiatives (JPIs) were also part of the framework.

The program introduced Knowledge and Innovation Communities (KICs) through the EIT to strengthen cooperation between research institutes, higher education institutions, and industry. Horizon 2020 focused on integrating innovation more

deeply into the Framework Programs and facilitated access to risk finance for innovative companies, aiming to bridge the gap between research and market applications by offering loans with guaranteed interest rates (European Commission, 2014) .The Framework Programme (FP) approach is inherently global, operating on the premise that the innovation process possesses universal characteristics applicable across various sectors. This means that the principles and methodologies underpinning innovation are not confined to or dictated by any specific industry. Whether the sector in question pertains to agriculture, energy, mobility, or environmental issues, the FP approach maintains that the fundamental aspects of the innovation process remain consistent. Essentially, it posits a sector-independent perspective, suggesting that the strategies and dynamics driving innovation can be generalized and effectively applied across diverse fields of activity.It is also generic in the sense that it assumes that the regional or geographic dependences of the Innovation enhancement policies are minimal, and the same recipes are valid for all the member states despite the strong differences concerning their socio-economic, cultural, educational & research organizational systems. One may think that the FP approach is contributing to the formation of a homogeneous European system by reducing regional differences and fostering innovation with similar policy recipes (albeit in different technology areas following the Smart Specialization Strategy), in parallel to increasing its competitivity at the world level compared to its competitors. Therefore, the FP approach to boost innovation is an ambitious one, and its continuation in the last 40 years seems to suggest that it is considered successful by the European Commission and the Member States.

There are several studies in the "knowledge economy" literature which analyze and question these generic hypotheses of the FP approach and challenge its success stories; there are even investigations detecting the emergence of "oligarchic networks under EU FPs" (Breschi and Cusmano, 2004). These analyses concern the validity of the uniform geographic approach of the FP programs' innovation accelerating policies and recipes, not distinguishing between the regional organizational and cultural differences (Autant-Bernard et al., 2007; Wanzenböck, 2014; Balland and Rigby, 2017; Nepelski et al., 2019; Kveton, 2022; Rohe and Mattes, 2022; Meliciani, 2022; Frenken et al.,

2023; Maisonobe and Bernela, 2023). Other studies challenge the activity sector independence hypothesis of the EU innovation fostering recipes by detailing some sub-thematic programs such as nanotechnologies (Pandza et al. 2011), renewable energies (Kang and Hwang, 2016; Rosina Moreno, Diego Ocampo-Corrales, 2022), the agri-food sector (Fernandez de Arroyabe et al., 2021) or the global satellite navigation system (Balland, 2012). There are also studies that address only some chronological parts of the programs such as only the most recent ones, seeking to discover evolutions between the programs' philosophy and their outcomes, for example between FP7 and H2020, together with the aid of the "institutional impulse" concept (Calvo-Gallardo et al. 2022). They question if any European coherence is gained between the member states in terms of the conception, design, and implementation of their innovation policies after 40 years of FP experience (Van der Loos, 2011; Akçomak et al., 2018; Erdil et al., 2022) and especially if any center-periphery relations still remain (Tijssen, 2008; Uhlbach et al., 2017; De Noni et al., 2018), or how the geographical and social distances are related to each other (Maggioni, 2007; 2009; Capello and Caragliu, 2018).

Most analyses use the statistical data generated by the European Commission, especially the CORDIS open databases (De Juana-Espinosa and Lujan-Mora, 2019; 2020). The content of these databases is explained in Chapter 3. Also, most of them mobilize statistical analyses tools, such as the descriptive conventional ones or the more sophisticated SNA approaches and metrics (Cerqueti et al., 2023). By doing so, another generic approach is however accepted, this time from the analyzers side, assuming that such tools are equally applicable to all STI systems and all cultural areas across the EU, independently of the geographical and socio-cultural variations.

Therefore, one can detect a gray zone in all these studies where the uniform validity hypothesis of the top-down FP approach by the European Commission, on the one hand, and, that of the used analysis tools, on the other hand, seems un-questioned. One may even question whether the two hypotheses are not reinforcing each other. In addition, the kind of circularity of the network approach reasoning seems also questionable: the EU is overtly requesting a network type STI system organization and the social analysts of the same system in the making are using some network analysis

tools, that the European Commission is also using (Balland et al., 2019), which seem to justify the request. In this dissertation we tried to soften these a priori global acceptances as much as we could.

Based on this brief examination of the present EU approach to boost its innovation capacities through the FP developed in the last 40 years and based on the studies analyzing this approach, we identified two main research questions for our work that we shall briefly expose in the next section.

1.2. Aims and significance of the research

The uniform nature of the EU FP approach to innovation processes appears to us questionable, in terms of its effectiveness and relevance for future developments that will be marked by several local or regional uncertainties and therefore by regional attempts to adapt the innovation systems to several local challenges. To detect what segments of the uniform approach to innovation should be amended, we decided to confine our analyses to portions of the FP experience, both thematically and temporally. This would help in future studies to test the relevance or weaknesses of the uniform approach by increasing the number of detailed sector and period specific case studies and by comparing them.

Thematically, we selected to focus on the Energy programs of FPs. We think that this is appropriate given the present importance of this area, its relations with global environmental issues such as the global warming and the recent CO_2 mitigation approach proposed by the EU, namely the Green Deal regulations (European Commission, 2019b). The extreme sensitivity of this domain to regional and rapidly changing geopolitical conditions also makes the energy area a perfect one to detect the impacts of any institutional policy changes in the innovation support mechanisms, the so-called "institutional impulse" (Calvo-Gallardo et al. 2021; 2022) on the re-organization of the European Energy STI System and Policy and on the outputs of the supported projects. We think that analyzing in depth one activity sector (here the FPs energy projects), and comparing with the insight from other activity sectors, may bring

some light on the hypothesis of the general validity of the FP approach adopted by the EU, independently of the proper features of each key topical area and their specific challenges. In addition, the FPs are not very often analyzed from the Energy domain glasses. The only studies we found on the comparison between Energy related FP projects in the FP7 and H2020 programmes concentrate on the corresponding network structural properties but they do not analyze the outputs of these programs, such as the patents and the publications (Calvo-Gallardo et al. 2021; 2022). In this dissertation we tried to fill this gap.

In terms of the contribution of this work to general innovation studies, we note that today's global evolutions in the Energy area seem to correspond to all the elements identified by Schumpeter (1942, 1947) to define an innovation situation such as (i) introduction of a new good (we may think of new mobility technologies such as electric cars, fuel cell and all their related equipment); (ii) introduction of a new method of production (here we may think of a generic development such as additive manufacturing which impacts several production sectors but primarily the energy sector with its huge market potential for home appliances and individual mobility; (iii) opening of new markets (here we may think about the renewable energy sector or the carbon trading sector or the waste to energy sector); (iv) conquest of a new source of supply of raw materials or half-manufactured goods (here we may think about the need for rare materials such as Lithium for electric car batteries, or Platinum for fuel cells, or the production of green hydrogen and green ammonia as new energy vectors; and (v) implementation of a new form of organization (here we may think about the digital transformation of the energy sector in relation to all the above elements but especially to energy efficiency and carbon mitigation technologies. Therefore, we are confident that the analysis of the energy sector RDI dynamics triggered by the EU Energy related FP will also inform us about the innovation dynamics in other sectors, both in terms of their similarities and differences compared to the dynamics in the energy sector.

Following Calvo-Gallardo et al. (2021; 2022), we also think that restricting the temporal dimension is necessary to better analyze those recent challenges and the dynamics of the project's responses to changes in the institutional innovation support policies Therefore, we also limited our analysis time span to only FP7 and H2020

programs. We think this is reasonable, as the transition from FP7 to H2020 was characterized by some new expectations from the EU, such as the request for more solution-oriented projects to respond to societal challenges (see section 1.1). To capture whether the modifications between FP7 and H2020 (FP8) objectives and ambitions effectively brought about the expected outcomes, we analyzed the evolution of the global and detailed structures of the established cooperation networks for Energy projects in these two programmes. In this context, the European Union's energy policy targets are particularly relevant. By 2030, the EU aims to source at least 32% of its energy from renewable sources, improve energy efficiency by at least 32.5%, and reduce greenhouse gas emissions by at least 40% compared to 1990 levels. The Framework Programmes, through their emphasis on innovation and R&D, play a crucial role in driving the advancements needed to meet these targets. The integration of new or improved technologies, as defined by the Oslo Manual, and the systematic work in R&D, as outlined by the Frascati Manual, are instrumental in progressing towards these policy goals. This alignment highlights the strategic role of innovation within the EU's broader energy and sustainability objectives. We did the same analyses for the statistics on patents and publications delivered by the Energy projects and estimated the average cost changes of a single patent and single publication between the two programs (Ertan, 2023a). In addition, we also made an analysis in terms of NUTs2 regional distributions for the Energy projects and participants in FP7 and H2020 programmes.

There solution-oriented projects with a focus on market dimension, we refer to the shift in focus from technological readiness to market applicability. This shift is evident in the transition from FP7 to H2020, where the Technology Readiness Levels (TRLs) have undergone significant change. In FP7, TRLs were generally lower, emphasizing early-stage research and scientific exploration. H2020, however, places a stronger emphasis on higher TRLs, prioritizing the marketability and commercialization of innovations.

This shift has profound implications for the structure of networks involved in EU-funded projects and their impact on regional development. The evolution from a

science and technology-oriented approach in FP7 to a market-oriented focus in H2020 is likely to influence how collaborations are formed and sustained. We think that, the policy shift from a science and technology orientation to a market orientation across various FP projects influence the network structure of collaborations.

Our research question, therefore, is: **How does prioritizing the market dimension of innovation in FP policies affect network structure in energy projects?**

As network structures evolve, policies must adapt. We posit that the increased market orientation of policies will lead to changes in network structures, necessitating policy adjustments at the micro, meso, and macro levels. This dynamic relationship suggests that policy frameworks must be flexible and responsive to the changing needs and priorities of innovation networks.

Sub-questions developed to explore this further include:

How can regional development policies be aligned with EU energy project goals to foster a more inclusive and innovative environment, considering the effects of EU policies on network structures?

These questions aim to explore how regional policies can be adapted to support the evolving landscape of energy innovation, ensuring that they promote inclusivity and drive competitiveness in line with EU objectives.

To explore these questions, we compared SNA results with those from more conventional descriptive statistical analyses (Ertan, 2023b). While this questioning is not the core focus of our thesis, we believe that micro-level studies can help refine macro-level analyses provided by the SNA approach. In our conclusive Chapter 5, we will propose some research lines in this direction.

1.3 Organization of the thesis

The thesis is composed of five chapters. Following this introductory chapter, chapter 2 focuses on the literature survey of the FP approach, delving into their evolution and importance in the realm of Research and Development and Innovation. A specific

emphasis is put on energy projects within FP7 and H2020 programmes, utilizing the European Commission CORDIS database as a critical source. Introduction to SNA as an analytical tool forms a pivotal component of this chapter, outlining its conceptual foundations and its applications in identifying collaboration networks within the energy domain. The comparative analysis of FP7 and H2020 energy projects, aligned with EU Commission expectations, serves as a cornerstone. The chapter concludes with a comprehensive discussion of SNA indicators and measures, offering a nuanced understanding of network metrics.

Chapter 3 includes the examination of the data sources we employed in our thesis and reviews the quantitative methodologies used to process and analyze our data. Three distinct parts cover a detailed descriptive statistical analysis of our data for FP7 and H2020 energy projects, providing preliminary results with SNA metrics, and an overview of the SNA approach with preliminary results to be developed in Chapter 4.

Chapter 4 is devoted to a detailed discussion of the results of the social network analysis and unfolds our findings. Employing SNA using the Pajek software package, the chapter is divided into three main parts: (i) Regional Network Analysis based on Energy Projects in FP7 and H2020, (ii) Comparison of Projects in FP7 and H2020, and (iii) Comparison of Participants in FP7 and H2020. They collectively address our research questions. Specific aspects such as NUTs2 regions' performances, innovativeness vs. energy demand/vulnerability, network hubs, structural holes, and brokerage roles are scrutinized. This chapter also presents a regression analysis, dissecting the impact of independent variables on the number of patents generated by the Energy projects we investigated.

Chapter 5 concludes the thesis. In this chapter, we first present a summary of the overall research findings of the thesis. Second, we discuss STI policy implications of the research from a holistic perspective and propose some policy tools for the improvement of the framework programmes in the field of energy. Finally, we state the limitations of the thesis and suggest some directions for future research.

CHAPTER 2

LITERATURE REVIEW

The Framework Programmes (FPs) for Research and Technological Development have been the principal funding mechanism for the EU's research and development policy. Since their inception in the early 1980s, energy has remained a pivotal investment area. This thesis utilizes data from the European Commission database on energy projects funded under the FP7 and H2020 programmes. The empirical analysis employs Social Network Analysis (SNA) tools to identify and examine collaboration networks within the energy sector, focusing on network formalization and structure. Initially, the analysis defines the units of analysis and their relational links (e.g., participants and projects), followed by the identification and application of key network metrics to categorize relevant actors based on their network positions. Furthermore, network visualization tools will be used to illustrate collaboration patterns.

Existing literature on EU energy policy underscores the Commission's expectations for fostering robust and dynamic collaboration networks to drive innovation, enhance energy security, promote sustainability, and ensure competitive energy markets. Specifically, the EU aims to create interconnected networks that facilitate the exchange of knowledge, integration of diverse expertise, and development of cutting-edge technologies. The policy expects these networks to include a broad spectrum of stakeholders, from academic institutions and research organizations to industry players and governmental bodies.

This study compares the structural and performance dynamics of FP7 and H2020 energy project networks to assess their alignment with the EU Commission’s expectations. Key network metrics, such as centrality, density, and clustering coefficients, will be analyzed to determine the efficiency and effectiveness of these

collaborative efforts. The evolution of these networks will be scrutinized to see if they have become more cohesive, innovative, and capable of addressing complex energy challenges.

By leveraging SNA, this research aims to provide a nuanced understanding of how EU-funded energy research networks have evolved over time. It will evaluate whether these networks have successfully facilitated the EU's strategic objectives, such as boosting renewable energy adoption, enhancing energy efficiency, and reducing carbon emissions. The findings will offer valuable insights into the role of network structures in achieving policy goals and will contribute to the ongoing discussion on optimizing EU research funding mechanisms to better support the energy sector's transition towards a sustainable and secure future.

The purpose of this chapter is to present an extensive overview of the formalization to analyze the structure and performance of R&D networks using SNA analytical tools. To do so, important indicators and their measures used in SNA will be presented and discussed. In addition, examples will be given on how these concepts are used in similar studies, not necessarily only for R&D networks but also for firms or other organizations. Section 2.1 below reviews therefore what SNA is, why it is used and how it evolved since its initial inception. This section addresses the fundamental definitions and concepts of the SNA framework. Section 2.2 discusses the relationships between network performances and network structures. In addition, SNA studies used in the analysis of other FP7 and H2020 programmes are summarized. Section 2.3 summarizes and concludes the chapter.

2.1 Social Network Analysis (SNA): what it is, why it is used and how it evolved?

Innovation and technological change studies suggest that networking between involved actors is the mechanism to achieve common research objectives between them (European Commission, 2015, p.10). An actors' network may be represented as a graph defined by the positions of the actors and the relations among them. Actors can be people, organizations or their units, technologies, products, regions, and

countries. Relations between the actors are considered to act as channels for the transfer of resources between them, including information, knowledge, and innovations. Networks are therefore complex structures which involve actors and patterns with their multiple relationships.

SNA is a methodology to decipher, decrypt and interpret the patterns of such relationships between the members of a network together with the directions and strengths of the flows of information. It allows to (i) "unveil the intensity and complexity of relational links, (ii) classify network actors according to their levels of access to information and their control over knowledge flows, and (iii) identify opportunities and potential bottlenecks for knowledge generation and diffusion" (Muniz and Cuervo, 2018: 1135).

The lineage of SNA started with Harvard scholars in 1920s and followed by mathematicians who developed the graph theory formalism. Mayo (1945) used graph theory in small groups suggesting that in such a group every person is linked by only one tie. The oldest and most well-known SNA is Milgram's small world concept (1967) in which although each person does not connect with every other directly, a chain of acquaintances links them. In the 1930s, Moreno (1937) conducted studies regarding people's choices on spending time with whom and at different distances. According to Freeman (2004), Moreno's studies became the heart of the SNA in which the terms "psychological geography" is used to investigate people's behavior and acting in their network (p.50).

The development of graph theory formalism spread to social anthropologists in the 1940s and to psychological studies. In 1970s the sociologists' network led the development of the field and after the 1990s the network of scholars consisting of Burt, Borgatti, Wellman, Cross and Freeman contributed to the social network methodology. Moreover, Manchester anthropologists Barnes, Bott, and Nadel investigated the structure of community relations in tribal and village societies in the 1950s. John A. Barnes published his influential work "Class and Committees in a Norwegian Island Parish" in 1954, introducing the concept of social networks in anthropology. Elizabeth Bott's seminal study "Family and Social Network" appeared

in 1957, examining the interconnections between family structures and social networks in urban England. S.F. (Siegfried Frederick) Nadel's contribution, "The Theory of Social Structure," was published in 1957, focusing on the theoretical underpinnings of social structures and relationships in various societies, including tribal and village contexts. Wambeke et. al (2012) discussed that original studies devoted a great deal of attention to the social and political relationships between individuals and the term “social network” was coined in late 1950s by social scientists focused on bounded group social categories. Freeman (2004) called the years between 1940 and 1960 as the dark ages of the social network analysis development because of the lack of “a recognized approach to social research that embodied the structural paradigm” (Zhang, 2010:9)

The contemporary SNA based on graph theory, which enabled mathematical calculations, started in 1960s. Freeman (2004) called this era the Renaissance of SNA, which was richly developed by Harvard scholars who contributed to theory building and research in this field by combining different SNA methodologies with also traditional approaches.

Another milestone for the progress of SNA is based on Granovetter’s “Strength of weak ties” theory (Granovetter 1973 and 1983) which stresses the importance of informal channels in establishing new relationships or finding new opportunities within the network (his data was based on finding new jobs). Zhang (2010) pointed out that Granovetter’s studies proposed the concept of embeddedness, expressing that social activities are embedded in social structures and that social structures are embedded in the individual’s social networks. Network embeddedness is a concept within the social network approach that refers to the degree to which individuals or entities are connected and integrated into a network of social relationships. It emphasizes the idea that social actors are not isolated entities but are embedded within a larger social structure characterized by various interpersonal connections and interactions. In the context of social network theory, the term "embeddedness" underscores the importance of considering the relationships and connections that individuals have with others in understanding their behavior, decision-making, and outcomes. A person's actions and choices are influenced not only by their individual

characteristics but also by the social context in which they are embedded. The concept highlights that social phenomena cannot be fully understood by studying individuals in isolation but require an examination of the broader network in which they are embedded. Therefore, it is claimed that introducing embeddedness to the social network approach brought this field closer to mainstream social research.

Freeman (2014) summarizes social network analysis in terms of four important features: (1) it involves the intuition that links among social actors are important; (2) it is based on the collection and analysis of data that record social relations that link actors; (3) it draws heavily on graphic imagery to reveal and display the patterning of those links; and (4) it develops mathematical and computational models to describe and explain those patterns.

SNA has become the core methodology utilizing graph theory, algebra, statistics and sociometry for extracting information contained in a network. The enormous data sizes and the urge to understand the relations in the networks generated the social network analysis methodology and the necessary tools for applications to many scientific fields.

2.1.1 SNA Fundamental Concepts

The aim of this section is to discuss the main concepts developed in social network analysis and provide definitions and metrics to use them.

Node

A social network is a composition of individuals, organizations, firms, regions, or countries that are called nodes which form the basic unit of networks (Kadry et al. 2014: 11). In graph theory, the word vertex is used instead of node. The smallest and most elementary social unit is a dyad which is a group composed of two nodes, while a triad is a group composed of three nodes connected to each other. A pendant is a node that is connected to the network by only one tie. An isolate is a node that is not connected to others within a network. These node definitions are represented in Figure 2.1 below.

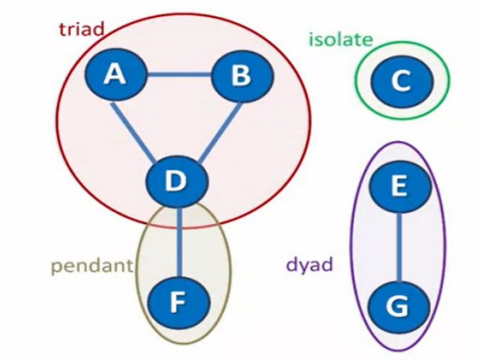


Figure 2.1: Nodes definitions

Tie

friendship, knowledge, etc. and these relations are called *ties* in social network analysis. De Nooy et al. (2005) distinguishes whether a tie can be directed or undirected. A *directed* tie is called an arc whereas an *undirected* tie is an edge. If the start and end points of the line are the same node, then it is called a loop. If a tie has both directions, then it is called a bidirectional arc. Figure 2.2 below shows the different tie representations which are discussed above.

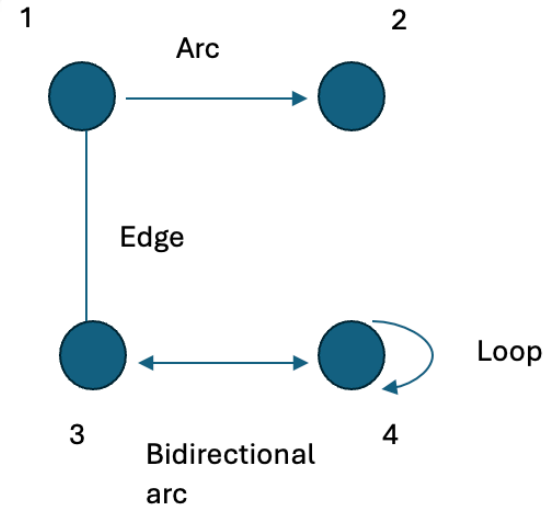


Figure 2.2: Tie Representations

Granovetter (1973: 1361) defined the concept of a strong interpersonal tie in terms of the time and emotions invested in a relationship, as well as the reciprocity involved between participating actors; examples of strong ties can be given as friendship and familial relationships. Weak ties, by contrast, involve more limited investments of time and intimacy, including an array of social acquaintances (Ruef, 2002: 428).

According to the transitivity relations in network models, Borgatti (2010) suggests that if A and B have a strong tie, they are likely to have weak ties with other individuals in the network. Conversely, if A and B, and A and C, both have strong ties, it is likely that B and C will also share at least a weak tie. This principle reflects the balance theory, where the presence of strong connections between a common individual (A) increases the likelihood of connections, even if they are weaker, forming between the other two individuals (B and C). These individuals, especially those with strong ties, can often be close friends.

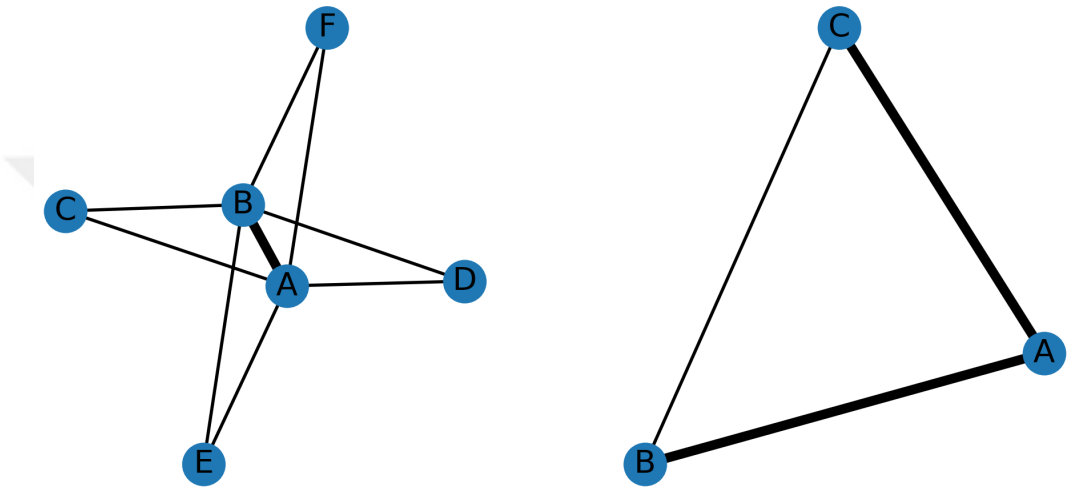


Figure 2.3:Transitivity Relations in a network

Source: Borgatti (2010) retrieved from:
http://www.analytictech.com/mgt780/slides/swt.pdf

Graph

A network is a graph that represents and somehow visualizes the relationships between actors or entities. A graph is a set of nodes and a set of lines/ties between pairs of nodes. A network consists of a graph and additional information on the nodes and the lines of the graph. Thus, basically a social network is a graphical representation defined by actors and by relations among them. There are different graph types regarding different groups of ties. A *directed graph* contains one or more arcs, on the other hand an *undirected graph* contains no arcs. An undirected graph only contains edges. A *simple directed graph* contains no multiple arcs, however there can be loops in this kind of graph, but it cannot contain multiple loops either. In addition, a *simple undirected graph* contains neither multiple edges nor loops. In this dissertation, the

graph type used is the undirected graph where there are only edges (and multiple edges) but not any kinds of arcs.

Semiwalk, Walk – Semipath, Path- Shortest Path

A semiwalk from node u to node v is a sequence of lines such that the end node of one line is the starting node of the next line and the sequence starts at node u and ends at node v. *A walk* is a semiwalk with the additional condition that none of its lines are an arc of which the end node is the arc's tail. *A semipath* is a semiwalk in which no node in between the first and last node of the semiwalk occurs more than once. *A path* is a walk in which no node in between the first and last node of the walk occurs more than once.

A network is weakly connected if each pair of vertices is connected by a semipath, and it is strongly connected if each pair of vertices is connected by a path. The shortest path is the path that connects a pair of nodes via the smallest number of ties. Social Network Analysis (SNA) focuses on these shortest paths, known as 'geodesic paths' or simply 'geodesics,' which are crucial for understanding various network properties. While geodesics themselves are not direct indicators of network cohesion, they play a significant role in analyzing the network's structure. Network cohesion refers to the extent to which nodes within a network are interconnected, measuring the strength and density of relationships. High network cohesion indicates robust interconnections and efficient communication pathways. Geodesics help in assessing these pathways by highlighting the most direct connections between nodes, thus influencing metrics that describe network cohesion, such as average path length and diameter. Therefore, although geodesics are not direct measures of network cohesion, they provide foundational data that contribute to a deeper understanding of a network's cohesiveness, robustness, and communication efficiency. (Borgatti, S.P. et al., 2018)

Density

Network density is the number of lines in a network, expressed as a proportion of the maximum possible number of lines. It is an indicator of the general level of connectedness of the network (Otte and Rousseau, 2002). A complete network is a network where every node is connected to every other node; thus, the density of a

complete network is one, this is the highest value for the network density indicator. In general, the larger the social network, the lower the network density will be since the number of possible lines may increase rapidly with the number of nodes, whereas the number of ties which each node may be limited. The network density for undirected and directed networks can be expressed as it is adapted from de Nooy et. Al (2011):

$D = \frac{2E}{N(N-1)}$, $D = \frac{E}{N\,(N-1)}$

where D is the network density, N is the size of the network, and E denotes the number of observed edges. Since network density depends on the size of the network, there is a problem with comparing the density of networks of different sizes. In this case, the average degree is used which is simply the average number of ties each node has and calculated for directed and undirected networks as in the relations below respectively (adapted from de Nooy et al, 2011):

$d = \frac{2E}{N}$, $d = \frac{E}{N}$

where d is the average network density, N the size of the network, and E denotes the number of observed edges.

Component

A *component* in a network is a maximum connected subnetwork. According to Otte and Rousseau (2002:442) "*a component of a graph is a subset where there is a path between any node and any other one of these subsets, namely if the whole graph forms one component it is said to be totally connected*". No other node can be added to the subnetwork without destroying its defining characteristics. The component is weakly connected when there is a non-directed path between every pair. If every node is reachable from every other node then the component is strongly connected.

Bridge

A *bridge* is a line whose removal increases the number of components in the network. There are several bridges in the network shown in Figure 2-4. Bridge exists between A and B, C and D, E and H and E and G. The tie between B and E is not a bridge because there is an alternative path between them.

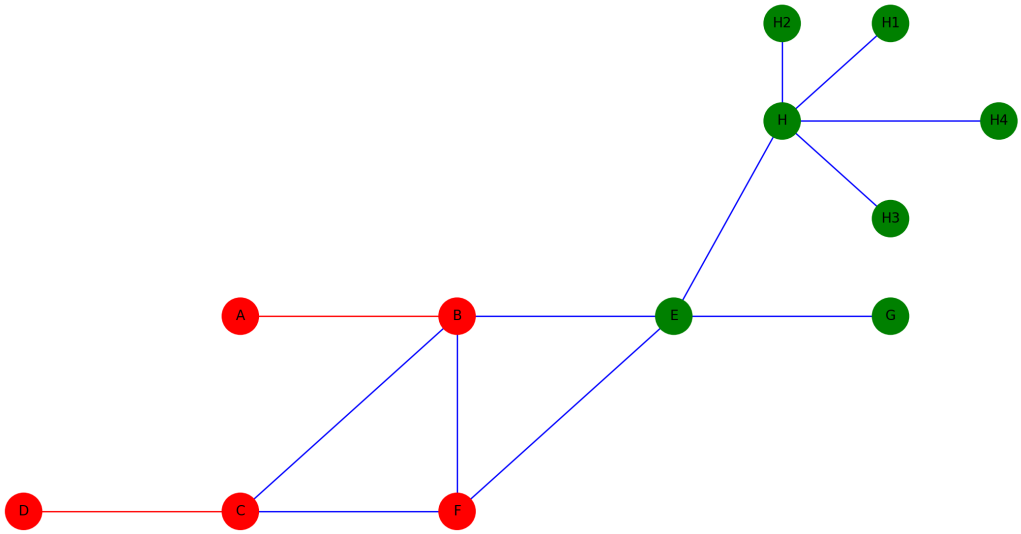


Figure 2.4:Identifying bridges

Source: Author's representation

Structural Holes and Brokerage Roles

If alter, ego and third parties are all connected with each other, then it generates a complete connected triad. Figure 2-5 below depicts a complete connected triad (1st visual on the left-hand side) vs. a connected triad with an absent tie (2nd visual). The absent tie between alter and third in the 2nd visual is considered as a structural hole and in this case, ego has advantages in terms of playing a brokerage role. Thus, ego can profit from the competition between the alter and the third and may control the information flux.

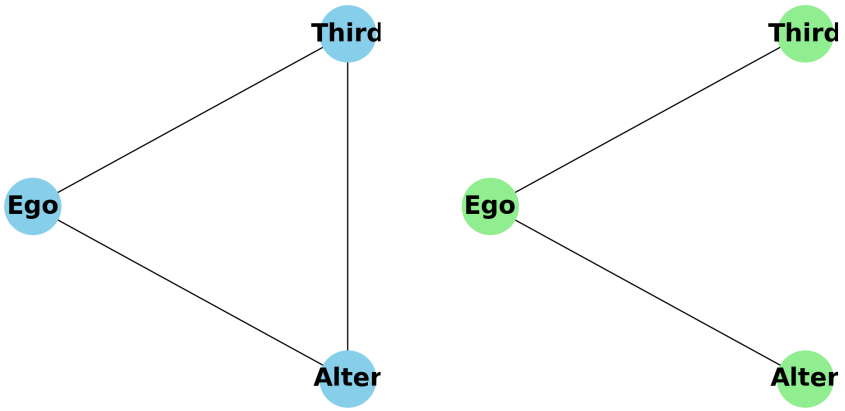


Figure 2.5: Complete connected triad vs connected triad with an absent tie

Zhang et. al (2016) stated that the ego may play various broker roles depending on its position in the network and they clarified the differences between internal broker and

external brokers in the networks by observing examples of online discussion networks. As show in Figure 2-6, The left side of the figure illustrates an Internal Broker Network characterized by weak connections and many structural holes within a single cluster. Nodes (individuals) are connected by edges (relationships) with node 'E' acting as the internal broker. This network has numerous gaps where certain nodes are not directly connected, such as node 'G' being linked only to nodes 'D' and 'F' without direct connections to nodes 'A', 'B', or 'C'. The presence of these structural holes indicates a weak network where communication and information flow are limited, making it less efficient and cohesive.

In contrast, the right side of the figure depicts an External Broker Network, which connects different clusters (Cluster B and Cluster C) through an external broker, node 'N'. This network has strong connections with fewer structural holes, facilitating better communication and information sharing between the clusters. Nodes 'L' from Cluster B and 'M' from Cluster C are directly connected by node 'N', bridging the clusters and enhancing the network's overall strength. The fewer gaps and stronger connections in this network indicate a more integrated and efficient structure, supporting robust interaction and exchange of information across different groups.

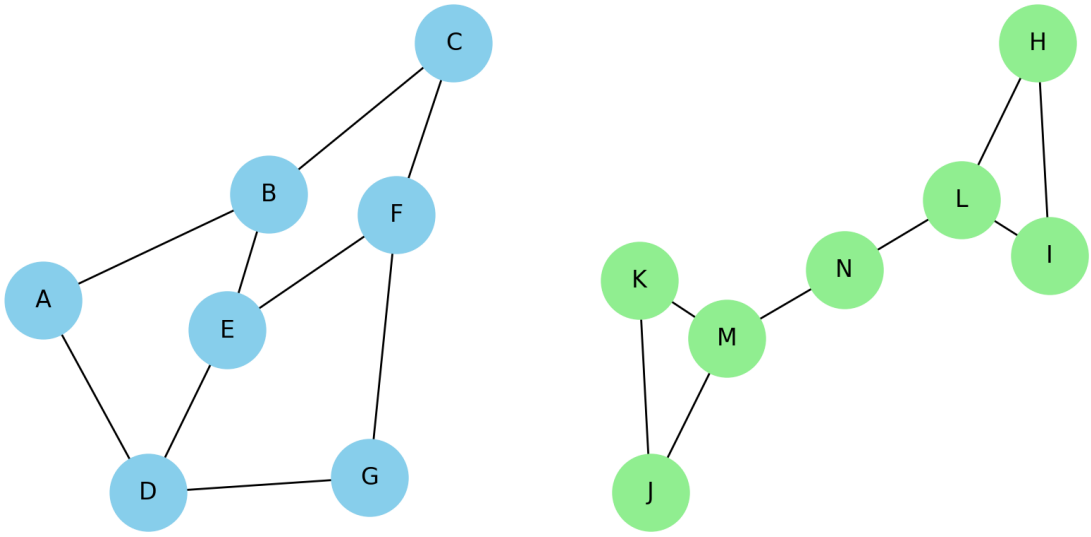


Figure 2.6:Internal vs External Broker

Source: Author's own representation

The concept of brokerage is fundamental in understanding the dynamics of social

networks, especially in how resources and information are mediated between different actors. In their study, Gould and Fernandez (1989) identify five distinct brokerage roles that arise when a set of actors is partitioned into mutually exclusive subgroups. These roles are the coordinator, itinerant broker, representative, gatekeeper, and liaison. The representation of these roles are shown in Figure 2-7 below.

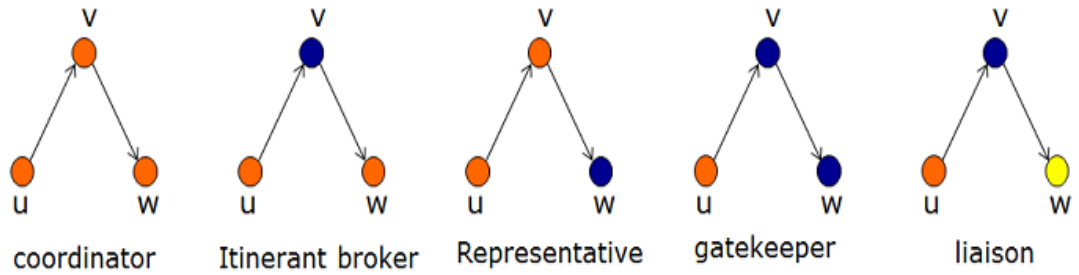


Figure 2.7: Different Brokerage Roles

Source: De Nooy et Al. (2005: 151)

Brokerage as a coordinator controls the information flow within the same group; he/she plays the role of mediator in the same group where he is also with other members. The coordinator role corresponds well to the brokerage type in EU R&D programmes. The coordinator is generally the actor (a person or an organization) who initiates the network and the R&D project. The primary responsibility of a coordinator is to ensure effective communication and collaboration among the members of the same group, facilitating the achievement of common goals.

An internal broker, often synonymous with the coordinator, focuses on managing and facilitating interactions within a single group. While a coordinator may specifically refer to someone who organizes and leads, an internal broker emphasizes the mediation and brokerage of information and resources among group members, ensuring that all necessary inputs are efficiently shared and utilized within the group.

An itinerant broker position refers to the mediation between the same group members while the mediator is from a different group. This brokerage type may correspond to an actor possessing some knowledge or access to information flows that the group or its coordinator may not have. For example, the itinerant broker may link an R&D

group to a group of industrial actors seeking solutions to their problems without being in the network of the R&D group. The itinerant broker may translate to the R&D group the needs of the industrial group. This type of itinerant brokerage may well strongly link the R&D group to the industrial group and generate a joint project at a later stage.

Brokerage as representative collects the information coming from his group and forwards it to different groups. This broker type represents his group and regulates the internal flow of information or goods from his group to external groups. In R&D networks, this role may be assumed by the coordinator or by one of the Work Package leaders. This type of brokerage may be needed when the R&D group is seeking to enlarge its network and tries to incorporate new expertise in it or when the R&D group is trying to join another network for various reasons, but essentially in order to strengthen its position when a new opportunity arises such as a new R&D programme requesting more interdisciplinarity or asking for more application or solution/product oriented research (high TRL projects).

The broker as gatekeeper obtains information from different groups and passes it to his/her group to regulate the flow of information or goods to his/her group. The gate keeper role in an EU type R&D project may again be played by the coordinator or a representative. This will depend on the size of the R&D network in terms of its partner numbers and the variety of the knowledge bodies involved in the network.
Finally, brokerage as liaison receives information from different groups and passes it through again to another different group or to other groups. In the liaison position, the broker mediates between members of different groups without belonging to any of these groups. In EU type R&D projects, the liaison type brokerage may correspond to different needs, actions, or intentions. For example, the liaison type actor may represent a network of actors addressing interdisciplinary problem areas or seeking solutions to significant social issues. In the context of EU energy-related programs, this may well correspond to building a very large energy transition project for example such as constituting a regional Hydrogen Valley project. Another type of liaison brokerage role may be played by an organization or firm holding a tool or a technical solution that may be useful to many networks and needing their joint action to acquire it, because of the cost of the tool or its strong complexity to be used and needing

various expertise. In energy-related EU R&D programmes, this situation is well illustrated by companies providing advanced experimental techniques (such as laser based optical measurement techniques) or those promoting advanced high performance numerical computation platforms. As a result of such brokerage actions, joint large networks may arise, usually also including the liaison brokerage actor.

It appears therefore that the various brokerage roles identified by the SNA approach correspond well to the real structures of FP7 or H2020 EU programs in the energy area. It is important to formulate and express indicators or metrics to represent, quantify, visualize them. This is the object of the next section.

Exploring of Structural Holes and Brokerage Roles in SNA:

Structural holes and brokerage roles in networks can be visualized and computed using social network analysis tools to identify key nodes by calculating three primary constraints: proportional, dyadic, and aggregate constraints. These constraints are essential for measuring the strength and limitations of relationships between partners or projects within a network.

From the perspective of an ego node, these constraints are derived from its ego network:

1. **Proportional Constraints**: The strength of a connection is inversely related to the node's total ties. For instance, if node u has four connections, its tie strength is calculated as 1/4=0.25. Similarly, if node v has seven connections, its tie strength is 1/7=0.14. This term is employed to assess the significance of each tie relative to the node’s overall network.
2. **Dyadic Constraints**: These constraints involve both direct and indirect paths between nodes. For example, the dyadic constraint from node u to node v is the square of the proportional strength of their direct tie. For more complex connections, such as from u to c, dyadic constraints include all possible paths, such as via other nodes like b and a. Dyadic constraints are crucial for understanding the dependency and influence between nodes by considering

multiple paths.

3. **Aggregate Constraints**: This constraint is the sum of all dyadic constraints for a node. High aggregate constraints indicate less freedom for an actor to withdraw from existing ties or exploit structural holes, aligning with Granovetter's theory on the strength of weak ties. Low aggregate constraints are associated with better performance and more successful careers, suggesting that actors with low constraints possess greater flexibility and strategic opportunities.

Furthermore, brokerage roles are contingent upon network positions and group affiliations. Nodes with weak ties and low constraints attain stronger positions for negotiations, thereby enhancing their brokerage capabilities.

De Nooy et al. (2005) state that "The higher the aggregate constraint, the less 'freedom' an actor in the network must withdraw from existing ties or to exploit structural holes" (p. 131). This assertion parallels Granovetter's idea, which emphasizes the strength of weak ties. Additionally, it is supported by other findings that actors with low aggregate constraints are hypothesized to perform better and have more successful careers.

2.1.2 Centrality Metrics

In general, centrality refers to the positions of individual nodes within the network and centrality metrics are used to identify the most important actors within a network. Centrality measures have often been involved in applied studies of social networks and used to identify the important actors of the network through measuring their relative power and influential attributes (Everett & Borgatti, 2005; Barbian 2011). Freeman (1978) is the founder of the structural centrality measures, which are degree, betweenness and closeness. Freeman conducted research on small groups to uncover consistency of these measures with institutions and his structural centrality measures stand up for many empirical studies in social network analysis. The concept of centrality was used by Camille Jordan who examined the island networks in Oceania (Hage & Harary, 1995).

Tutzauer (2007) summarizes Freeman centrality categorizations as follows: degree

centrality measures node's activity; whereas betweenness centrality corresponds to node's control capacity, and closeness centrality refers to communication efficiency (Freeman 1978). For example, perceived leadership can be measured in terms of centrality by adding attributes like control, independence, or activity level. In the next section, studies related to degree and betweenness centrality from node's point of view as well as those about network's centralization will be examined, respectively.

Degree centrality and centralization

The *degree of node* is the number of total connections – sum of links with other nodes - established by that specific node. An isolated node is a node with zero degree. In graph theory terminology, the *degree centrality* of a node is defined as the number of ties this node has with other nodes. The degree centrality of node i, d(i), is calculated as in the following equation:

$$\text{d (i)} = \sum_{j} m_{ij}$$

In this equation $m_{ij} = 1$ if there is a link between nodes i and j, otherwise $m_{ij} = 0$ if there is no such link (Zhang, 2010).

Degree centralization of a network of a given size is the variation in the degrees of nodes divided by the maximum degree variation which is possible in a network of the same size. Variation here refers to the absolute differences between the centrality scores of the nodes and the maximum centrality score among them. Thus, a higher degree variation results in a higher degree centralization. Note that "centralization" is a network-related concept, and it is different from the "centrality" which is a node-related concept ranging from 0 to 1.

Wambeka et al. (2012) stresses the importance of degree centrality in the literature as it identifies the key members of the network and shows the distribution of the relationships within the network and captures the structurally central part of the network. In other words, degree centrality corresponds to the popularity of a node,

since if a node/actor has many ties compared to other actors in the network, this makes this actor popular and powerful in the network. A lot of research in the literature suggests similar ideas that the most central actor is the most active in the sense this actor has the largest number of ties meaning that having high degree centrality compared to other actors in the network (Zemljič & Hlebec, 2005: 75). Faust (1997) studied centrality measures in affiliation networks and proposed a conceptualization of the positions of actors.

Centrality indexes vary between 1-mode and 2-mode networks[1]. In 1-mode network, the centrality of a node depends on the total ties of that node; however, in 2-mode networks, degree centrality of a node "is equal to the sum of the sizes of its events and degree centrality of an event is equal to the sum of the number of memberships of its actors" (Faust; 1997:167).

Betweenness centrality and centralization

Betweenness centrality may be defined as the number of times a node needs a given node to reach another node. To calculate this centrality metric, first we need to revisit the walk, path, and shortest path concepts.

A path is a walk in which no node in between the first and last node of the walk occurs more than once. A semiwalk from node u to node v is a sequence of lines such that the end node of one line is the starting node of the next line and the sequence starts at node u and ends at node v. A walk is a semiwalk with the additional condition that none of its lines are an arc of which the end vertex is the arc's tail. The shortest path is the path that connects pair of nodes via smallest number of ties (De Nooy et al, 2005: 67).

Betweenness centrality is the number of shortest paths that pass-through a given node. As a mathematical expression, the betweenness centrality of node i, denoted as b(i), is obtained as:

[1] *For a detailed explanation of the differences between 1-mode and 2-mode networks, see Section 3.3.1.*

$$b(i)=\sum_{j,k}\frac{g_{jik}}{g_{jk}}$$

where g_{jk} is the number of shortest paths from node j to node k (j, k ≠i), and g_{jik} is the number of shortest paths from node j to node k *passing through node i*.

The betweenness centrality of a node is the proportion of all shortest paths between pairs of other nodes that include this node, and this measure focuses on the communication potential between information sources: "betweenness centrality for an actor quantifies the extent to which the information flow between other pairs of actors in the network is reduced if the observed actor is removed from the network" (Zemljič & Hlebec, 2005:76). It is an indicator of how important a node is for the transmission or control of information. Wambeka et al. (2012) summarized the main point of betweenness in terms of being central in the path of communication and propose that in many real-life situations, communication path do not follow the geodesic paths so all possible paths and random paths should be examined when identifying betweenness centrality of an actor. We recall here that geodesic refers to the shortest path between two nodes and the distance from one node to another is the length of the geodesic between these two nodes.

Among the explanations of betweenness centrality, Everett and Borgatti (2005) claim that high betweenness centrality is strongly correlated with the existence of structural holes providing advantages to the ego in the network. For this reason, Zhang (2010) stresses that there is a huge potential to act as gatekeeper controlling the flow of resources if an actor is high in betweenness in the network and this centrality type highly correlates with efficiency and power in the network because of holding the shortest paths in the network.

De Nooy et al. (2005) claim that bilateral connections are important in terms of centrality because information may easily reach actors who are central in a communication network and other actors in the network may easily reach them. Furthermore, centrality is associated with the reachability of the node in the network; a node is reachable by another node if there is a path from the latter to the former.

Similarly, Kilduf et al. (2006) suggest that actors who already occupy central positions may have advantages in terms of gaining diverse information about the structure of the network through short paths. Actors may gain these central positions in part through small initial advantages that translate into accumulating network ties as the network changes and grows over time.

Betweenness centralization of the entire network is the variation in the betweenness centrality of nodes divided by the maximum variation in betweenness centrality scores possible in a network of the same size. If there is a clear boundary between the center and the periphery of the network, this network is considered highly centralized. If the centralization of the network is high, information spreads easily but the center is indispensable for the transmission of the information.

Logically, centrality measures are higher when the network is denser, and density has the greatest effect on the reliability of measures of centrality, so density is related to the cohesiveness of the network (Zemljic & Hlebec, 2005; Borgatti& Everett, 2006). More importantly, since those centrality measures are strongly connected with the cohesive subgroup structure of the network, the network is "fit" if all nodes revolve closely around a single core called the core-periphery structure.

Closeness centrality and centralization

Closeness centrality and centralization are other metrics of centrality that considers the distances between the nodes. *Closeness centrality* is based on the notion of *distance* and *closeness centrality of a node* is equal to the sum of geodesic distances of this node from all other nodes (Wambeka et al. 2012). As we introduced above, De Nooy et al. (2005) define geodesic as the shortest path between two nodes and the distance between two nodes is the length of the geodesic between these two nodes.

The closeness centrality of node **i**, **c(i)**, can be derived from the equation shown below:

$$c(i) = \sum_{i} d_{ij}$$

where d_{ij} is the number of links in a shortest path from node i to j. Closeness is an inverse measure of centrality so that a larger value indicates a less central actor while a smaller value indicates a more central actor. The closeness centrality of a node is the number of other nodes divided by the sum of all distances between the node and all others, in other words the inverse of the average distance (Zemljič & Hlebec, 2005:75). An average shortest path for the network is an average number of steps along the shortest paths for all possible pairs of network nodes.

If a node is close to all others in the network, then it is not dependent on any other to reach everyone in the network. Closeness centrality measures independence in communication. With loosely connected networks, closeness centrality must be calculated for each component (Zhang 2010).

Closeness centralization is the variation in the closeness centrality of nodes divided by the maximum variation in closeness centrality scores possible in a network of the same size.

Eigenvector Centrality

Apart from degree, betweenness and closeness centralities, Rusinowska et. al (2011) highlighted other centrality measures which should be taken into consideration indicating actors' importance depending on the importance of actors' neighbors, especially used in measuring power relations (Ruhnau, 2000; Bonacich, 2007). Similarly, Landherr, Friedl and Heidemann (2010) contributed to node's prestige by suggesting that actor's own centrality depends on its more popular neighbor than less popular one. Thus, eigenvector centrality refers to the importance of a node in the network based on node's connections. Nodes with high eigenvector centrality fill in the structural holes by setting links with important nodes.

2.1.3 Measures of cohesion

In social network analysis, the term network cohesion refers to a measure of the connectedness and togetherness among actors within a network (Frey, 2018). The index of network cohesion is a single value that captures the togetherness of the group which is generally calculated as density discussed previously (see 2.1.1). Network

cohesion can be measured in a variety of different ways, most of which are based on the dyadic cohesion which refers to the closeness between a pair of actors and depends on the structure of the network.

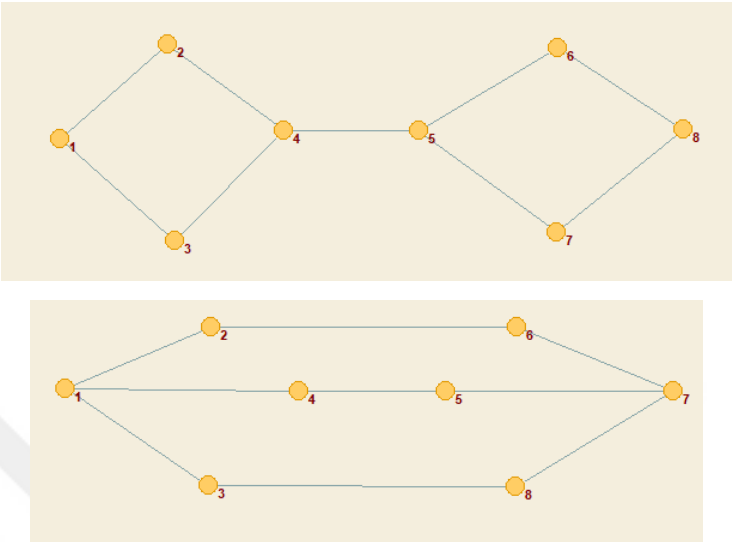


Figure 2.8: Network X and Y with different structures

For example, in Figure 2-8 above, two networks share the same density of relations. However, the network structures are different. Network X (top figure) is setup as two groups linked by a bridge, while Network Y (bottom figure) consists of a single group. Therefore, in Network Y the positions of nodes are more reachable compared to Network X and new ideas and other information flows will have more chance of spreading over in the Network Y. Furthermore, in Network X, the nodes are numbered 4 and 5 are the cut nodes; any information exchange should pass through them to reach their own groups. These two network samples are good examples for biological networks. For example, in Network X if node 4 is vaccinated for a contagious disease, then the illness cannot reach to the left-hand side group members. On the other hand, in network Y, although node 4 is vaccinated there are several options for the spread of the disease if the node 1 it is contaminated. Therefore, dyadic cohesion is higher in Network Y compared to Network X since the pair of actors are closer. Measures for network cohesion can also be built upon the subgroup-level cohesion, namely, structural cohesion. These measures not only consider the number of ties but also the structure and clustering among ties. (Frey, 2018: 3). The next concepts to be discussed

are the clustering coefficient, hubs, small world scale free properties; they indicate how nodes in the network tend to connect.

Clustering coefficient

In graph theory, a clustering coefficient is a measure of the degree to which nodes in a graph tend to cluster together. In other words, the clustering coefficient is a measure of the proportion of weak/strong ties in the network. A low clustering coefficient is indicative of a network comprised of numerous weak ties. High clustering coefficient indicates that in the ego network, all the connections of the ego tend to connect with each other.

Hubs

Hub is defined as "a node with large number of connections or alternatively as a node that is highly influential in playing the role of network connector; that is the one which connects the nodes that would otherwise remain unconnected" (Breschi et al. 2009:195). Therefore, hubs play important roles in the partnership and knowledge networks since they contribute to knowledge diffusion even to the nodes in the periphery of the network. Hubs can be identified by degree and betweenness centralities because the first is related to having large number of connections and the second is related to the control over knowledge transfer. These concepts will be described in the next section.

Small World – Scale Free Networks

One of the most discussed network phenomena is the small-world networks which are characterized by two parameters: the clustering coefficient and the path length. Small world networks have a low average path length, which indicates that there is a path between a pair of nodes that involves only a few edges and a clustering coefficient significantly higher than expected by random chance. In short, a network is considered as small world if two nodes can reach each other through a short sequence of acquaintances (Wattz and Strogatz, 1998).

On the other hand, scale-free networks are constructed by using a preferential

attachment concept. If new nodes are added to a network and preferentially attached to the nodes with high degrees, the "rich gets richer" and the result is a hub of very high degree.[2] According to Perera et. al (2017), scale-free networks are characterized by the presence of small number of highly connected hub nodes and a high number of weakly connected nodes. The presence of distinct hubs in scale-free networks make them more vulnerable to information rupture risks compared to small-world networks.

In most real networks, the typical path length is short, in particular when compared with the number of nodes of the network. The small-world effect has a substantial implication for network systems. For example, when rumor (or a disease) is spreading over a social network, clearly it will reach people much faster if the network has short path lengths.

According to the Watts-Strogatz model (1998), most real-world networks have a high clustering coefficient, but low average path length as in small world networks. In the experiment conducted in 1999 by A-L. Barabasi a small portion of the Web was crawled, and it was discovered that the degree distribution follows a power law which reflects real networks. Thus, Barabasi's power law model produces scale-free networks and incorporates two important general concepts which are growth (number of nodes increase in the network over time) and *preferential attachment* (rich get richer) (Barabasi, 2014). According to Barabasi et al. (2002), each node has a different probability to connect to the network and the existence of hubs is another factor for the growth of the network. Therefore, real networks with small world properties having average short separations between the nodes show a degree of clustering higher compared to random networks.

2.2 Network Performance

The aim of Section 2.2 is to explore the concept of network performance within innovation networks, focusing particularly on collaboration networks in EU Framework Programs. This section delves into how social structures and interactions

[2] Nykamp DQ, "Scale-free networks." From *Math Insight*. http://mathinsight.org/scale_free_network

among actors influence innovation activities and knowledge diffusion. By integrating various theoretical perspectives and empirical findings, it offers a comprehensive understanding of how different network configurations impact the effectiveness and efficiency of innovation processes within the EU context.

The organization of this section is designed to systematically address the core components of network performance, including network structure, structural holes, brokerage roles, social capital, and the dynamics of collaboration. Each subsection has been carefully selected to provide an in-depth examination of these elements, demonstrating their collective influence on innovation outcomes and regional development, particularly within the framework of EU research and development initiatives.

The section begins by laying the theoretical foundation, introducing key theories and concepts that underpin the analysis of network performance. This theoretical focus provides the necessary context for understanding the subsequent discussions on how social network theory and social network analysis (SNA) are applied to study the dynamics of collaboration networks in EU Framework Programs.

Following the theoretical groundwork, the section examines the various structural characteristics of networks, such as complexity and diversity of ties, and their impact on economic and innovation outcomes. This part emphasizes the significance of network structures in EU Framework Programs, highlighting how the complexity and diversity of collaborations are critical for effective knowledge exchange and innovation.

Next, the discussion moves to the concepts of structural holes and brokerage roles, exploring their advantages and disadvantages in fostering innovation and information flow within networks. This part highlights how actors occupying brokerage roles in EU Framework Programs can bridge gaps between otherwise disconnected groups, facilitating the flow of diverse and non-redundant information, which is essential for innovative activities.

The section then addresses the role of social capital in network performance,

discussing how relationships and connections within networks contribute to innovation and collaborative success. In the context of EU Framework Programs, this part explores how social capital enhances the ability of organizations to access valuable resources and information, thereby improving their performance and innovation capabilities.

Finally, the section analyzes the patterns and dynamics of collaboration among organizations, focusing on the context of EU R&D programs. This part discusses how collaborative networks are formed, the factors influencing their structure, and their impact on regional development and innovation performance. By examining case studies and empirical data from EU Framework Programs, this part provides insights into the strategic positioning and collaborative efforts that drive innovation within the EU's policy framework.

By structuring the section in this manner, the aim is to provide a coherent and comprehensive overview of network performance, offering valuable insights into the strategic positioning and collaborative efforts that drive innovation and regional development within the EU Framework Programs. This approach ensures that the analysis is relevant and directly applicable to understanding the intricacies of collaboration networks in EU-funded research and development initiatives.

2.2.1 Theoretical Focus

Social network theory, rooted in sociology, provides a robust framework for understanding how actors within innovation networks and their interactions influence innovation activities and facilitate knowledge diffusion through learning processes. This theory highlights the importance of social structures and relationships in shaping innovation outcomes. Social network analysis (SNA), which is distinct from social network theory, is a methodological approach that draws from various disciplines, including sociology, anthropology, mathematics, and psychology. SNA focuses on examining patterns of connections between actors, analyzing how these connections reflect behavioral, cognitive, and emotional ties. By exploring these patterns, SNA

offers valuable insights into the dynamics and performance of networks, shedding light on how social structures impact innovation processes and knowledge dissemination (Burt et al., 2013).

Network performance, in this context, refers to the effectiveness and efficiency with which networks facilitate innovation and knowledge diffusion. High network performance is characterized by optimal connectivity among actors, resulting in accelerated information flow, enhanced collaborative opportunities, and improved innovation outcomes. Conversely, poor network performance can hinder knowledge dissemination and limit the potential for innovative activities.

Otte and Rousseau (2002) referred to social network analysis as a structural analysis, which is not a formal theory but a strategy to investigate social structures. Furthermore, the questions addressing how transactions are interwoven with meaning in a network and how components are shaped by categories and relationship models should be analyzed through network data collected in interviews or conversation analyses. Incorporation of these issues in social network analysis and network research can be carried out successfully and meet the required analysis constraints (Fuhse, 2009).

In this section, relevant literature is reviewed to show how network positions and structures affect network performance. Additionally, a discussion is conducted on how EU R&D programs are related to regional development within the EU's policy framework by analyzing important concepts related to network structure and deciphering with whom organizations collaborate. This comprehensive review aims to elucidate the intricate relationship between network configurations and their performance, providing insights into the strategic positioning and collaborative efforts that drive innovation and regional development.

Network Structure

During the last 20 years, there has been a growing attention in the literature to understand and explain the overall structure of networks. Most real-world networks are characterized by high complexity and there is a high level of diversity in the type of ties in terms of their weight and content, and in the nodes themselves. Studying

networks and how they evolve is valuable in many aspects, because a dynamic network perspective enables us to see how economic outcomes are influenced by the nature of networks and how networks influence economic processes. (Ozman, 2009)

Network structures change as a function of conditions related to proximity, knowledge base, complexity, and uncertainty. For example, Heller-Schuh et al. (2011) observed structural changes over time in the EU R&D networks for successive FPs, concluding that the networks have 'increased in size and have become more cohesive as collaboration has evolved with time'. Others have found that the structure of networks in the EU R&D programmes tends to remain unchanged (large, and complex social networks) regardless the level of analysis (Paier & Scherngell, 2011; Ploszaj & Wojnar, 2009; Roediger-Schluga & Barber, 2007)

Empirical work in many areas, (such as the World Wide Web, scientific collaboration networks, movie actor networks), reveals that most of the real-world networks exhibit small world properties meaning that shortest-path distance between nodes increases sufficiently slowly as the number of nodes in the network increases. However, as Barabasi (2002) discusses, small world explanations have limitations in modelling real world networks in some important respects. In these models the network size is held fixed, whereas in the real-world networks grow, mostly following certain rules like preferential attachment. It is claimed that there are few nodes attracting most of the nodes, and majority of the nodes have few connections in real networks which are considered as scale free depending on preferential attachment (see above) and a growing network. Since every node is not connected perfectly with each other, there appear structural holes in real networks. This feature of network structure affects actor performances and capabilities of innovation.

In the beginning of 2000's, Burt (2001, 2002, 2004, 2005), one of the most important names investigating the structural hole concept, claims that when network closure is high, meaning that members of the network know each other well, the level of redundant ties are high, then the network performance is minimized because of a reduction in diversified perspectives, skills and resources. In his later research, Burt (2012) investigated the relationship among the success of firm managers, their

positions in the network by adding personality as explanatory variables. As a result, he found no significant association between the dimensions of personality and network advantages. Overall, Burt's research is considered an important building block in the field. He claims that people who extend themselves across the structural holes between different groups may reach diverse ways of thinking leading to a pool of diversified options and information fluxes. On the other hand, communication is more frequent and influential in the same group of people, which leads to sharing explicit and implicit understandings and more likely to receiving sticky knowledge from homogenous group members. As a result, more homogenous opinions and common traits construct cliques and, in those cliques, members know what other actors know and therefore are exposed to redundant information.

Ahuja (2000) proposed that structural holes may have negative influences on innovation unlike Burt's opinions and indicated that in the case of collaborating firm networks, the increase in structural holes may have negative effects on innovation because structural holes may trigger disadvantages like dealing with the costs of indirect ties.

After examining the advantages and disadvantages of structural holes, it is useful to return to "Granovetter's strength of weak ties" concept as the starting point. Granovetter (1973, 1983) emphasizes the strength of weak ties and claims that strong ties with people who are already in relation yield less useful information than weak ties with people who do not know each other. Granovetter suggests therefore having ties outside the same group would yield more diverse information. From the network point of view, networks with weak ties and structural holes may also have bottlenecks. These networks may be vulnerable to the slow diffusion of information but may be advantageous against the spread of redundant information flows. The following section of this review is devoted to the effects of structural holes, brokerage roles and social capital on network performances. Social capital refers to "the advantage created by an actor's location in a structure of relationships" (Burt, 2005:4; Lizardo, 2012; Andersson, 2017). Burt (2005) suggests that social capital has the potential to become a powerful concept when applied to network analysis to test actor's position regarding to its network performance. Social capital therefore complements human capital, and

this combination is used to explain how people do better when they are better connected with other people in traditional social sciences to conduct research at an individual level. In addition to individual level, from the network point of view, well connected groups perform better. Thus, social capital is an important influencing factor, for example of better incomes in workplaces (Meverson, 1994). Consequently, Lin (2005) defines social capital as "resources embedded in one's social networks; such resources cannot be accessed or mobilized through the ties in the network" (p. 4). It is claimed that through social relations an actor can only borrow or capture other actors' resources such as wealth, power, or reputation. Therefore, networks provide the necessary condition for access to embedded resources and to "necessary antecedents exogenous to social capital" (p. 11).

According to the strength of weak ties theory (Granovetter, 1973), social benefits, such as obtaining information about job opportunities come from weak ties. Lin and Dumin (1986) also confirm that weak ties with friends and acquaintances rather than relatives provide better access to white collar and other range of occupations. On the other hand, van der Leij and Goyal (2006) conducted a study contrasting Granovetter's strength of weak ties theory. They stress the importance of the strength of strong ties, which supports the transitivity of strong ties: if two actors have strong ties with each other, the third actor that connects with these two actors strengthens the existing strong tie.

There was a debate in the literature about the views of Coleman (1990) and Burt on social capital. However, recent discussions suggest that both views might be important depending on the situation. Burt argues that social capital comes from open networks with many gaps, where different kinds of information flow through these gaps. In contrast, closed networks with strong ties limit the information flow. On the other hand, Coleman believes that social capital is built from closed networks with strong ties, which help actors develop better (Borgatti, 2010). The resolution of this debate shows that the usefulness of social capital is contingent on the context, with both open and closed networks offering different benefits depending on the circumstances.
Studies combining structural holes and social capital constitute an important area for the constitution of informal and local networks. Coleman (1990) defines social capital by its function consisting of "some aspects of social structure and facilitating certain

actions of individuals within the structure". On the other hand, Burt (1992) defines social capital as friends, colleagues, and other close contacts through whom one receives opportunities to use to increase financial and human capital. Podolny and Baron (1997) conducted a study on social networks and carrier mobility in high technology firms and found evidence that better mobility performance results are more likely to arise from small dense networks. Therefore, this study contradicts Burt's theory stating that sparse networks are more advantageous for professional mobility.

Even though scholars use different definitions of internal and external social capital, the main idea addresses that social capital feeds itself from closed networks in which there is high similarity in actions and behaviors. Therefore, it is unlikely to expect benefits of social capital from networks rich in structural holes. Similarly, Burt, Kilduff and Taselli (2013) suggest that sticky information is found in dense and closed networks.

Network embeddedness, as defined in SNA, underscores the interconnectedness of individuals or entities within a social network. This concept highlights that the characteristics, behaviors, and opportunities of these entities are intricately shaped by their relationships within the broader social structure. The strength of ties and connections among nodes assumes a pivotal role in the relational dimension of embeddedness, influencing the flow of information and access to resources. In the exploration of network embeddedness, Azarian (2010) draws attention to the potential overestimation of causal effects or the extent of network integration. The scholar advocates for a balanced approach, emphasizing the need for equilibrium between the analytical sophistication of contemporary network methodologies and the theoretical depth that underpins them to highlight social network complexities. Crucially, the sources that give rise to the formation of ties are emphasized, as they significantly alter the consequences of network embeddedness. Recognizing this, discussions in subsequent sections delve into the presentation of structural holes and brokerage roles within the framework of SNA.

Software programs nowadays enable us to analyze large amounts of data so that the visualization techniques lead to monitor the previously hidden relations in the social network analysis. After 1990's there has been a significant interest on the social

network methodology in different fields: behavioral sciences, epidemiology, management research, telecommunications industry, economics, marketing, intelligence gathering for security, fashion trends prediction, etc. Moreover, Zhang (2010) claims that social network analysis has been gradually associated with social capital after Ronald Burt's works on structural holes. Burt (2001, 2002) argues that social capital cannot be associated with only the strength of weak ties, but it can be understandable with the existence of structural holes.

In the relevant literature, researchers are divided into two groups as those insisting on the advantages or disadvantages of structural holes. Those who stress that these structures are useful defend their theses under two strategies, which are those of "tertius gaudens" and "tertius iungens" types. Tertius gaudens strategy refers to brokerage as a structural hole position in long term relations and enabling the exchange of information between the brokered parties by acting as the only passage through which information flows across the structural hole. Tertius iungens strategy refers to brokerage as an information exchange position facilitating the flow of information across the structural hole by enabling a direct exchange between brokered parties (Quintane and Carnabuci, 2016). It is argued that brokerage strategies differ in three critical ways. In one strategy, brokers collect more information via short-term interactions with colleagues outside their network of long-term relationships. The second strategy is consistent with the tertius gaudens strategy in which brokers control the flow of information better compared to actors in dense network positions in unembedded brokerage. The third strategy is consistent with the tertius iungens strategy in which brokers are more likely facilitating a direct information exchange between brokered parties compared to densely connected actors in embedded brokerage (Garriga, 2009). Interestingly, Obstfeld (2005) claims that adding new ties between unconnected nodes may create more structural holes in the network and defends the importance of tertius iungens strategy. In addition, Alhazmi and Gokhale (2015) revealed that when networks of online social platforms are rich in brokerage capital, there are more socialization opportunities among actors.

"The value of a relationship is not defined inside the relationship; it is defined by the social context around the relationship" (Burt; 2005: 11). For this reason, sometimes it

is more important for a node to have connections with important actors in the network than to have many connections. Brokerage roles constitute the backbones of the network; they build bridges to connect structural holes to the network generally by building weak ties. These weak ties are built through short-term interactions unlike having strong ties with closest colleagues or family members. Actors may gain valuable information through short-lived interactions with unfamiliar contacts who have been known since long time (Granovetter, 1983; Quintane and Carnabuci, 2016).

Rega Kent et al. (2016) suggested that network power relies on "the ability of an actor to influence others or to avoid being influenced by others" and on "being at the right place". The right place and the right position allow actors to have more access to the resources and more control over information flows. At this point, their opinion diverges from Burt's opinion which stresses the redundancy of the same type of knowledge coming from similar contacts (Burt, Kilduff and Tasselli, 2013). Kent et al. (2016) claim that powerful network positions are related to closeness to non-redundant information.

Therefore, it can be summarized that people whose networks bridge structural holes between groups have an advantage in detecting and developing opportunities. In fact, people with networks rich in structural holes are the people who know more about rewarding opportunities, have a hand in and exercise control over information (Burt; 2005: 16). Their positions provide innovative ideas and their opinion have greater influence within the organization structure.

With whom do organizations collaborate?

Organizations participating in EU framework programs collaborate with a diverse array of partners, forming intricate network structures that enhance innovation and research outcomes. These collaborations span academic institutions, research organizations, private companies, non-governmental organizations (NGOs), and public sector entities, including government agencies and international bodies. The network structure of these collaborations is shaped by various factors, such as network embeddedness, knowledge management, and innovation performance.

In stable industry regimes, firms are more inclined to explore codified knowledge, which significantly influences the formation and characteristics of their collaborative networks. According to Ozman (2008), in such stable environments, firms seek to build networks with weak ties, structural holes, and bridges. These weak ties are beneficial as they provide access to diverse and non-redundant information, fostering innovation through the integration of new and varied knowledge. Structural holes—gaps between non-redundant contacts—allow firms to act as brokers, connecting otherwise disconnected actors and facilitating the flow of information and resources across the network. Figure 2-9 shows that how knowledge type and industry regime affect network formation.

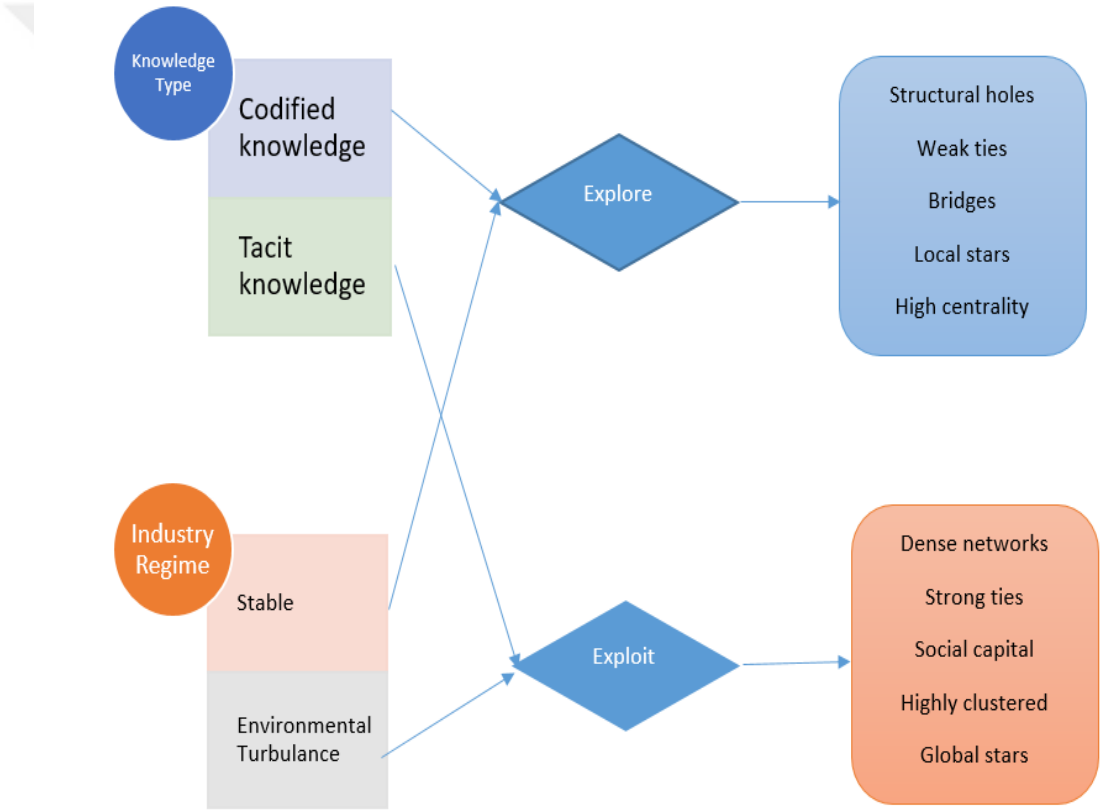


Figure 2.9: How knowledge type and industry regime affect network formation

Source: Based on Ozman (2013)

The network structure in these stable regimes is often characterized by a high degree of centrality, where certain firms, referred to as local stars, become key nodes within

the network. These local stars are sought after for collaboration due to their strategic position and the extensive connections they maintain, which enable efficient information dissemination and resource allocation. The presence of these local stars enhances the overall network performance by optimizing the exploration of new knowledge and ensuring that innovative ideas are effectively shared and developed across the network.

Thus, in the context of EU framework programs, the collaboration among organizations in stable industry regimes underscores the importance of strategic network positioning, weak ties, and the role of local stars in driving exploratory innovation. This collaborative network structure supports the EU's objectives of fostering scientific advancement and technological development by leveraging the collective strengths and capabilities of diverse partners engaged in the exploration of codified knowledge.

Powell and Grodal (2005) suggested that collaboration built with weak ties and high centrality metrics results in more patenting. They emphasized that strong ties contribute to social control and to the exchange of tacit knowledge; therefore, they need to be integrated in equity alliances, joint ventures, and R&D partnerships. On the other hand, weak ties are bridges to novel information and are integrated in licensing, patent agreements and marketing relations. The cost of knowledge transfer determines the decision of knowledge transfer. If the value of output is expected to exceed the cost of transfer and application, then knowledge codification occurs. Moreover, Powell and Grodal (2005) point out that the division of innovative labor and invisible colleagues in the informal networks of researchers create diverse collaborations generally associated with increased patenting.

Eklinder-Frick, Eriksson and Halln (2014) claims that structural features of networks and the density of ties trigger the effects of structural holes and influence access to and mobilization of knowledge. It is found that actors with high centrality are advantaged in forming new collaborations. On the other hand, actors with high centrality within cohesive groups are less advantaged towards bridging ties.

There is considerable research into firms' network positions and their effect on network performance. For example, Zaheer and Bell (2005) investigated how firms benefit from their network positions in terms of their capabilities and the presence of structural holes. They assert that firms within dense network structures exploit their internal capabilities to enhance their network performance. The importance of structural holes is highlighted in their study as they are seen as key instruments of innovative firms. The hypothesis that innovative firms enhance their performance by bridging structural holes and perform better than other firms are confirmed by their regression analysis of the data on the members of the Investment Funds Institute of Canada.

Burt (2015) attempted to analyze structural holes' properties from a specific point of view. He examined the case in which if a new connection has other connections that do not allow making new connections, then there will be a reinforced structural hole formation in the network. As discussed in section 2.1.1, brokerage roles in a structural hole rich network provide various advantages to actors in terms of autonomy, competition opportunity, recognition, information arbitrage and innovativeness (Rodan, 2010; Liao and Phan, 2015). In the following section, structural holes are analyzed regarding the actor's absorptive capacity and network's embedded structure.

Many studies investigated how the network structure affects the relationships between actors in the network. Willer (2007) has a unique perspective analyzing how actors alter the network structure. His research emphasizes the benefits of occupying positions in structural holes on accessing to unique information and controlling information flows. Similarly, Frank et al. (2012) examined scientists who fill structural holes in networks and observed they are more likely to be engaged in policy-oriented behaviors than others in non-structural holes and raised the issue that specific actors may shape the network structure.

Wang et al. (2015) examined the importance of network centrality in affecting organizational innovation and performance. The evidence they found indicates that the impact of network centrality is stronger for organizational innovations in small size organizations rather than large size ones.

There are many studies examining co-authorship networks through SNA lenses. The study of Fleming et al. (2007) exploits a database on patent co-authorship to investigate the effects of collaboration networks on innovation. Their analysis reveals the existence of regional small-world structures and the emergence and disappearance of larger components in patent collaboration networks. Fleming et al., (2007) observed that cohesive clusters connected by occasional non-local ties enhance innovative productivity within geographic regions. In addition, it is found that shorter path lengths and larger connected components increase innovation.

Abbasi et al. (2011) used correlation and regression analyses and attempted to combine performance and social network measures in identifying the effects of co-authorship networks. They analyzed how normalized degree centrality, closeness centrality, betweenness centrality and average tie strength influence citation-based performance of scholars. The first part of this study lays out the definitions of social network measures including the impact of each measure on the network analysis. Degree centrality is defined as popularity of a node in the network and plays a structural influence on leadership, and efficiency. Closeness centrality is measured as the shortest distance from all other nodes in the network. Betweenness centrality is calculated as the number of shortest paths passing through a node in the network, and it is the indicator of the existence of a broker or a gatekeeper in the network. In addition, betweenness centrality identifies the transition point of the information flow in the network. Betweenness centrality and degree centrality of a node have a high influence on network performance. It is found that scholars who are connected to many distinct scholars have better citation performances and scholars who have large average tie strengths, meaning repeated co-authorships, have better research performances. Moreover, scholars who have strong co-authorship with one author perform better compared to researchers who have many relationships to the same group of linked co-authorship.

Some recent studies acknowledge the important role played by firms' network positions in emerging economies. For example, Darvish and Tonta (2016) conducted a study about the diffusion of nanotechnology knowledge in Turkey and the corresponding network structure. They examined centrality measures regarding

collaboration at different levels, which are individual, institutional, and international levels. Moreover, Shi et al. (2012) suggested that the importance of network position depends on the status of the economy - developed or emerging. For instance, in developed economies, firms with high centrality are preferred as attractive partners.

However, in emerging economies, the firms holding structural hole positions or brokerage positions are preferred as attractive partners. Therefore, it is expected that networks with dense and clustered relationships, also possess mechanisms enabling trust and close collaboration. Shi et al. (2012) define small world networks as "clusters of locally dense interactions connected via a few bridging ties". They stress that few research has systematically investigated the relationship between network properties and innovation potential within given geographic regions and most of the studies fail to find evidence that small world structures enhance innovative productivity within geographic regions.

At this point, authors ask why some regions are more innovative than others, and collect the answers from different fields as in the Table 2-1 below:

Table 2-1: Why some regions are more innovative?

Fields	**Why some regions are more innovative**
Finance researchers	Importance of venture capital to innovative risk taking
Labor researchers	Importance of skilled labor to innovation and creation of regional infrastructure to support new firm formation
Legal scholars and sociologists	Lax enforcement of laws designed to restrict the flow of people and ideas contributes to job mobility and higher levels of innovation
Social network analysis	Social networks as crux of innovation, importance of informal networks of friendship and collaboration

Source: Fleming et al. (2007; 938)

Glückler (2007) claims that regional growth and innovation largely result from the bridging and brokering of unconnected networks or network clusters. Thus, Glückler (2007) investigates the structural aspects of social capital and structural holes through the lenses of geographical network trajectory, which refers to a path in which the formation and dissolution of ties in earlier stages generate cumulative propensities for

the formation and dissolution of ties in the future. Path dependency refers to the tendency of institutions to become committed to develop in certain ways because of their structural properties or their beliefs and value (Krücken, 2003).
Moreover, the preferential attachment (or cumulative attractiveness) hypothesis of Glückler's (2007) states that firms with many ties at one point of time are more likely to receive new ties in the future than those with fewer ties. Thus, in his study path dependency and preferential attachment are investigated and observed how they affect firms' behavior in the network. First, geographical location strongly affects the evolution of the network trajectory because persistent network structures emerge from social and cognitive embedded mechanisms based on trust, which is facilitated by strong ties resulting from geographical closeness. Second, the study discovers the major source of contingency and variation in network structures by examining network structures variations in time. Peripheral firms were found to be more likely to connect to each other and there are less structural holes. Therefore, peripheral firms are much more path dependent than core firms.

Asheim and Gertler (2005) discuss the effects of tacit knowledge and geography on innovation activity in terms of regional innovation systems. They stress that the new economic system requires an entrepreneurial regional innovation system when the disruptive technology arrives in the market. However, it is highlighted that when the innovation activity and technological trajectories become path dependent then institutional regional innovation system approach works well. In this case tacit knowledge is the key determinant of the geography of innovative activity and because of the sticky nature of tacit knowledge, spatial proximity is the effective key for production and transmission by learning through interaction. The more knowledge intensive the economic activity is, the more geographically clustered structures emerge. The flow of tacit knowledge requires indeed face-to-face interactions, trust-based relations and a regional (or proximity) culture.

Davids and Frenken (2018) describe the proximity concept as referring to types of inter-organizational relationships that are expected to facilitate interactive learning and collaborative innovation. Table 2-2 provides different forms of proximity which have geographical, cognitive, social, institutional, and organizational dimensions.

Table 2-2: Proximity types and definitions

Proximity type	**Definition**
Geographical proximity	The spatial distance between actors
Cognitive proximity	The extent to which two actors share similar knowledge backgrounds
Social proximity	Generally associated with personal relationships between actors resulting from friends, family, and past collaborations
Institutional proximity	Refers to the extent norms, practices and/or incentives are shared
Organizational proximity	Refers to the membership to the same organizational entity

Source: Davids & Frenken (2018); Boshma (2005)

The literature largely concentrates on geographical proximity as a reason lying behind collaboration. For example, Belussi et al. (2008) suggest that geographical proximity is important in knowledge production and innovation as they are strongly rooted in specific local environments including social and institutional components. Moreover, the study highlights that knowledge is generated, transmitted, shared more efficiently when spatial proximity is present and economic activities based on new knowledge have a high propensity to cluster in a geographic area. Furthermore, one of the key findings of this study is that scientific collaborations would be less spatially clustered than technological collaborations. The other finding is that R&D cooperation networks appear to be generally stronger for the regional public research organizations rather than private firms.

The study of Maet al. (2015) from another region acts as a reference to examine cities as structural holes in which cooperation level is not high and full of weak links; this study also found geographical proximity as a driving force for cooperation. In addition, Ter Wal (2011) remarked that networks of collective learning emerged in information technologies but not in life sciences, for example, and noted that small firms (more important in numbers in information technologies) play important roles in establishing

local networks. Contrary to most of the previous literature, which primarily addresses the importance of geographical proximity, this study indicates that this factor is not a sufficient condition for local collective learning to take place.

The study of Whittington, Owen-Smith and Powell (2009) focused on the impact of geographic proximity and network positions on organizational innovation by analyzing patent data in regional clusters for a 12-year period and found out that regional agglomeration and network centrality have complementary and contingent influences on organizational innovation in research intensive sectors. Among network positions, centrality of physically collocated partners depends on the extent to which firms are also embedded in global networks comprising physically distant partners. There are important outcomes of this study. First, it is found that network structures are affected by geographic variables. Second, it is observed that regional characteristics influence the degree at which centrality enhances innovation and regional characteristics shape the character of information and resource flows through networks.

The study of Nooteboom et al. (2007) indicates a great deal of consensus over the relationship with cognitive proximity and innovation performance of technology-based alliances. The results demonstrate that the novelty value of innovation is increasing as the cognitive distance is getting higher. Therefore, novelty value is found higher in exploratory alliances than exploitative alliances.

Another study focused on knowledge diffusion between European neighboring countries and the European Union, which can be blocked, hindered by spatial distance, cultural differences, and institutional and linguistic borders (Autant-Bernard and Chalaye, 2013). The results show that there has been a weak development in knowledge diffusion channels between European Union and European neighboring countries and only a few countries have been in the central position in patent cooperation and publication cooperation in 6th FP.

For knowledge diffusion performances, the absorptive capacity of network members is an important factor. Thota and Munir (2011) describe absorptive capacity as “the capacity of an organization to absorb new knowledge” (p.5). Zahra and George (2002) summarized the description of absorptive capacity from other scholars (Table 2-3) and

stressed the need of adding dynamic dimensions of the term to define it clearly.

Table 2-3:Definitions of Absorptive Capacity

Scholars	**Definitions**
Cohen & Levinthal, 1990	The ability to value, assimilate, and apply new knowledge
Mowery & Oxley, 1995	A broad array of skills, reflecting the need to deal with the tacit components of transferred technology, as well as the frequent need to modify a foreign resourced technology for domestic applications
Kim, 1998	Absorptive capacity requires learning capability and developed problem solving skills; learning capability is the capacity to assimilate knowledge-for imitation-and problem-solving skills to create new knowledge-for innovation

Source: Zahra and George (2002: 188)

In addition to definitions, Zahra and George (2002) add key elements to the definition by reformulating absorptive capacity as "a set of knowledge-based capabilities embedded within the firm's routines and strategic processes". They also adopt a dynamic view suggesting that "absorptive capacity follows a multidirectional and fluid path, rather than a patterned trajectory of knowledge acquisition and exploitation" (Zahra & George 2002:198). Furthermore, Tsai (2001) attempts to find effects of network position and absorptive capacity on business unit innovation potential and performance by pointing out that a central network position provides access to new knowledge, innovative opportunities, and better performance results all of which depend on unit's absorptive capacity. The centrality of the organizational unit's network position is more positively related to innovation when the unit has high absorptive capacity.

Discussions above directly link to the question of the relations among absorptive capacity, structural holes, and innovation activities. In this sense, a key study of Kallio et al. (2010) observed that higher absorptive capacity enables structural holes in innovation systems by the involvement of the social capital of actors in the network. It is important that absorptive capacity can play a significant role as a capability that aids knowledge transfer in the regional innovation system. Thus, it secures the

exploitation in the strong ties of the network. This study analyzes the role of personal social capital in the creation of regional absorptive capacity and innovativeness of the region and stress that bridging social capital creates bonds of horizontal weak ties and bonding social capital connects homogenous groups of strong ties.

In addition, Shi et al. (2012) describes structural holes as local tacit knowledge brokers as they may enable reaching more diverse information in timely fashion. However, scholars also emphasize that brokers find advantage in the flow of information familiar to the information that broker has rather than diverse information. An important study by Parjanen et al., (2011) claims that successful brokerage and related improvement of absorptive capacity requires a holistic approach to the entire innovation process and their wider environment promoting innovativeness in regional innovation network. They summarize the various roles of brokers in terms of crosser of distances, sniffer of future, creative actor, policy executor and shaper of organizations. It is claimed that weak links and structural holes enable the most important innovation potential in the network; however, this can also be problematic if there is a huge geographical distance in order to achieve information flow. Although geographical proximity is important, it does not automatically lead to innovations, but it may facilitate social proximity. Looking from a different perspective to the absorptive capacity with a geographic dimension, the study of Belso Martínez (2017) integrates both network and evolutionary geography perspectives to develop a model that links innovation performance with the suggested term “multiplexity”. Multiplexity refers to the size of linkages and the strength of the absorptive capacity, which are expected to have a direct influence on innovation capability. They found that local networking depends either on reinforcing existing ties or increasing brokerage activities, for example in the bio cluster in the Valencia region in Spain that they studied.

It is clear from the results of Xavier Molina-Morales et al. (2016) study that knowledge acquired from diversified and cognitively distant sources (liaison brokerage) is more valuable compared to the coordinator position. It is important that being in a liaison or coordinator position is not enough for enabling innovation capability; combination of diverse knowledge coming from different brokerage positions is a great advantage.

In this strand of literature, characteristics of a network and the position of the firm in the network are investigated to answer the question of whom firms collaborate with. The studies in this perspective make use of the concepts such as Embeddedness, Imitation, and Isomorphism. In addition, social capital advantages consist of proposing good ideas, reaching evaluations that are more positive, recognition, higher compensation and faster promotions. In this section, the network performance framework will be examined according to three important factors, which are embeddedness, trust, and social capital.

Concept of embeddedness stresses that economic actions take place within networks of social relationships (Sytch and Kim, 2018) and social embeddedness theory of Granovetter (1985) plays a bridge role in the usage of social network methodology for organizational management studies. It is argued that innovation and technological change theories propose that innovation takes place effectively as a collaborative process in which social networks play a central role. Effects of social networks can be examined in terms of three bullets which are embedded relationship, embedded structure and embedded resources when individuals or organizations do not connect with the whole network (Cong et al., 2017).

In accordance with studies on embeddedness, Burt (2002; 2005) claims that there are two kinds of relationships in the network in terms of embeddedness. First, if two people connect, this can be a result of a deep history. Second, embedded relationships are structural in which people have many mutual contacts. It is claimed that when the relationships become more embedded there is a high possibility to detect bad behaviors of the actors. Therefore, in embedded relationships people are expected to be more careful about their behaviors in order not to be caught with bad or inappropriate behaviours. Hence, most importantly, trust factor is facilitated in embedded relationships, which leads to occur in connected networks. Figure 2-5 describes the embedded relationships of Robert and Jessica in different network structures. In Situation A, there is no embedded relationship between Robert and Jessica, therefore there is no trust factor. In situation B and C, trust factor between Robert and Jessica is expected to exist since they build embedded relationship with each other. However, it is not possible to identify in which situation the relationship between Jessica and

Robert is more fragile because when trust is involved in situations B and C, the consequences of the behaviors can be more destructive even though trust exists in these embedded relations.

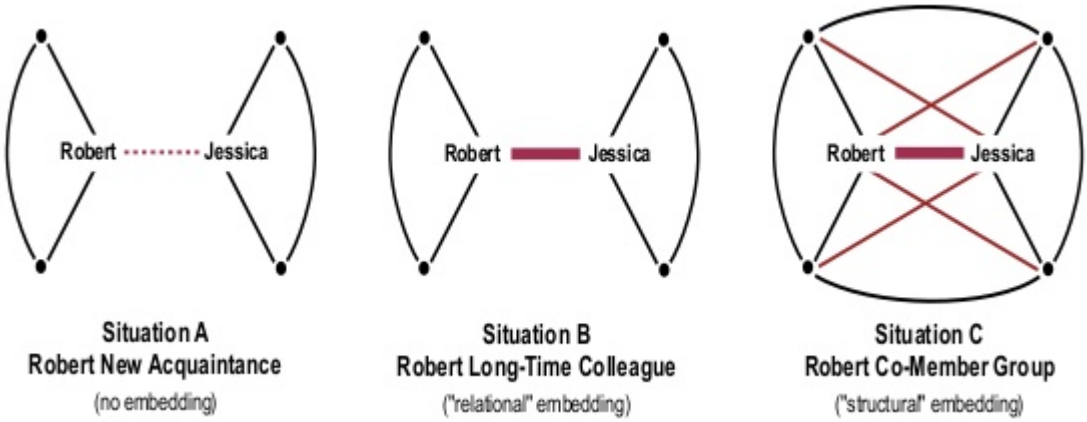


Figure 2.5: Different types of embeddedness

Source: Burt (2005)

Uotila and Ahlqvist (2008) proposed a synthetic knowledge infrastructure model which refers to industrial settings where innovation takes place through application of existing knowledge or new combination of knowledge. In their view, this is strongly different from an analytical knowledge infrastructure which refers to industrial settings where scientific knowledge is highly important, and where knowledge creation is often based on cognitive and rational processes, or on formal models.

The synthetic knowledge infrastructure model insists on the importance of brokerage roles[3] between knowledge generating and exploiting subsystems and through intermediary subsystems playing the brokerage role. Uotila and Ahlqvist (2008) suggest therefore that for regions with a synthetic knowledge infrastructure, "the logic behind the RIS should be to support and strengthen localized learning of an existing industrial specialization, i.e. to promote historical technological trajectories based on sticky (tacit) knowledge".

Molina-Moraleset al. (2016) analyzed the impact of social capital on innovation in firms belonging to a territorial cluster. Although the body of research on social capital

[3] see "structural holes and brokerage roles" part in section 2.1.1.

includes a huge number of perspectives with many criteria to be classified, social interactions and trust are determined as indicators of social capital in their study. They found that increasing level of social capital provides no additional benefits or even decreased returns in terms of innovation and value creation for the firms involved in territorial cluster. Therefore, the effect of trust on firm value creation can be described as an inverted U-shaped curve. However, the hypothesis that this relationship between social interactions and value creation was not confirmed in the literature. Furthermore, it is found that the cost associated with trust and the physical and cognitive proximities between firms in clusters may reduce the costs of maintaining highly intense social interactions.

The literature review about the influence of social capital on network performance raises critical questions about value and innovation creation in territorial agglomerations (clusters in specific territorial or regions). Huggins and Johnston (2010) emphasized that firms which are reliant on local knowledge networks are more likely to invest in social capital. In addition, they suggest that social capital investment is related to the firm size. In contrast to the arguments presented about the firm size, they claim that firm size is significant in knowledge network patterns.

2.2.2 SNA Studies on FP and H2020 Programmes

The use of Social Network Analysis (SNA) has provided profound insights into the impact of public expenditure on collaborative networks formed under the European Union's Framework Programme (FP) and Horizon 2020 (H2020). Studies employing SNA have uncovered significant findings regarding the dynamics of these networks, highlighting how public funding fosters innovation and enhances organizational capabilities. Key discoveries include the identification of scale-free network characteristics, the pivotal roles of hub organizations, and the influence of centrality on funding success and network sustainability. Furthermore, research has shown the critical importance of collaboration among various organizational types, the uneven distribution of knowledge and resources, and the evolving structure of these networks over time. This section synthesizes these findings, offering a comprehensive understanding of how SNA metrics inform strategies for maximizing the effectiveness

of public expenditure in collaborative research and innovation networks.

Impact of Public Expenditure on Collaboration Networks

SNA is used in several studies to answer if public expenditure creates sustainable effects beyond the infusion of resources and outputs such as improving competences, capabilities, organization and strategies of the firms. The European Union's FP and H2020 initiatives foster collaboration networks that provide an environment for SNA to test for the impact of public spending on these outputs. Breschi et al. (2009) claim that these collaborative networks exhibit the characteristics of scale-free networks, meaning a pattern of preferential attachment underlining the extensive influence of relatively few hub organizations and the relatively minor influence of a much larger number of peripheral organizations. They underline small world characteristics in which efficient communications between local clusters facilitate knowledge dissemination.

Therefore, the results of SNA studies on FPs data provide strategies for engaging key stakeholders within the European knowledge network, enhancing connectivity among participants, and facilitating the effective generation and dissemination of new knowledge. (Ortega and Aguillo, 2010). Ortega and Aguillo (2010) combine SNA and regression analysis to test if being a hub affects the amount of received funding in the health thematic area of FP6. They used degree centrality, total number of partners, number of coordinated projects and total number of projects in their model. Betweenness centrality was rejected by the model because this variable showed strong collinearity with degree centrality. Results show that the network is constituted by a dense core of government research organizations and universities which act as large hubs that attract new partners to the network, mainly companies and non-profit organizations.

Moreover, it is found that there is a strong relationship between projects and partners which suggests that the increase of partners would raise the likelihood of participating in new projects and therefore to obtain more funding from the programme. Similarly, Bralić (2017) conducted a study using SNA to analyze country participation in the Horizon 2020 programme by using measures of centrality. It is found that countries with the highest centrality measures receive high funding.

Enger (2018) tested whether influential network positions positively affect next participations by using FP7 and H2020 data. His approach based on the cumulative advantage theory in which accumulated advantages perform as an underlying process reinforcing other advantageous factors similar to the concept of "preferential attachment" discussed previously. Importantly, Enger (2018) highlights that due to the advantages of preferential attachment, the influential positions positively reinforce resources and capabilities and there is a possibility of lock-in situation as a disadvantage. In his study, the dependent variable measures the number of applications of the project participant; the independent variables are size, funding, capabilities and productivity which is the number of publications. In addition, SNA metrics such as betweenness and eigenvector centrality are used in order to identify gatekeepers and other prestigious nodes in the network. It is found that a higher level of network centrality (influential position in collaborative EU FP networks) has a strong positive effect on the number of approvals of the H2020 applications.

Muniz and Cuervo (2018) analyzed ICT projects for energy efficiency in FP7 to explore the links and influences in the cross-country knowledge flows generated. They used SNA to distinguish who collaborate with whom in ICT calls in the FP7 programme. The aim of the research was to detect countries acting as hubs and gatekeepers in the promotion of research and the improvement of energy efficiency. With this regard, network analysis is conducted by using centrality metrics. They identify key actors with greatest access to knowledge by using degree and betweennees centrality metrics. They detected hubs which are nodes with high degree and betweenness centralities. They also identified gatekeepers (nodes with high betweennees centralities) which connect different groups that provide access for knowledge transfer between clusters. They also used network measures as independent variables to test whether there is a relation with the dependent variable which is the energy efficiency at the country level. Countries are sorted by hubs, gatekeepers and peripheral actors and it is found that the position a country holds within the network increases with its energy intensity. Some countries act as "pulse takers" with high closeness values but fail to utilize their position effectively. In contrast, "hubs" and "brokers" in the network, mainly comprising research-intensive countries, play a vital role in knowledge diffusion. The research highlights the unequal

access to knowledge within the network, with certain countries positioned as "peripheral nodes." Recommendations are made to strengthen collaboration between hubs and peripheral nations, to improve information management, and to address obstacles to research participation. Additionally, the study emphasizes the importance of research cooperation with non-member states, particularly those with significant energy consumption and global pollution impact. It underlines the need for effective knowledge transfer to address sustainability challenges, emphasizing that the solution involves more than just increasing the R&D investment; it requires adapting solutions to specific country-level challenges.

Influence of Organizational Types

Other studies have focused on specific organization types within the FPs. For example, Morison et al. (2020) used H2020 network data to conduct SNA and found that public organizations and universities are actors with high betweenness centralities playing gatekeeper and brokerage positions at the center of the participant network. While Barber et al. (2006) examined the structure of the first five FPs and found that the networks were shaped by the domination of large scientific organizations including other characteristics such as scale free, power law distribution, high clustering, and small diameters.

Vonortas and Okamuna (2013) conducted a study on ICT networks within FP6 and FP7, revealing a critical insight. They observed that a small cluster of hubs, comprising just 3% of the participants, holds the key to maintaining network's cohesion. Additionally, a larger group of non-hub connectors, constituting 39% of the participants, plays a substantial role in the overall network activity, providing a robust foundation. Despite the removal of integrated projects and targeted research initiatives from ICT programs, the network's performance remains consistent. Consequently, the recommended policy shift should encourage core participants to achieve transition from predominantly public research institutions to private-sector companies.

In a related context, Pinheiro et al. (2016) addressed a unique concern by exploring the influence of social capital on resource sharing in collaborative R&D projects under

FP7. They accomplished this through SNA. Their findings indicated that perceived trust and shared language were significant factors in forming clusters and fostering network closure, as opposed to physical proximity.

Another important study regarding detection of hubs is conducted by Cassi et al (2009) which investigates the efficacy of IST-RTD programmes in technology development for NUTSs regions. Their methodology is based on SNA and field interviews. Multinational cooperations and SMEs are found as hub organizations which are key actors in the deployment of networks diffusing technological and market information, defining standards and emerging products and providing demand for application results. According to the interviews with these organizations, although networks are reported as important structures in raising research diversity by allowing the involvement of many sectors and making research more problem solving oriented, they lack behind in providing support to deployment activities and market commercialization. They stress the importance of hubs which play important roles on bridging research and deployment networks by disseminating knowledge of all kinds through various knowledge channels and providing access to resources and opportunities. (Cassi et. al 2009)

Technological Focus and Network Structure

Roediger-Schulga and Dachs (2006) suggest that the specific technological focus of a project significantly affects the network structure. They note substantial structural differences in EU FP subprograms. For instance, in telecommunication projects, the dominant actors are primarily industrial partners engaged in high levels of collaboration. Conversely, in agricultural projects, public research institutions take on key roles, shaping the network's structure.

Collaboration within FPs is primarily valued for its potential to facilitate the exchange of knowledge, skills, and techniques (Arnold et al., 2008; Kuitunen et al., 2008). Nonetheless, Must (2010) argues that the nature of collaboration varies depending on the research field. To explore this, scholars conducted SNA using data from FP6 related to 'citizens and governance in a knowledge-based society' (CIT) to examine collaboration trends in social and applied sciences. Their findings indicated a similar

trend in both research areas, emphasizing the significance of collaboration and trust in influencing institutions' choice of partners for collaboration. Moreover, at the national level, factors such as geographic proximity, language, culture, history, and strategic interests play a pivotal role in selecting collaboration partners.

The performance of actors has been extensively studied using SNA centrality metrics. Breschi et al. (2009) used network and patent data from the Society for Research and Technological Development (IST-RTD) Projects in FP6 to identify hubs in their research on "European Policy Favoring Networks in ICT." They built three types of networks: IST-RTD project network (organizations linked if they are partners in at least one IST-RTD project), global network (organizations linked if they share at least one strategic alliance), and knowledge network (organizations linked if one's patents are cited by the other's). They used degree and betweenness centralities to capture hubs in these networks and defined gatekeepers as organizations that play the role of hub in more than one network. They found that the IST-RTD network carries scale-free characteristics, implying that such networks contain relatively few highly connected hubs while the majority remain weakly connected. IST-RTD hubs are found to be most effective in terms of enriching the network with new knowledge and facilitating the dissemination of knowledge among other organizations. As a result, they suggest that public policy should facilitate the development of more European organizations characterized as hubs to draw a larger number of technologically dynamic organizations into this program.

Another study contributes to the debate on the engagement of peripheral regions into collaborative research networks and explores factors that promote or hamper their participation in the networks using FP7 data (Amoroso et al., 2018). They used descriptive statistics to observe how interregional collaborations relate to centrality and proximity measures for participation in FP7 projects. They used geographical distances between NUTS2 regions, GDP, and patent data as independent variables. Not surprisingly, they found that the number of joint R&D projects is concentrated mainly in more developed regions, in line with previous empirical studies suggesting that distance, whether geographical or institutional, matters (Olson and Olson, 2003; Maggioni and Uberti, 2009). Thus, regions collaborate more among themselves if they

are similar, and there is a certain path dependency on regional R&D collaborations where peripheral regions are left alone. FP programs have created a dense network of regional partnerships, but this is a network mainly among close and similar regions, with a high degree of persistence over time. Therefore, it is suggested that policymakers coordinate the excellence among leading regions and integrate peripheral regions separately.

On the other hand, Calignano (2022) highlights an important issue: although relatively innovative regions may play a key role in transnational innovation networks, their inadequate action as gatekeepers represents a negative aspect for peripheral regions in general and especially in marginally innovative countries. He conducted this study using SNA and econometric modeling, specifically focusing on the EU nanotechnology network created as part of the Horizon 2020 program.

Analyzing studies on technological focus and network structure is crucial for understanding the dynamics of collaboration and innovation within different sectors and regions. The differences highlighted by Roediger-Schulga and Dachs (2006) between industrial and public research roles in various technological domains underscore the need to tailor collaboration strategies to specific contexts. This variation in network structures influences the efficiency and effectiveness of knowledge exchange and innovation diffusion, as evidenced by the work of Arnold et al. (2008) and Must (2010).

Furthermore, the identification of hubs and gatekeepers in networks, as discussed by Breschi et al. (2009), provides insights into the critical nodes that drive technological advancement and dissemination. Understanding these roles helps in formulating policies that support the development of strategic alliances and knowledge-sharing mechanisms.

The engagement of peripheral regions, explored by Amoroso et al. (2018), and the challenges highlighted by Calignano (2022) point to the need for inclusive policies that address regional disparities. By integrating peripheral regions more effectively, the overall network can benefit from a broader range of innovations and collaborative efforts.

Dynamic Analysis and Evolution of Networks

One of the most comprehensive studies in literature is Balland et. al (2019)'s "Network dynamics in collaborative research in the EU". They use SNA to describe the evolution of the EU research networks across countries based on data covering collaborative projects launched during the first four years of implementation of Horizon 2020 and its predecessor programmes, FP6 and FP7. This type of dynamic analysis contributes to understanding how these networks are formed and how they have evolved over time. This may provide useful policy implications for the design and structure of the current and future EU Programmes aimed at shaping and creating a unified European Research Area (Protogerou et al. 2012). The primary objective is to observe to what extent the network has been subject to changes during the period 2003–2017 to observe the issue of the centrality metrics of organization types. They also compared countries' positions in the programmes. It is observed that higher education institutions are the real hubs of the networks in general. Other important findings show that EU-15 and EU-13 countries have become more integrated, and some organizations fulfil a bridging function in the EU research network. EU-13 countries are more heavily engaged in parts of the programme on lower complexity research activities.

Calignano and Trippl (2020) conducted a study that focused on H2020 energy projects within NUTS2 regions. They examine whether innovativeness ('innovation-driven' participation) or energy demand/vulnerability ('challenge-driven' participation) determine a different degree of participation in the context of the energy programme funded under Horizon 2020 (2014–2020 period). The study employed a combination of SNA and econometrics for its empirical analysis. They used centrality measures (degree, betweenness and eigenvector) as dependent variables and Regional Innovation System indicators and energy use indexes as independent variables. The results show that the more innovative EU regions hold a central or key position, while the regions characterized by higher energy demand or vulnerability play a marginal role in the EU energy network.

Structural Transformation of FP7 and Horizon 2020

Several investigations have examined the structural transformation of FP7 and

Horizon 2020. Notably, Kim and Yoo (2019) undertook one such study, which involved an in-depth analysis and assessment of the alterations in the European Union's science and technology policies as they transitioned from FP7 to Horizon 2020. The aim of this research was to furnish valuable insights for research organizations and academia, aiding them in the formulation and execution of future studies related to international collaboration with the EU.

European Commission (2015) published a report on the results of FP7 participation in which "effects and outcomes of networking at the macro level" were analyzed through network analysis and at the micro level through case studies, in-depth interviews and a survey. The SNA methodology conducted "provided a broad view of networking activities that took place in FP7 and its different specific programmes and underlying thematic areas". It is found that there is a strong core-periphery network structure across both FP6 and FP7 at the organizational, regional, and national levels. At the organizational level of both framework programmes, universities and research organisations dominated the core of the co-participation network while the private sector, small and medium-sized enterprises (SMEs) and public bodies populated the network periphery, surrounded by the network's structural holes and with fewer direct links between them than the organisations at the network core. The integration of business enterprises, including SMEs, in intersectoral partnerships was found to foster innovation. Bibliometric and survey data revealed that knowledge transfer from research to market and the propensity of projects to introduce innovation in the form of new products or processes were both significantly increased when SMEs were involved in projects in all specific programmes where such activity could be measured.

2.3 Summary of the Literature Review

In the first section of this chapter, fundamental concepts of the SNA approach and network performance are discussed in terms of questions such as which organizations collaborate with whom and how networks evolve. In the last section, studies based on FPs which uses SNA are examined. These studies explore collaborative research networks formed through the European Union's Framework Programmes (FP) and Horizon 2020 (H2020). The key findings include collaboration network's role in the establishment of a European Research Area, the presence of scale-free and small-

world network characteristics, and the identification of hubs and gatekeepers within these networks using network analysis metrics.

The studies emphasize the importance of network centrality in influencing participation and funding approvals in EU research initiatives. Factors such as trust, language similarities, and proximity play vital roles in shaping collaboration trends, and regional collaborations tends to concentrate in more developed regions. Additionally, public organizations and universities often act as gatekeepers in these networks. These findings offer valuable insights into the structure, dynamics, and impact of collaborative research networks, providing a foundation for informed policy decisions and further research in the field. The table below provides a comprehensive summary of pivotal studies, encompassing data, conceptual frameworks, research methodologies, and their respective findings.

Table 2-4: Summary of Data, Concepts, Methodology and Findings

Author	Sample	Methodology	Metrics	Findings
Impact of Public Expenditure on Collaboration Networks				
Breschi et al (2009)	Society Research and Technological Development (IST-RTD) Projects in FP6	Network data and analytical methodology	Number of patents, number of citiations received, number of highly cited patents used for building knowledge network. Degree, betweenness centrality	IST-RTD projects can attract global hubs whether these hubs are based in Eurorpe or not. Hubs are effective in producing and diffusing knowledge. ISRTD hubs are more effective than other participants in knowledge transfer
Bralić (2017)	Projects under Horizon 2020 (2014-2020)	SNA	Degree, betweenness, closeness centrality	Countries with highest centrality measures have high received funding, however having high centrality measures (degree,

				betweenness, and closeness) is not necessarily a good indicator of the rate of success of countries.
Enger (2018)	HEIs participated in FP7 and H2020	Descriptive statistics and SNA	Dependent variable is measured as the number applications of participant, independent variables as size and funding, capabilities as productivity which is the number of publications. In addition, SNA metrics such as betweenness and eigenvector centrality used in order to identify gatekeepers and other prestigious nodes in the network.	due to the advantages of preferential attachment, the influential positions positively reinforce resources and capabilities there is possibility of lock-in situation as a disadvantage. a higher level of network centrality has a strong positive effect on the number of the H2020 applications and funding approvals.
Ortega and Aguillo (2010)	FP programmes	Regression analysis (f funds and centrality degree of each countr) and SNA	Degree and betweennes centrality	Social network measures (centrality degree and betweenness centrality) not only have assessed the collaboration performance of these countries, but also have estimated and quantified the funds that a country may receive participating in the EU research programmes
Muniz and Cuervo (2018)	ICT calls for energy efficiency at FP7 programme	SNA	SNA Metrics: Degree and betweenees centrality Dependent variable: energy efficiency, readiness and	The levels of connectedness within the FP7 knowledge-related network do matter in terms of the results in energy

			vulnerability	efficiency, but it matters for energy intensity. countries acting as hubs and gatekeepers are important in the promotion of research and the improvement of energy efficiency
Influence of Organizational Types				
Morison et al (2020)	H2020 Smart Specialization Strategy projects in Calibra region	SNA	SNA metric: betweenness centrality	Public organizations and universities are actors with high betweenness centralities acting gatekeeper and brokerage positions at the center of the participant network.
Barber et al (2006)	FP1,FP2,FP3 and FP4 programmes	Molloy-Reed version of random intersection graphs and a Bernoulli-type model	Graph characteristics: Degree, clustering coefficient, diameter, path length	The network was shaped by domination of large scientific organizations including other characteristics such as scale free, power law distribution, high clustering, and small diameters.
Vonortas and Okamuna (2013)	ICT network in FP7 and H2020	SNA: project-participant and Patent Citation Network	Topological properties, degree and betweenness centralities, hub analysis, number of patents, number of citations received	ICT-RTD network of collaborative RTD projects formed through the FPs was characterized as scale free (a very large periphery and a small core of very active participating organizations, large number of hubs). e ICT networks are

				deeply influenced by public research and teaching organizations.
Pinheriro et al (2016)	R&D projects at FP7 programme	Logistic regression quadratic assignment procedure and random graph models	Dependent variable: Social capital – independent variables: time spent, shared vision, trust and commitment	Perceived trust and language similarities are found as significant indicators for clustering and closure in the network.
Cassi et. al (2009)	FP6 IST-Thematic Area1 projects eTen and eContent Projects	SNA indicators and field interviews	Network density, size of largest component, average degree, average distance, maximum distance, clustering coefficient	Multinational cooperation and SMEs are found as hub organizations which are key actors in the deployment networks diffusing technological and market information, defining standards, and emerging products and providing demand for application results
Technological Focus and Network Structure				
Roediger-Schulga and Dachs (2006)	Telecommunications and the agro-industrial industry in FP4	SNA	Degree and betweennes centrality and network structural metrics	There are systematic differences which we attribute to differences in the underlying knowledge base, the research trajectories pursued in EU-funded R&D and the organisation of knowledge production in the two industries.
Roediger-Schulga and Dachs (2007)	First 5 FP programmes	Network analysis	Global network characteristics: Hubs, degree; edge weights and network cores	Structural features (scale free and small world) are remarkably similar across FPs,

				indicating similar network formation mechanisms despite changes in governance rules. The core players in the network mainly consist of HESs and RECs
Amoroso et al (2017)	NUTs2 regions funded during the period 2007-2013 under FP7	Descriptive statistics: a negative binomial gravity process	Regression model to test dependent variables such as centrality, proximity, and number of collaborations between regions. Independent variables: geographical distance, GDP, and patent data	Disparities in human capital &technological proximity on regional R&D cooperation is relevant and differs across subgroups of collaborations.Des pite the efforts of integrating marginal actors, peripheral regions have lower rates of collaborations. Centers of excellence should be promoted to increase cooperation for knowledge transfer between regions to overcome structural weakness in the network.
Calignano &Trippl (2020)	H2020 (2014–2020 period) Energy Programme	SNA and econometrics	SNA: density, density by groups, degree centralisation and core-periphery model Econometrics: Dependent variables: degree, eigenvectorbetweenness, structural holes Independent Variables: RIS, HCDD, EVI index	The more innovative EU regions hold a central or key position, while the regions characterised by higher energy demand or vulnerability play a marginal role in the EU energy network.
Must (2010)	"Citizens and governance in a	SNA	Compare collaboration with	FP network evolution trend is

	knowledge-based society'' (CIT) in FP6 programme		all partners; and collaboration with core partners networks.	similar insocial and applied sciences, in which collaboration and a degree of trust play a significant role in the institutions' choices of collaboration partners. Also, at the country level, proximity, in geographic, linguistic, cultural, historical and strategic terms, plays an important role in the choice of collaboration partners.
Dynamic Analysis and Evolution of Networks				
Balland et al (2009)	FP6,FP7 and H2020	SNA	Centrality metrics of organization types	HES are the real hubs of the networks in general. Other important findings show that EU-15 and EU-13 countries have become more integrated, and some organizations fulfil a bridging function in the EU research network. EU-13 countries are more heavily engaged in parts of the programme on lower complexity research activities
Structural Transformation of FP7 and Horizon 2020				
European Commissi on (2015)		Network analysis, survey, case studies including in-depth	SNA: betweenness centrality,	The integration of business enterprises, including SMEs, in intersectoral partnerships

		interviews, a representative stakeholder workshop and regression analyses		fosters innovation. The FP6 and FP7 networks are characterised by a core-periphery structure at the organisational, regional and national levels. Extensive intersectoral linkages may have an adverse effect on innovation. Structural holes mostly exist between peripheral actors. Extensive intersectoral linkages may have an adverse effect on innovation.

CHAPTER 3

DATA AND METHODOLOGY USED FOR THE GLOBAL STATISTICAL ANALYSIS and SNA: SOME PRELIMINARY RESULTS

This chapter describes the data sources, the process of data collection and extraction as well as the quantitative analysis techniques used to investigate the research questions of this dissertation. The purpose of this chapter is to provide insights about the Chapter 4 which will offer in-depth analysis and evaluation of the changes in the network structures and performances of the Energy related projects from FP7 to H2020 using SNA metrics. In this chapter, a methodological strategy comprising descriptive statistical analyses, social network analysis (SNA), graph visualization, and econometrics (ordinary least square estimation) was adopted to conduct the empirical analysis. We used SNA measures, such as degree, betweenness, eigenvector and closeness centrality metrics as well as hub detection to map the performances of the energy projects in the targeted networks and determine the possible associations among the dependent variables and main independent variable, the number of patents, to measure project outcomes.

The first part of the chapter presents data sources and data collection processes, which will provide us with the data to be used subsequently in the descriptive statistical analyses and SNA for FP7 and H2020 energy projects. The second part presents a preliminary statistical analysis of the data to prepare the SNA. The third part summarizes the SNA approach we used and presents some preliminary results in preparation of Chapter 4.

3.1 Data Sources, Data Collection and Preliminary Analyses

3.1.1 An introduction to the global structure of FP7 and H2020 Energy projects

The EU R&D projects are performed, most generally, by a network or group of laboratories, institutes, research groups belonging to large public or private research centers or universities or companies. This is the case for all the energy-related projects

in FP7 and H2020. Therefore, the projects are themselves networks of different sizes depending on various factors, such as the call topic, the available budget, the scientific and technological perimeter of the project, its Technology Readiness Level (TRL)[4] etc. However, especially in H2020 Energy programs, there are also single partner/coordinator projects from SMEs. In our analysis, we shall try to take into account this pecularity of the H2020 program in our comparison with the FP7 program energy projects.

In general, multi-participant FP projects -such as Reserach and Innovation Actions (RIA), Innovation Actions (IA), Coordination and Support Actions (CSA)-[5] to be eligible should form a consortium of participants from several member or associated states and involve different organisms. Therefore, these FP projects also genuinely have a social network structure. Each participant in a given project is composed of various numbers of members with different competencies and qualifications: junior or senior researchers, academics with different seniority levels from professors to PhD studients, engineers and other types of personel including administrative staff. Therefore, each participant team to an EU project is already a social network. The participant teams are affiliated administratively to a well identified organism (with a single identity called the PIC number in the EU jargon) such as research organisms (for example TÜBİTAK, CNRS, CNR...), universities (for example METU, Imperial College...) or companies (for example TÜPRAŞ, SIEMENS...). But, in general, project participant teams belong to a department or a sub-unit of such a larger organism. Therefore, each participant team in a framework project also belongs to a social network within its immediate surrounding, i.e. within its own organism.

The participant team joins other teams in other organisms and/or other eligible EU countries, to constitute the EU project team, which is then a social network of a higher complexity or variability in terms of the qualifications, background, cultural and

[4] TRL represent a scale for determining the maturity stage of a specific technology. Each project is assessed based on criteria defined for each level, and it is assigned a TRL rating that reflects its advancement. The TRL scale consists of nine levels, with TRL 1 indicating the earliest stage of development and TRL 9 indicating full maturity, Please see https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels/

[5] https://european-union.europa.eu/live-work-study/funding-grants-subsidies_en

geographic affiliations, etc.

Usually each team or participant to an EU project has one or several leaders, depending on the size of the participant team. The building of the EU project network may take several forms but is generally initiated by the leader of one of the participant's teams. Usually again, this initiator plays the role of the coordinator of the EU project both during its preparation and submission phase and, if the project is successful, during its implementaion phase. Such projects last in average between 36 to 48 months from the signature of the grant agreement between the EC and the project consortium and the closure of the project. This is how a typical EU project is structured.

A schematic representation of the superposition of this 3-level network structure is shown below in Figure 3-1, using the example of the OPTIMASH project in FP7 (*https://cordis.europa.eu/project/id/283050*).

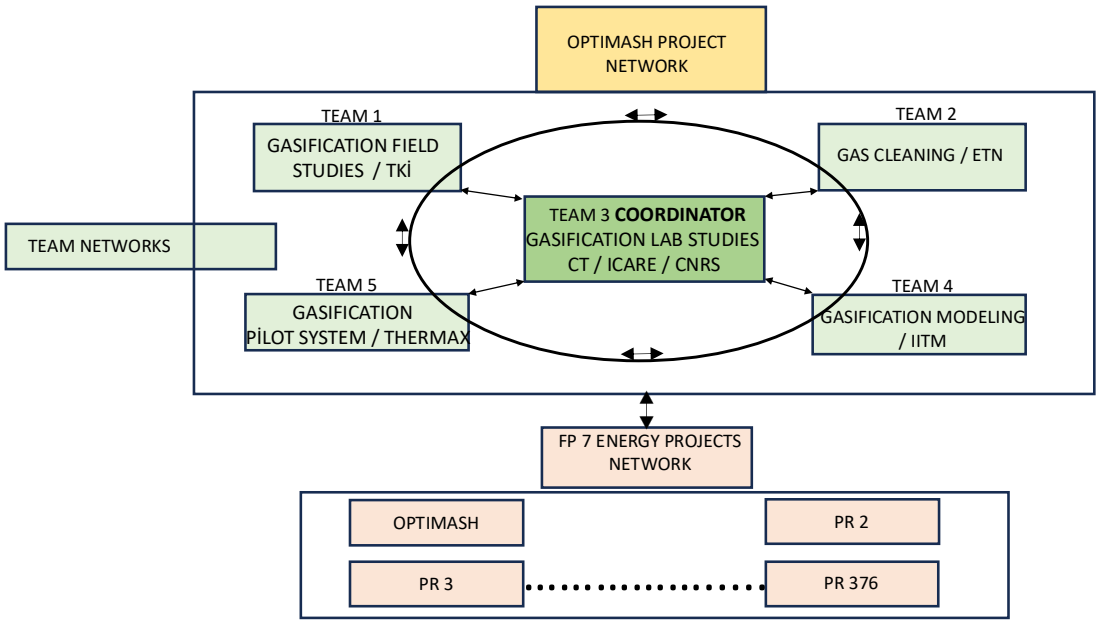


Figure 3.1:Example of the superposition of networks in a EU FP project

The example fo the OPTIMASH project in FP7 (Optimizing gasification of high-ash content coals for electricity generation, 1/11/2011 – 30/4/2016. Total cost: 5 303 906 €, EU contribution: 3 430 036 €. Coordinated by Dr. İskender Gökalp, ICARE-CNRS, Orléans. (*Source: Dr. I. Gökalp, personal communication*)
The first-level network is that of the participant's team (green boxes). For example, at the center of the graph, the CNRS (the administrative Coordinator of the OPTIMASH

project and with its headquarters in Paris) hosts the research institute ICARE located in the city of Orléans where the research is physically conducted. ICARE hosts the research team (Combustion Turbulente, CT) which actually conducts the OPTIMASH project related research within ICARE. The imbrications between these actors constitute already a complex socio-technical network which mobilizes primarily the scientific team (CT) but also all the admisitrative and technical staff of ICARE. These imbrications also concern the global CNRS structure (through its administrative structures located in the Regional CNRS Administration Delegation, in Orléans also) mobilized for the financial and juridictional management of the OPTIMASH project (*Gökalp, 2023, personal communication).*

Such first-level networks show the other four participants of the OPTIMASH project. They collectively constitute the OPTIMASH project consortium which is the second-level network. Finally, all the 376 FP7 Energy projects constitute the third-level network, that is the FP7 Energy projects network.

It appears, therefore, that the global networks we are interested in (for example the FP7 Energy projects network) are in fact a kind of superposition of several intimately imbricated social networks with increasing complexity levels in terms of relations between the partners, the partners' parent organisations, and the project consortium.

During the implementation phasess of the projects, the scientific and technological roles are assumed by individual actors (the team members of participants) and the administrative roles (management of the financial and juridictional aspects, such as the intellectual property rights) are assumed by the corresponding administrative units and staff of the participant's organisation. This two-level management of the projects are also source of various conflicts both within the partner organisation's structure and between the partners of a given project, especially between the project coordinator's organisation and those of the project participants (*Gökalp, 2023, personal communication).*

In the present dissertation such detailed social linkages will not be analysed. Such analyses should be performed in the context of micro-sociological or socio-etnographic studies concerning the detailed conduct of scientific activities, similar to

those inspired by STS type approaches (initiated by *Bruno Latour and Steeve Woolgar in Laboratory Life. The construction of scientific fact, Sage Publications, 1979*). Our aim in this dissertation is a macroscopic study of the global structure of FP7 and H2020 Energy domain projects' networks. We essentially use the statistical analysis tools provided by the Social Network Analysis. However, we also conduct a more descriptive statistical analysis of the same data. The objective by doing so is to enlighten the SNA analysis results with some global and descriptive characteristics of the two networks. In this way, we hope to sharpen the refined contributions of the SNA approach that can not be attained by global descriptions of the same networks.

FP7 Energy data base, for example, is composed of 376 projects with 2347 participant teams (*see below*). Some of them (in fact their leaders) play the coordinator role in a given project. In this thesis, the networks we are interested in is the global network constituted by the 376 projects in the FP7 Energy projects network. But this FP7 Energy projects' network has its characteristics shaped by its participants. The analysis of these characteristics of participants is therefore important, especially with regard to some possible correlations with the outputs of the projects (such as the patent and publication numbers) and the global FP7 Energy network structure. In addition, the comparison with the H2020 Energy projects which we will implement later, may provide useful indications on the global dynamics of thee programs and on the compatibility of their outcomes with the changes introduced compared to the previous program (in our case the FP7 program).

The possible relations between the participants of a given FP7 Energy project (in fact, any FP programme) and other participants - other FP7 Energy projects or any other FP programme- may take several forms. Some of them are illustrated in Figure 3-2 below; for example, the same team may participate to several FP7 Energy projects (Participant 3 in Figure 3-2) or the coordinator of one project could be a participant in another FP7 Energy project (Participant 5 in Figure 3-2) or vice versa (Participant 2 in Figure 3-2). The analysis of such relations or linkages between FP7 Energy projects will enlighten the structural features of the FP7 Energy projects's network in terms of the power or the leading role of each participant (and consequently of the corresponding project coordinator).

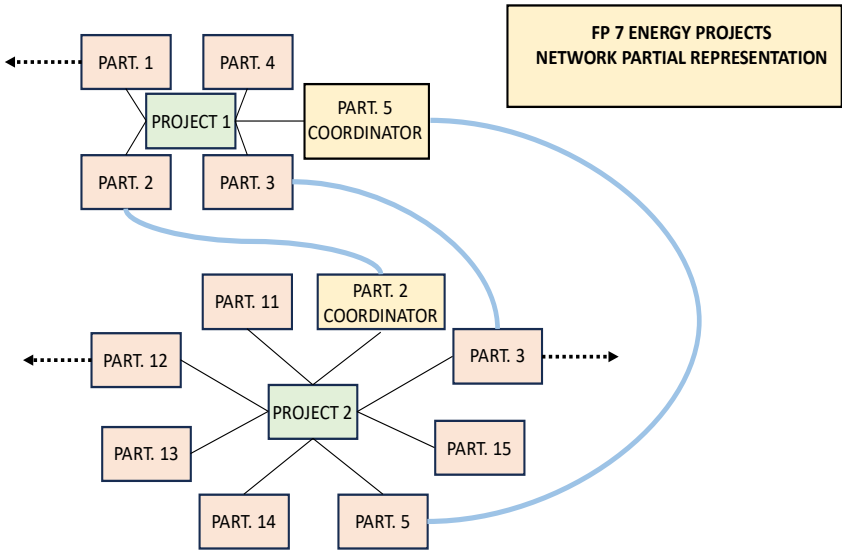


Figure 3.2:Partial representation of the FP7 Energy projects' network.

Source: Dr. I. Gökalp, personal communication.

The distribution of the FP7 Energy network projects within the EU member states (and the associate members) will inform us on the solidity (or homogeneity or coherence) of the European Research, Development and Innovation system, on the leading sub-regions (for example at the NUTs2 levels), on the relations between the central regions in the EU RDI system and the peripherial ones[6]..

Detailed analysis of a number of characteristics of the FP7 Energy project networks(such as frequency of the coordinator role of a given participant, number of participants in a given project, frequency of a participant to appear in several projects, distribution statistics of the EU financial contributions at the project and participants levels, and frequency of the linkages between the participants) will be conducted. Findings concerning these charateristics will provide us with RDI policy recommendations at several levels. For example, such analyses will identify EU regions RDI strong as well weak ones. In addition, comparing FP7 and H2020 Energy programs networks will higlight if the changes in EU RDI policy were able to improve (or worsen) some indicators regarding the EU Energy RDI landscape.

[6] *see chapter 1 and references provided therein.*

In this section an exploratory descriptive nalysis of the FP7 and H2020 Energy projects will be conducted based on the CORDIS database. Thisanalysis will serve to be acquainted with the data we use in our thesis. This analysis will be later compared with more sophisticated metrics we will extract using SNA tools.

3.1.2 Dataset used in the SNA of FP7 and H2020 energy projects

FP7

The European Union CORDIS database provides datasets that contain information on organizations, projects, topics, weblinks, legal basis present in all FP7 projects. CORDIS provides these datasets as *open data* in its database, i.e. they are publicly available (De Juana-Espinosa and Lujan-Mora, 2019; 2020). The excel files for energy projects were retrieved from the CORDIS database in September 2023[7]. We have then created our own dataset by connecting organizations and projects using the unique project ID.

The *organization dataset* provides participants' information in all framework programmes. Information fields in this dataset contain the project ID and acronym, participant role (participant or coordinator), organization ID, organization name, EU financial contribution, country, address, organization Url, contact info. It is important to mention that even when the organization's different departments/institutes (not necessarily in the same geographical location) participate in separate projects, they have the same organization ID (same PIC number and therefore same geographical address).

A second dataset includes all types of *projects* in the FP7. The project information data set contains project control number (rcn), project id, acronym (short name of the project), status (payment phase of the project), programme topics, project title, start and end dates, project URL, objectives, total cost, EU financial contribution, call, funding scheme, coordinator, coordinator's country, participants, participants'

[7] The raw data of all FP7 programmes is reachable in CORDIS database's links provided below. https://cordis.europa.eu/data/cordis-fp7projects-xlsx.zip

countries, and project subjects.

To isolate energy projects among all FP projects, the ENERGY theme s selected in the program section of the *project data set* to reach related topics and subprograms. All selected energy projects have an end date; this new dataset is combined with *organisations dataset* by matching with the project ID number. The resulting data set contains 2347 participants (from *organisations* dataset) and 376 completed projects that are part of the energy project theme in FP7.

H2020

The *organization dataset* is retrieved from CORDIS open dataset like we did for the FP7, inside the H2020 projects zip file.. H2020 *organizations dataset* consists of participants' information in all framework programmes. Information fields in the organization's dataset contain the project ID, organization acronym, role (participant or coordinator), organization ID, organization name, EU financial contribution, country, address, organization Url, contact info, and contact e-mail. In this dataset too, as for the FP7, when the organization's different departments/institutes (not necessarily in the same geographical location) participate in separate projects, they have the same organization ID (same PIC number and therefore same geographical address). The dataset for completed H2020 energy projects is collected from the Horizon Dashboard by choosing R&I Projects in Self-Service BI mode. We filtred H2020 program by choosing "Secure, Clean and Efficient Energy" as thematic priority and Project ID as dimension and then download the data[8] by right clicking the table. We reached the full data by matching Project IDs with participant and project dataset retrieved for CORDIS open dataset for H2020.

Table 3-1: General Statistics for FP7 and H2020 Energy Projects

Programme	Budget (billion €)	No. of projects	Number of participants	Average duration of projects (days)	Average total cost of the projects(billion €)	Average EU funding of the projects

[8] https://dashboard.tech.ec.europa.eu/qs_digit_dashboard_mt/public/sense/app/d58f3864-d519-4f9f-855e-c34f9860acdd/sheet/QCdc/state/analysis

						(million €)
FP7	1.8	376	2347	1302	2.9	4.8
H2020	4.9	1476	6566	1149	6.6	4.4

Source: CORDIS data base and own calculations

Table 3-1 presents the summary statistics for FP7 and H2020 energy projects. According to the data, it is observed that the budget allocated to energy projects as well as the number of projects have doubled. However, although the average cost of the projects has declined by 47%, when only the EC contribution per project is considered (most probably due to the presence of an important number of SME projects with small size fundings), it is observed that the average financial support received by H2020 projects is higher than FP7 by 41 %.

When the FP and H2020 data are compared, we might expect, in terms of SNA terminology, that increased funding will lead to (i) further projects being financed, (ii) increased number of nodes (projects and project's participants), and (iii) to an increased number of connections between participants and projects, which would then mean a denser network from FP7 to H2020 Energy project.

NUTS2 Data of Participants in Energy Projects for FP7 and H2020:

Since, NUTS2 data of participants in FP7 and H2020 is not available in CORDIS database, we used Horizon Dashboard to access this data. For FP7, we used Self-Service BI mode of Horizon Dashboard then we chose FP7 program and "Energy" thematic priority and filtered data by selecting Project Number, Project Title, Legal Name, Organization PIC and NUTS2 Name as dimensions. In order to download this data[9], we clicked right and select table. For H2020, we followed the same way to reach data[10] like in FP7 with an only difference in selecting thematic priority as "Secure, Clean and Efficient Energy"

[9] https://dashboard.tech.ec.europa.eu/qs_digit_dashboard_mt/public/sense/app/d58f3864-d519-4f9f-855e-c34f9860acdd/sheet/QCdc/state/analysis

[10] https://dashboard.tech.ec.europa.eu/qs_digit_dashboard_mt/public/sense/app/d58f3864-d519-4f9f-855e-c34f9860acdd/sheet/QCdc/state/analysis

3.1.3 Some detailed descriptive statistics on FP7 and H2020 Energy projects

Number of participants per project

The CORDIS database indicate that in FP7 Energy projects 2347 participants (partners with identified PIC numbers) contributed to 376 projects. Several of the partners participated to more then one project as coordinator or participant; therefore, the total individual contract number[11] is much higher than the participants number. For example, for FP7 Energy projects this number is 4536. This means that, on average, each partner participated to almost 2 projects (1.93). This also means that on average about 12 (12.06) partners participated to each project.

For the H2020 Energy projects, the corresponding numbers are, respectively, 6566, 1476 and 14378. This means that (i) on average almost 10 (9.74) partners participated to each project (ii) on average, each partner participated to around 2 projects (2.19), a number close to that observed for the FP7 projects. The increase of the number of participants in H2020 should be noted as well as the number of the individual contracts. Figures 3-3 and 3-4 show the distribution of the number of participants according to the number of project partners in FP7 and H2020 energy projects, respectively. Both distributions peak around an average participant per project number of about 10 to 12, if we exclude projects with very small number of participants. Such projects are very few in FP7 but their number is much higher in H2020 due to the increased participation of SME type companies, very often as a single participant/cordinator. Another important difference between FP7 and H2020 is the appearance of few projects with very high number of participants, a number which doubled in H2020. This could also be an effect of clustering[12] in H2020 that should be checked in detail.

Coordination frequencies

As we shall discuss in the following sections, SNA tools enable us to determine the centrality or the dominant role of some participants or projects in the FP7 and H2020

[11] These are contracts signed between the European Commission and the participants

[12] i.e. projects granted to a cluster involving a high number of participants

Energy projects' networks. A simple indicator can also be obtained by determining the number of project coordination roles played by the same participant (defined as the frequency of coordination[13]).

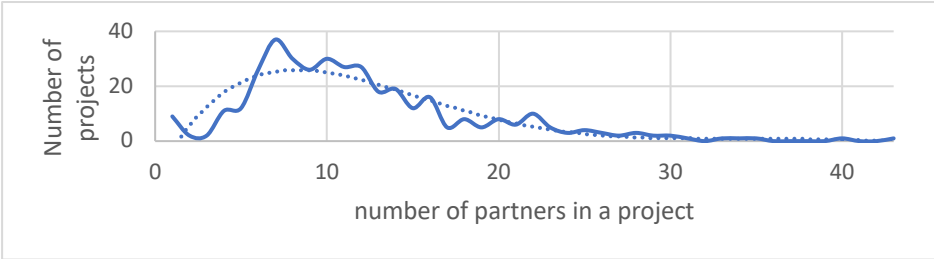


Figure 3.3: Distribution of the number of projects according to the number of project partners in FP7 Energy projects

Source: CORDIS data base and own calculations

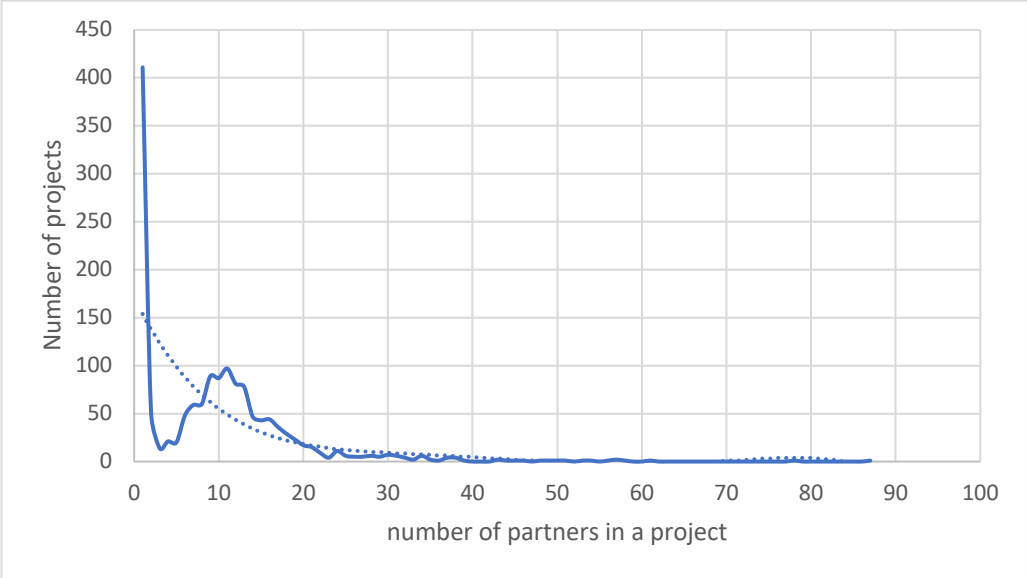


Figure *3.*4: Distribution of the number of projects according to the number of project partners in H2020 Energy projects

Source: CORDIS data base and own calculations

This information is given in Figures 3-5 to 3-7 for FP7. For example, out of the 2347 participants (but excluding projects with less than 3 participants), 2114 did not play

[13] It should be noted that in FP programs a coordinator is not counted as a partner. This means that in a project with 10 participants, for the FP statistics there is one coordinator and 9 participants. Or in an SME project, with one participant, there is one coordinator and zero partner.

the coordinator role (about 90%). 171 participants were coordinators just once. 1 participant coordinated 11 projects and 2 coordinated 9 projects, 1 coordinated 8 projects, 4 participants coordinated 6 projects. Not surprisingly such high coordination frequencies correspond generally to large research institutes such as CNRS, CEA in France, Fraunhofer in Germany, etc.

Figures 3-8 and 3-9 indicate the coordination frequency information for H2020 Energy projects. Out of the 6566 participants, 5625 (about 86%) did not fulfill any coordination role. This figure is lower than the FP7 one because of the increased number of SMEs in single participant projects and which therefore accounted as coordinator. This major difference between FP7 and H2020 Energy project's structure should not be forgotten when comparing the two programs. As shown in Figure 3-9 there is one participant who coordinated 19 projects (*not seen in Figure 3-9 but see Table 3-3*) and 2 others who coordinated one 16 and the other 15 projects. There are also 3 participants who coordinated 11 projects. The participants with a large coordination frequency are generally the same as those in the FP7 programme. We shall see in the next sections, if the coordination frequency is confirmed by the centrality metrics as determined by SNA.

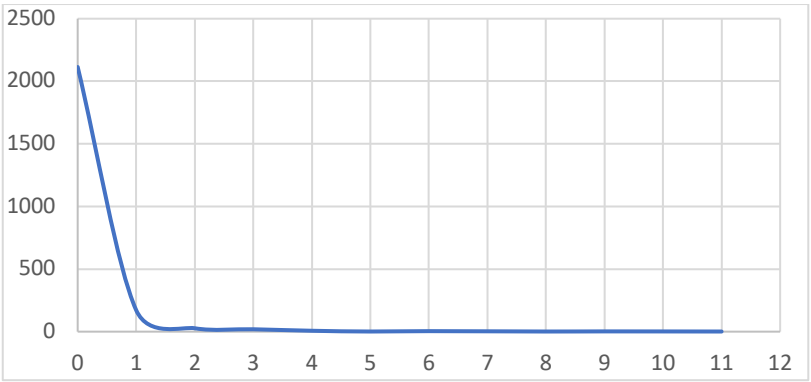


Figure 3.5: Frequency of project coordination in FP7 Energy projects .(Between 0 and 11). X axis: number of coordination roles played. Y axis: number of participants

Tables 3-2 and 3-3 below show the Top20 project coordinators and project participants in FP7 and H2020 Energy programs. A strong correlation is observed between the two categories for some of the large participants. On the other hand, some partners seem to strongly prefer the participant role rather than the coordinator

role, meaning that there are partners having a high number of participation roles but zero coordination role.

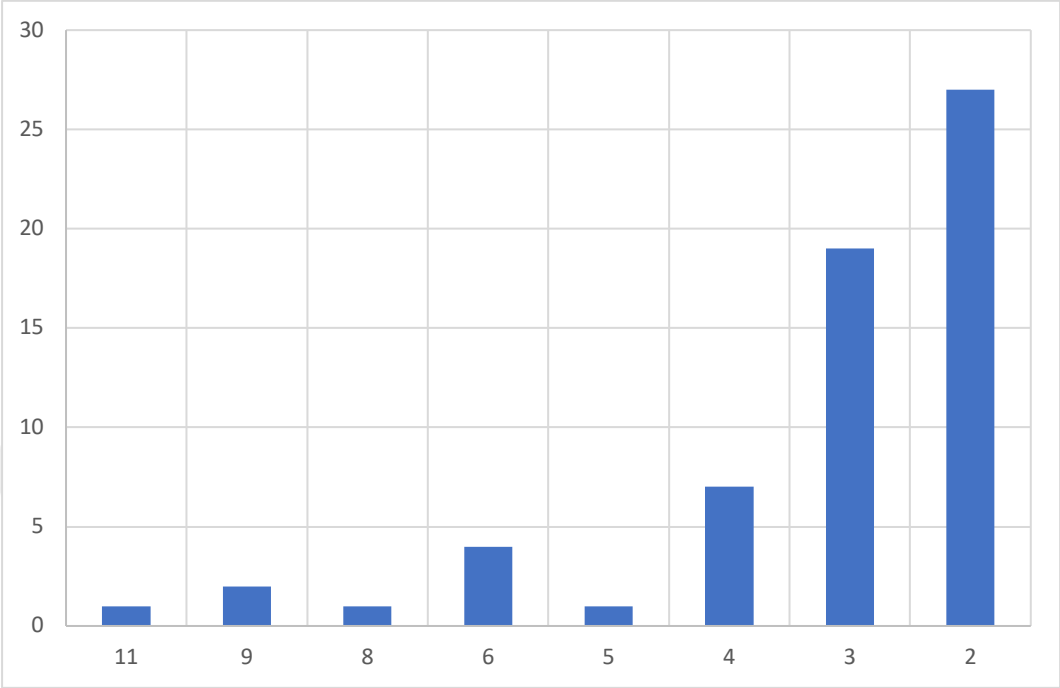


Figure 3.6: Frequency of project coordination in FP7 Energy projects (Between 2 and 11). X axis: number of coordination roles played. Y axis: number of participants

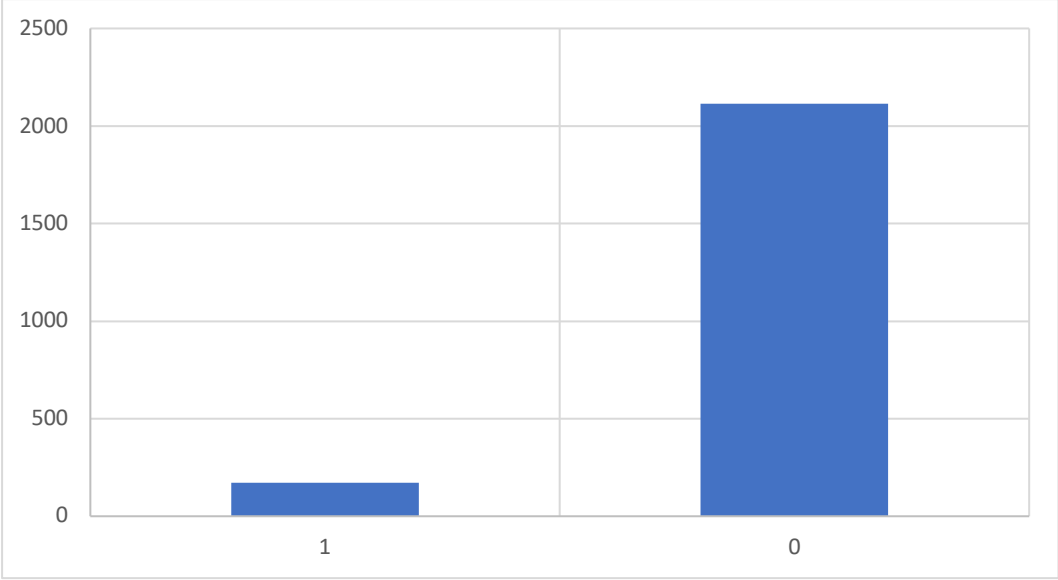


Figure 3.7: Frequency of project coordination in FP7 Energy projects (Between 0 and 1). X axis: number of coordination roles played. Y axis: number of participants

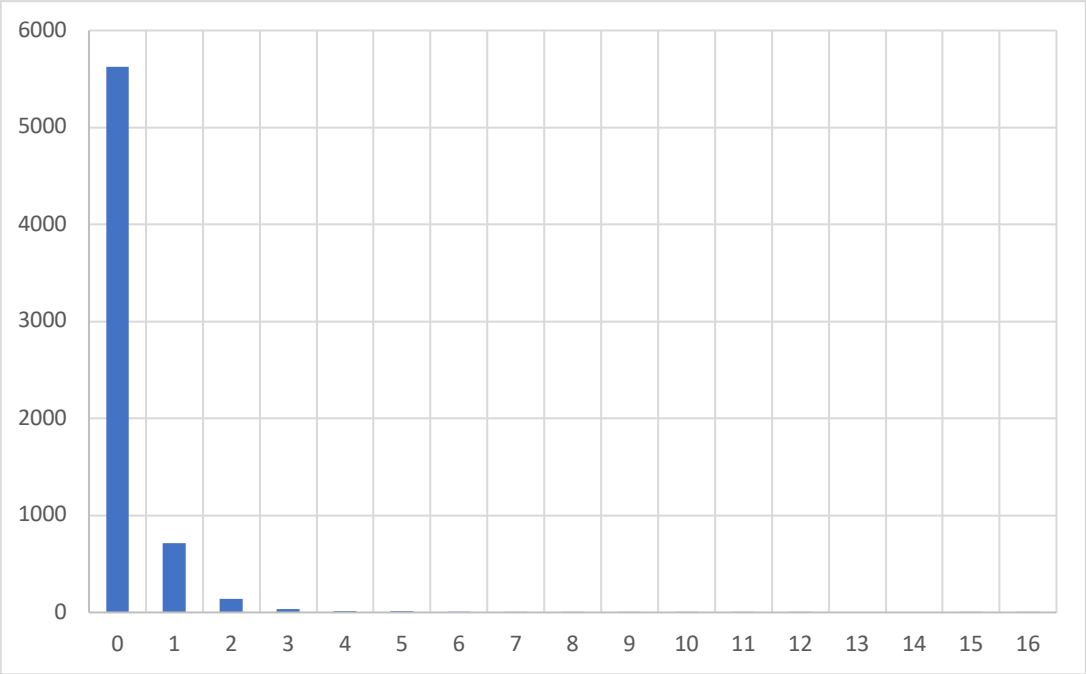


Figure 3.8: Frequency of project coordination in H2020 Energy projects

(Between 0 and 3). X axis: number of coordination roles played. Y axis: number of participants

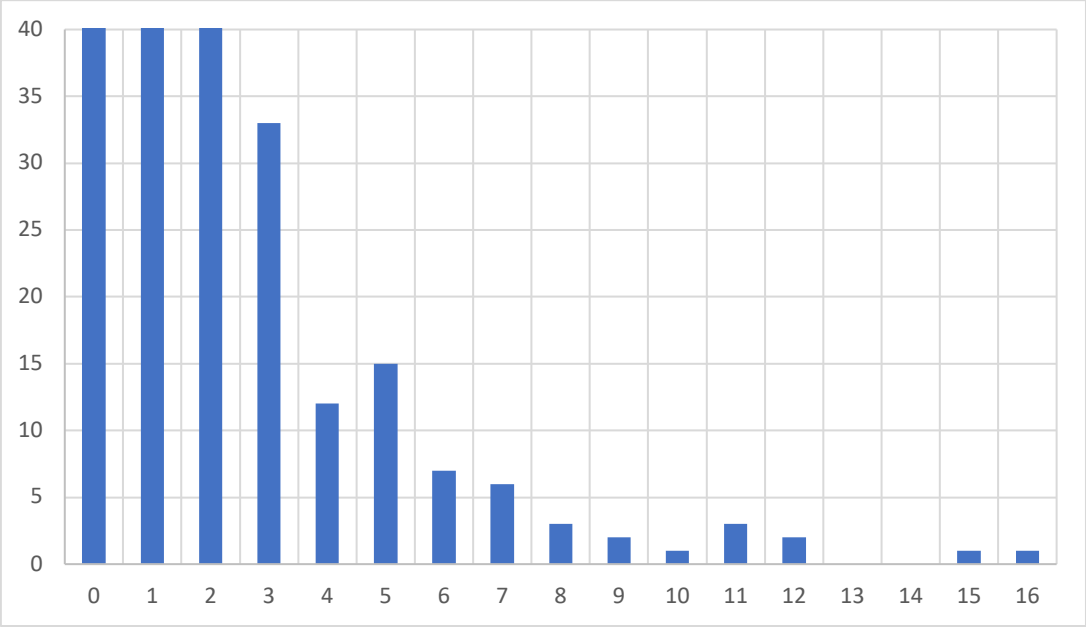


Figure 3.9: Frequency of project coordination in H2020 Energy projects

(Above 3 coordination). X axis: number of coordination roles played. Y axis: number of participants

This is observed in the FP7 program but not at all in the H2020 program. This is also

an important evolution between the two programs that should be explained.

Table 3-2: Top20 Project coordinators and Participants in the FP7 Energy program

Top Twenty Coordinators					Top Twenty Participants				
PIC	**Part No**	**Participant Na**	**Participant**	**Coordinator**	**PIC**	**Part No**	**Participant Na**	**Participant**	**Coordinator**
999984059	part159	FRAUNHOFEI	95	19	999984059	part159	FRAUNHOFEI	95	19
999988901	part190	WIRTSCHAFT	59	17	999992401	part150	COMMISSAR	45	11
999764100	part343	TEKNOLOGIA	53	15	999764100	part20	DANMARKS	41	9
999904013	part252	FUNDACION	50	12	999940408	part43	NEDERLANDS	41	4
999992401	part150	COMMISSAR	45	11	999904013	part252	FUNDACION	50	12
999991043	part430	SINTEF AS	41	10	999910629	part103	TEKNOLOGIA	53	15
999985029	part20	DANMARKS	41	9	999611676	part495	ETHNIKO KE	30	9
999945065	part738	RINA CONSU	37	11	999951467	part738	RINA CONSU	37	11
998944054	part159	FUNDACION	36	10	998944054	part159	FUNDACION	36	10
999517295	part742	AGENZIA NA	31	11	999517295	part742	AGENZIA NA	31	11
999611676	part495	ETHNIKO KE	30	9	999903840	part54	AALBORG U	33	7
999926829	part569	OSTERREICH	29	8	999866689	part133	CENTRE NAT	33	9
999645238	part484	VLAAMSE IN	28	8	999495500	part495	SINTEF AS	41	10
999892976	part214	NORGES TEK	27	8	999745051	part116	EDDIE TECH	28	8
999478010	part189	INSTITUTE F	26	7	999749923	part128	EULERIA	26	7
999977366	part364	POLITECNIC	34	7	999987939	part193	UNIVERSITA	24	7
999903840	part54	AALBORG U	33	7	999872024	part432	UNIVERSITY	32	7
999991722	part99	UNIVERSITY	32	7	999959219	part312	KENTRO FOT	32	9
999897729	part347	CONSIGLIO N	34	7	998572537	part13	ACCADEMIA	15	7
998572537	part13	ACCADEMIA	15	7	998413466	part494	ICLEI EUROP	31	2

Source: CORDIS data base and own calculations

Table 3-3:Top20 Project coordinators and Participants in the H2020 Energy program

Top Twenty Coordinators					Top Twenty Participants				
PIC	**Organization**	**Part number**	**Coordinator**	**Participant**	**PIC**	**Organization**	**Part no**	**Coordinator**	**Participant**
999984059	FRAUNHOFEI	part176	11	49	999984059	FRAUNHOFEI	part176	11	49
999992401	COMMISSARI	part83	9	23	999990655	DANMARKS	part99	8	38
999988715	STICHTING EI	part89	9	30	932760440	TECHNICAL I	part18	2	34
999990655	DANMARKS	part99	8	38	999988715	STICHTING E	part89	9	30
999604110	FUNDACION	part12	6	25	999993468	IMPERIAL CO	part178	2	28
999997930	CENTRE NATI	part34	6	26	999997930	CENTRE NAT	part34	6	26
999513221	SINTEF ENER	part115	6	14	999604110	FUNDACION	part12	6	25
999529420	RICERCA SUL	part311	6	21	999988909	NEDERLANDS	part110	5	25
999988909	NEDERLANDS	part110	5	25	999992401	COMMISSAR	part83	1	23
999645238	VLAAMSE INS	part25	4	13	999988521	AGENZIA NA	part67	4	22
999988521	AGENZIA NAZ	part67	4	22	999529420	RICERCA SU	part311	6	21
999974844	UNIVERSIDA	part80	4	4	999973971	ECOLE POLY	part84	3	20
999981149	INTERUNIVE	part85	4	7	999974747	UNIVERSITAI	part97	0	20
999993371	IFP Energies	part108	4	10	999854128	AUSTRIAN RI	part128	1	18
999980761	STIFTELSEN S	part116	4	17	999970015	Eidgenössisch	part107	0	17
998852651	WIRTSCHAFT	part126	4	6	999980761	STIFTELSEN	part116	0	17
999804803	ENEL DISTRIE	part9	3	7	999988740	FORSCHUNG	part70	0	17
990797674	Karlsruher In	part38	3	13	999973666	TECHNISCHE	part117	0	17
999973971	ECOLE POLYT	part84	3	20	999926829	ELECTRICITE	part5	0	17
999981731	DEUTSCHES	part131	3	11	999991722	AGENCIA ES	part69	0	17

Source: CORDIS data base and own calculations

Tables 3-2 and 3-3 are further exploited below. Table 3-4 presents the Top20 coordination and participation frequency rankings for the FP7 Energy program. The table also contains the Top20 ranking in terms degree centrality figures calculated in our thesis[14] and compared with those calculated in Calvo-Gallardo et al. (2021). The

[14] In other words, the ranking indicated in the two first columns of Table 3-4 are based on the degree centrality indicator.

findings on the various centrality metrics from SNA will be discussed in length in Chapter 4. Here we only discuss the dynamics of coordination and participation frequencies between FP7 and H2020. But for FP7 projects, we also compare the coordination frequency data with the Degree centrality data taken from Chapter 4.

We tested here the correspondence between the centrality metrics of the participants computed from SNA and the frequency of coordinator roles played by the same participants (taken from Table 3-2). Table 3-2 above presents for FP7 Energy projects, the frequency of coordination and that of project participation for the Top20 participants. When we compare the Top20 ranking for degree centrality and the frequency of coordination, the following observations can be made. The Top20 coordination frequency list contains in its first upper half, only participants from the Top20degree centrality list. There are 8 new entries in the second half of the ranking. They are 2 RECs from Belgium (VITO and IMEC), 2 HES (Karlsuhe Institute of Technology and Politechnic of Madrid), 1 REC from France (IFP Energies Nouvelles), 1 REC from Germany (DLR), and 2 PRCs, one from Germany (WIP) and one from Italy (ENEL). It appears therefore that Top20 frequent coordinators is dominated by the RECs (14), followed by + HES (4) and 2 PRC.

A close inspection of Table 3-4 shows some interesting features in terms of the CIE. The column on the participation frequency shows indeed high participation numbers for frequent coordinators, ranging from 49 for the top participant of the list (Fraunhofer Gesellschaft) to around 20 for the mid-ranged participants of the list (CEA, ENEA).

The average CIE indicator is equal to 4 (4.02) for these frequent coordinators, meaning that per coordinated project they participated in 4 other projects as participants. But there are exceptions as some partners obtained very high CIE indicators: 14 for Imperial College, 17 for VTT and TUDelft, 17+ for EDF, 13 for CENER-CIEMAT, 18+ for ETH, 15 for the University of Manchester and 10 for Strathclyde University Glasgow. These high CIE values correspond to high number of participations but very few coordination tasks, even 2 no-coordination (EDF and ETH) which explains the 17+ and 18+ scores in Table 3-4. All these high CIE scored participants are also in the Top20 degree centrality ranking list. Therefore, there seems to exist two strategies for

the high degree centrality participants to increase their participation success rate: either to increase their attractiveness by increasing their visibility through frequent successful coordination tasks, or by increasing their scientific excellency perception by the network participants.

Table 3-4: Degree centrality, Coordination & Participation frequencies

RANK (degree centrality)	RANK (degree centrality by Calvo-gallardo (2021)	TOP20 (degree centrality by calvo-gallardo, 2021)	COORD. FREQ.	PARTICIP. FREQ.	PARTICP. FREQ. / COORD. FREQ.	PART. TYPE
1	1	FRAUNHOFER (DE)	11	49	4.45	REC
2	2	DTU (DK)	8	38	4.75	HES
3	3	TECNALIA (ES)	6	25	4.17	REC
4	4	ECN (NL)	9	30	3.33	REC
7	5	RSE (IT)	6	21	3.50	REC
5	6	IMPERIAL COL. (UK)	2	28	14.00	HES
6	7	CNRS (FR)	6	26	4.33	REC
9	8	TNO (NL)	5	25	5.00	REC
11	9	SINTEFenergi (NO)	6	14	2.33	REC
8	10	VTT (FI)	2	34	17.00	REC
10	11	CEA (FR)	9	23	2.56	REC
14	12	ENEA (IT)	4	22	5.50	REC
11	13	SINTEFstiftelsen (NO)	4	17	4.25	REC
15	14	EDF (FR)	0	17	17+	PRC
18	15	CENER (ES)	1	13	13:00	REC
12	16	CRES (GR)	3	16	5.33	REC
17	17	EPFL (CH)	3	20	6.67	HES

15	18	TUDELFT (NL)	1	17	17	HES
19	19	ETH (CH)	0	18	18+	HES
	20	STRATHCLYDE UNIVGLASGOW (UK)	1	10	10	HES
20 MANCHESTER UNIV (UK)			1	15	15	HES
VITO (BE)			4	13	3.25	REC
POLITEC. MADRİD (ES)			4	4	1.00	HES
IMEC (BE)			4	7	1.75	REC
IFPEN (FR)			4	10	2.50	REC
WIP (DE)			4	6	1.50	PRC
ENEL (IT)			3	7	2.33	PRC
KIT (DE)			3	13	4.33	HES
DLR (DE)			3	11	3.67	REC

This last strategy seems to be preferred by the universities, as 5 out of 8 of these high CIE participants are HES type participants; but 2 of them are RECs and 1 is a PRC (Ertan, 2023a)

Table 3-5 presents the Top Coordination and Participation frequencies ranking for the H2020 Energy projects participants. This is a mixed list between the Top20 Cooperation and the Top20 Participation frequencies data (see Table 3-3) which explains the more than 20 entries in Table 3-5. Compared to the similar table for FP7 (Table 3-4 above), there are 13 new entries, which is an important evolution compared to FP7 (6 REC, 4 HES, 2 OTH and 1 PRC). There are several individual important

evolutions too. Fraunhofer Gesellschaft is again at the top of both frequencies' rankings with increased numbers, 11 to 19 for the coordination frequency and 49 to 95 for the participation frequency. CNRS is no longer in the top 20 coordination frequencies ranking list, albeit it still accomplished 5 coordination tasks compared to 6 in FP7. But CNRS increased its participation frequency from 26 to 38. Imperial College also disappeared from the Top20 participation frequency list despite its 29 participations record compared to 28 for FP7. TUDelft, ETH, Manchester University and Strathclye Universities also disappeared from the top participation frequency list.

This finding shows the importance of other participants' participation records, both for those already on the FP7 list and for the newcomers in the H2020 list. The participation record of the 20th rank is 31. The 5 HES who are no longer in the Top20 participation frequency ranking were those with the lowest coordination record and therefore with the highest Coordination Impact Efficiency (CIE) for the FP7 Energy programme (see Table 3-4).

The average CIE for Top20 frequency participants for H2020 Energy programme is 3.74, slightly lower than the figure for FP7 (4.02). There are no longer participants in the Top20 frequency ranking with zero coordination task (as this was the case for EDF and ETH in FP7, see Table 3-4). For the H2020 programme, the highest 2 CIE figures are for 2 newcomers, CRES (16.33) and ICLEI Europe (15.50). These dynamics indicate that some strong evolutions occurred between FP7 and H2020 Energy programmes that should also be reflected in the SNA metrics (Ertan and Gökalp, 2023b).

EU financial contributions to the projects

The amount of the EU financial contribution to the framework projects is one of the independent variables that directly influences the performance of projects, measured by output indicators such as the numbers of patents and publications. We will later use these output indicators in our regression analysis to understand the main factors affecting the performance of the projects. In the figures below, we have ranked the Top20 projects and participants in FP7 and H2020 who received the highest EU contributions.

Instead of presenting the whole raw data, we preferred such a presentation for two reasons. One reason is because we want to identify the major projects and participants in the FP7 and H202 Energy projects that lead the RDI activities in the EU and also establish their geographical distribution among EU regions. The second reason is that this presentation will allow comparisons to be implemented with the rankings obtained from SNA.

Figure 3-10 shows the Top20 projects with the highest EU contributions in the FP7 Energy projects. Here, our intention is not to perform a detailed analysis between the EU contributions received and the scientific and technological content of the project; such an analysis is far beyond the scope of this dissertation. - however, we will attempt briefly such an analysis in chapter 4. Here our objective is to conduct a comparative analysis for the FP7 and H2020 projects. For example, Figure 3-10 shows that there is a ratio of around 2 between the largest contribution and the 20th one in FP7. There is also a two-level variation of EU contributions between the first 10 projects and the second 10 tier.

Figure 3-11 is based on similar data but for H2020 Energy projects. Several changes can be observed. First, the ratio between the largest contribution and the 20th one is reduced to around 1.75. In addition, the dynamics from the highest contributions to the last Top20 ones show a more gradual three-level evolution. Is there any explanation for this change between the two programs? Can SNA explain it? Or do we need a much more sophisticated analysis or is it simply a bureaucratic decision to partition the available budget? We need to ask such questions and seek answers, but they are not easy to obtain without a very deep and detailed analysis, which is not in the scope of this dissertation. Figure 3-12 shows the ranking of the Top20 participants in the FP7 Energy program in terms of the received EU contribution. The EU contribution figures correspond to the total contribution received by a participant for all the projects it was granted during the FP7 program, as coordinator or participant. The ratio between the highest contribution and the 20th is close to 4. The figure also shows the corresponding NUTs2 regions, but we shall deal with regional issues in the next sections and Chapter 4. There is some diversity in the Top20 participants in terms of their organization

Table 3-5: Top Coordination & Participation frequencies for H2020 Energy projects

RANKING (based on degree centrality indicator)	**TOP20 PARTICIPIPANTS (according to the degree centrality indicator)**	PARTICIP. TYPE	COORD. FREQ.	PARTICIP. FREQ.	CIE
1	FRAUNHOFER (DE)	REC	19	95	5.00
2	WIP (DE)	PRC	17	15	0.88
3	VTT (FI)	REC	16	53	3.32
4	TECNALIA (ES)	REC	15	50	3.33
5	CEA (FR)	REC	12	69	5.75
6	SINTEF (NO)	REC	12	25	2.08
7	DTU (DK)	HES	11	61	5.56
8	RINA (IT)	PRC	11	37	3.36
9	CIRCE (ES)	REC	11	37	3.36
10	ENEA (IT)	REC	10	44	4.40
11	CERTH (GR)	REC	9	50	5.56
12	AUSTRIAN ENERGY AGN.	OTH	9	29	3.22
13	VITO (BE)	REC	8	33	4.13
14	NTNU (NO)	HES	8	23	2.88
15	IEECP (NL)	REC	8	10	1.25
16	POLIMI (IT)	HES	7	40	5.71
17	AALBORG UNIV (DK)	HES	7	39	5.71
18	CNR (IT)	REC	7	33	4.71
19	UNIV COLL. CORK (IE)	HES	7	17	2.43
20	EURAC BOLZANO (IT)	REC	7	15	2.14
21	TNO (NL)	REC	6	61	10.12
22	DLR (DE)	REC	6	31	5.17
23	CNRS (FR)	REC	5	38	7.60
24	EPFL (CH)	HES	5	34	6.80
25	SNRC (ES)	REC	4	31	7.75
26	CRES (GR)	REC	3	49	16.33
27	ICLEİ EUROPE (DE)	OTH	2	31	15.50

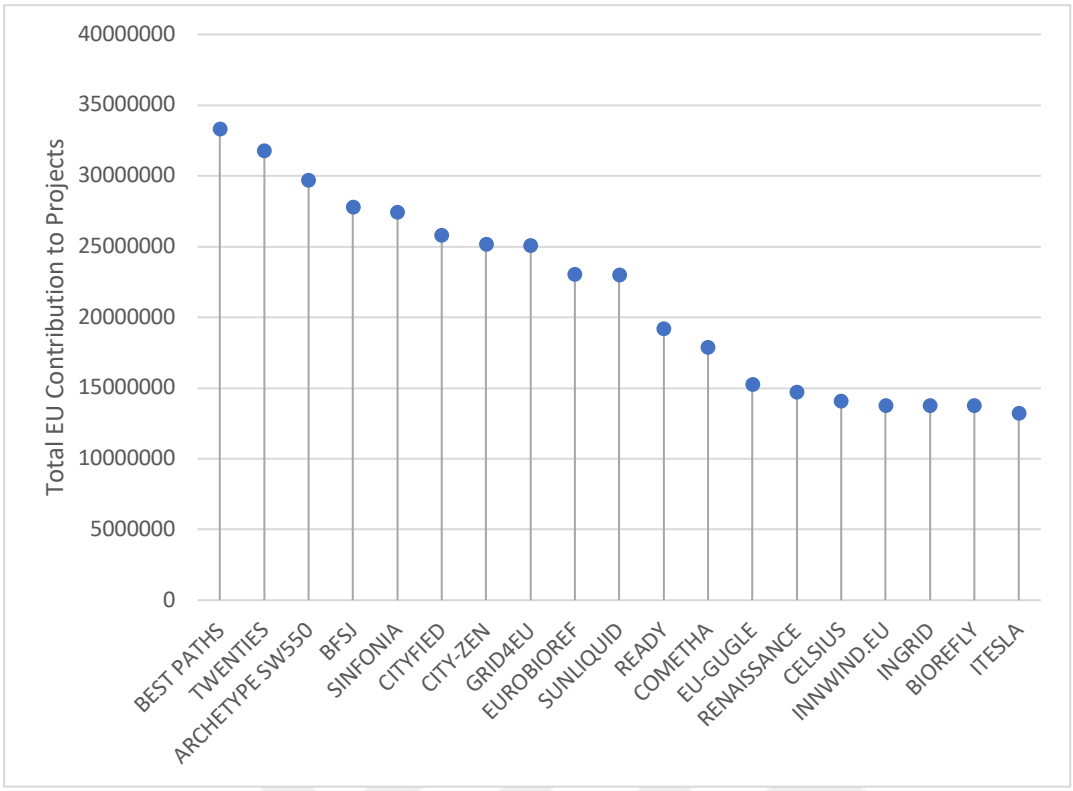


Figure 3.10: Top20 projects for EU contributions ranking in the FP7 Energy programme

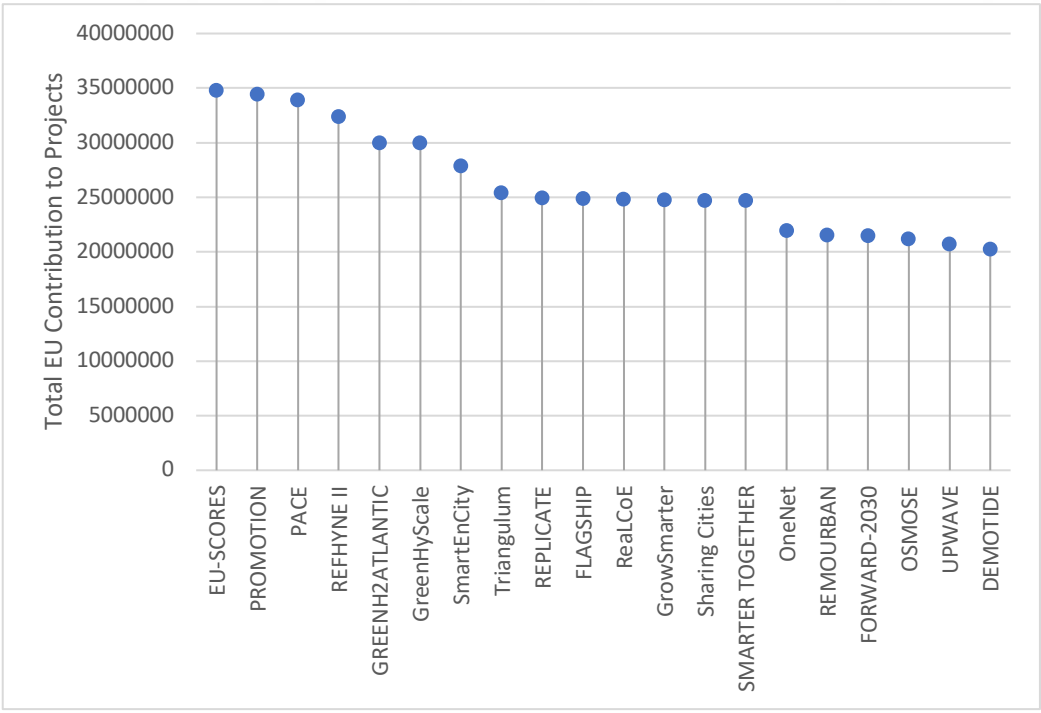


Figure 3.11: Top20 projects for EU contributions ranking in the H2020 Energy programme

types, ranging from large research centers to universities and companies. The highest contribution in both programs goes to the same participant.

Figure 3-13 presents the same information for the H2020 Energy projects. Globally, the EU contributions received by the participants for the total H2020 program is higher than for the FP7 program but the ratio between the highest contribution and the 20th one is again close to 4. However, if we exclude the highest contribution, the dynamics from the highest contribution to the 20th is smother and the ratio is around 2.5. The Top20 participants did not change much between the two programmes albeit there are some newcomers such as the MCPHY Energy, ITM Power and Aalborg University. Again, a micro-level analysis is needed to track and explain such changes which are beyond the scope of this dissertation.

We have shown above only the Top20 participants who received the highest EU contributions during the FP7 and H2020 Energy programmes. There are obviously important differences in the distribution of EU contributions to all partners. This is shown in Figure 3-14 for the FP7 programme for all the 2347 participants (all the participants are not distinguishable in the graph but the data concern all of them), where the EU contribution is normalized by subtracting the calculated average EU contribution form the contribution received by a given participant and the difference is divided by the average contribution. The negative values on the vertical axis identify the participants who received EU contributions lower than the average contribution. The graph is strongly asymmetrical indicating that there are much more participants receiving EU contribution lower than the average compared to those receiving financial contributions higher than the EU average in the FP7 programme. In addition, the deviation intensities from the average EU contribution are also asymmetrical: the positive deviations may go as high as 30 times the average contribution, but for the much more numerous negative ones, the deviations are around one time the average contribution. H2020 data also show similar behavior. The progress towards a harmonious development of the EU Research & Development Innovation potential is often discussed in terms of the NUTs2 regions (Erdil et al., 2022; Christopoulos and Wintje, 2023). Figures 3-15 and 3-16 show the EU contributions received by the Top20 NUTs2 regions for the FP7 and H2020 Energy projects,

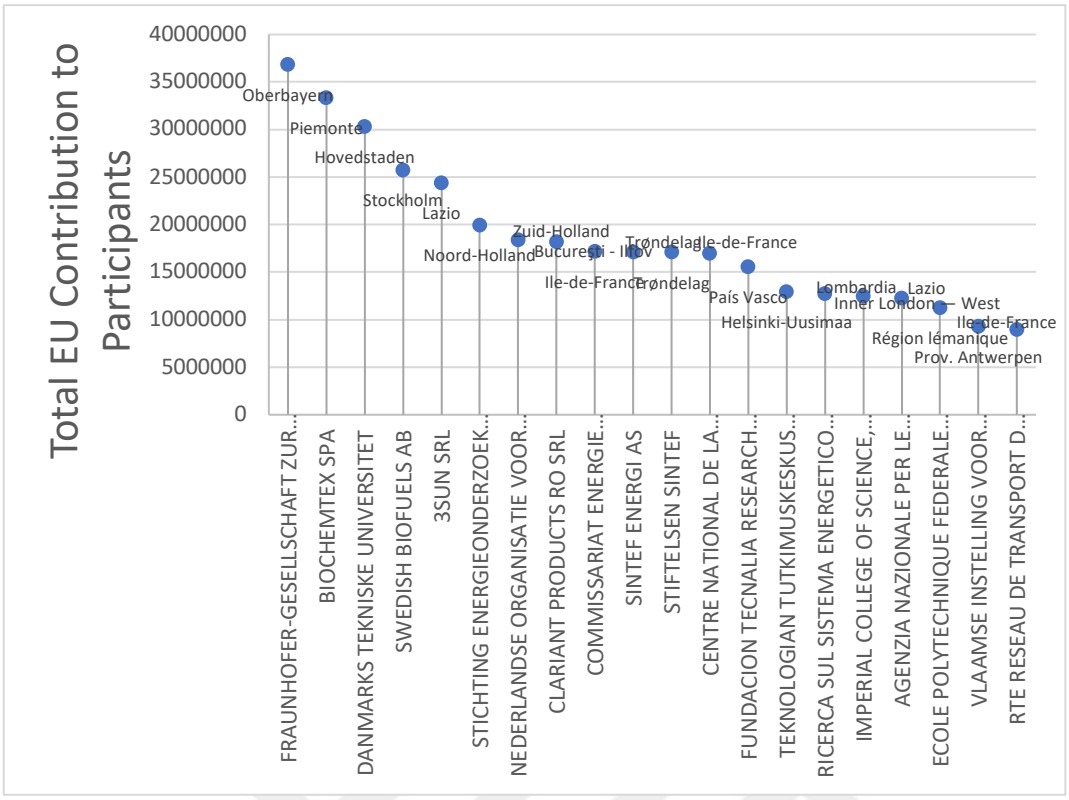


Figure 3.12: Top20 participants for EU contributions ranking in the FP7

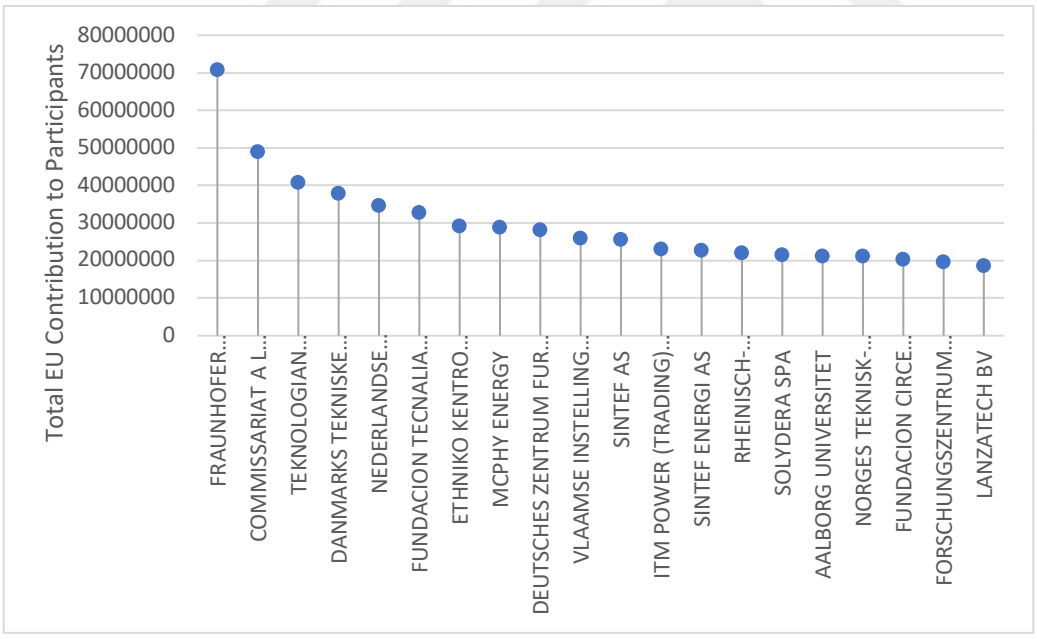


Figure 3.13: Top20 participants for EU contributions ranking in the H2020

respectively. Ile de France dominates both programs, but much more strongly in H2020. Other dominant regions are Lazio, Oberbayern, Comunidad de Madrid in both programmes. We shall come back to this analysis below and in chapter 4 using the SNA metrics.

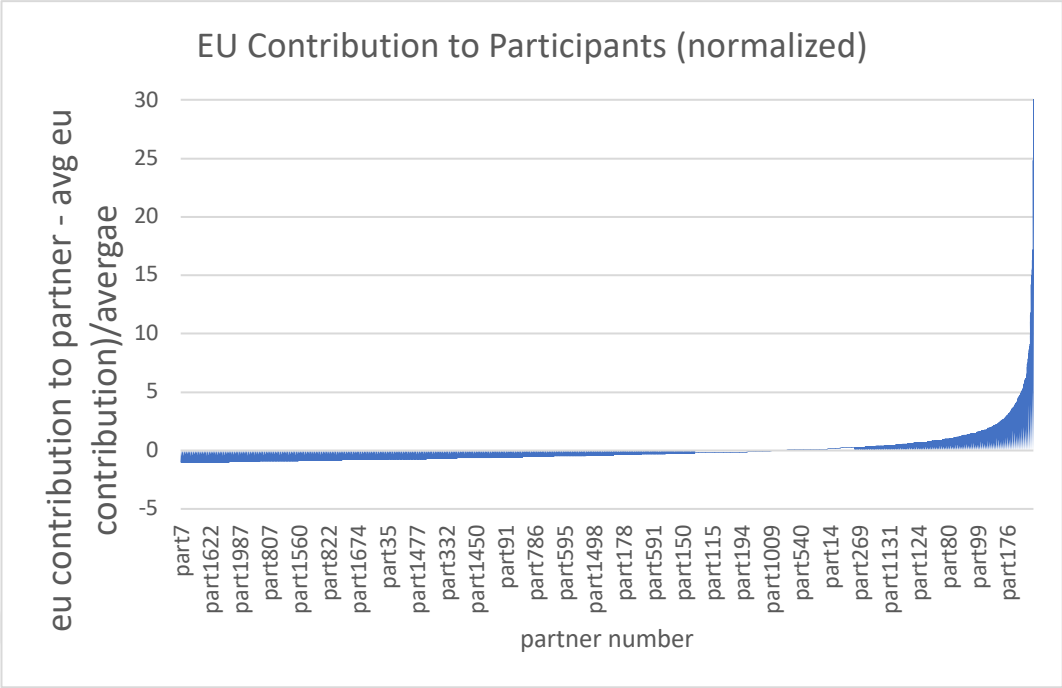


Figure 3.14: Normalized distribution of the total EU contribution to participants for the FP7 Energy programme

3.2. Analysis of the Output Data for FP7 and H2020 Energy programmes

There are several outputs expected from EU framework programmes. For the energy related projects, the outputs may concern several types of publications, patents, prototypes, and demonstration facilities. As the main outputs, we shall concentrate in this dissertation on the patents and publications. The first one can be justified for the energy domain projects as the generated scientific and technological knowledge should be translated into products that will be designed, manufactured, and sold essentially by companies. Therefore, for the involved companies-(but also the whole project consortium- patenting is an important indicator of the performance of a project. The publications are also important outputs but essentially for participants from academia. On the other hand, publications are much more difficult to analyze than patents since there are several types of publications, from books to journal articles, and from conference papers to reports. In addition, publication data analysis should be accompanied by citation analysis and be graded following the journal or conference quality etc. In that sense, patent data is more meaningful and straightforward to analyze: “a patent is a patent” (*but see below*).

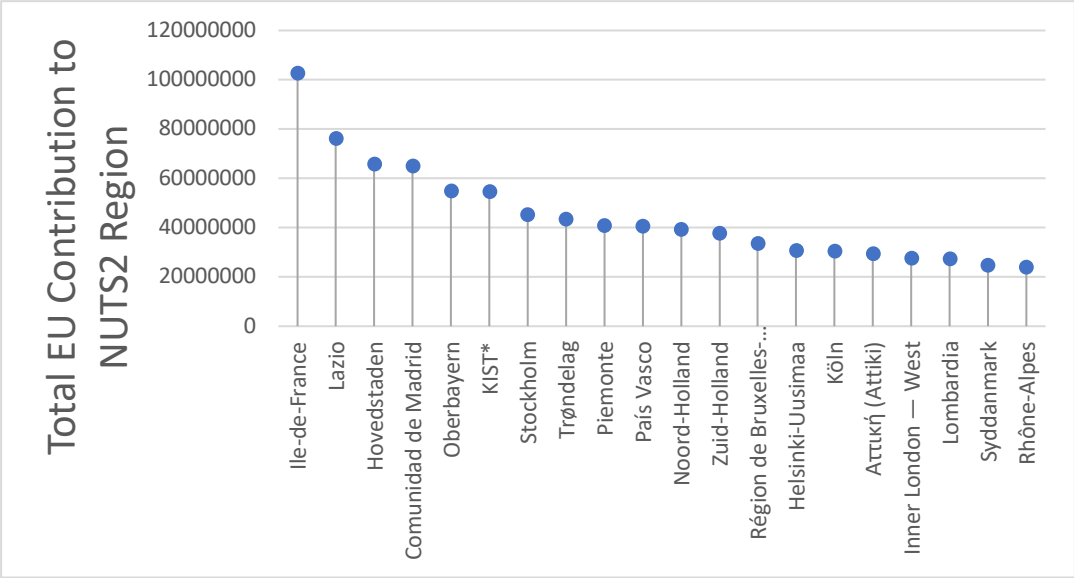


Figure 3.15: Top20 NUTs2 regions for EU contributions ranking in the FP7 Energy Programme

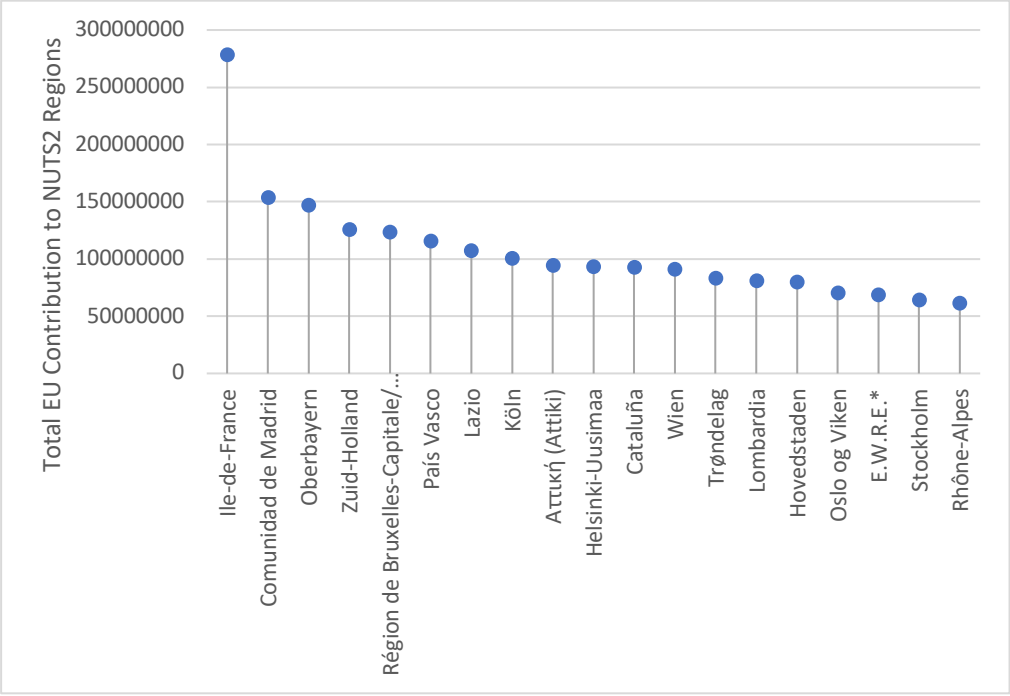


Figure 3.16: Top20 NUTs2 regions for EU contributions ranking in the H2020 Energy Program

Moreover, the knowledge disclosed in publications is difficult to be patented directly or this information is already patented, or a patent application is already issued. Therefore, we think that in RDI programs where innovation is strongly expected such as in the energy area, data on patent numbers is a good indicator of the project performance. However, there are also problems with patent data; a detailed inspection

of the patents secured by the same partner shows that most of them are re-published versions of the same patent within an extension process of the patent protection to different countries or for purely technical protection reasons by changing the wording in the patent applications. Therefore, the patent data should also be used with care. The publications data will also be presented in the following sections, but its drawbacks should be kept in mind. The detailed analysis of the distortions occasioned by the use of patent and publication data are beyond the scope of this dissertation.

3.2.1. Patenting in FP7 and H2020 Energy Projects

The list of IPRs linked to FP7 and H2020 projects is retrieved from CORDIS database accsesed onSeptember 2023[15], which contains information on the projectID, type, title, organisationID, applicantName, applicationDate, applicationPrefix, applicationIdentifier, applicationKind, epoAppUrl, priorityDate, patentType, awardDate, awardPrefix, awardIdentifier, awardKind, epoPubUrl, patentFamilyIdentifier. The full list of FP7 and H2020 energy projects' number of granted patents (and publications) is available in the google drive link provided below[16].

We present below in Table 3-6 some relevant global data concerning patenting indicators in FP7 & H2020 Energy projects. Table 3-6 summarizes the global patenting indicators for FP7 and H2020 Energy projects. We recall our doubts about the validity of the patent data we used, especially in terms of multiple publications of the extensions of the same patent. But we decided to use the existing data as it is and add some comments when an obvious anomaly is observed.

Table 3-6: Summary table of the global patenting indicators for FP7 & H2020 Energy projects

ENERGY PROGRAMME	**FP7 (2007-2013**	**H2020 (2014-2020)**

[15] https://cordis.europa.eu/data/projectIrps_fp7.xlsx
https://cordis.europa.eu/data/projectIrps_h2020.xlsx

[16] https://drive.google.com/drive/folders/1sD8HtH5Va5G4oLUsixHwHNG33lsdt8Qn?usp=sharing

NUMBER OF PROJECTS	376	1476
NUMBER OF PARTICIPANTS	2347	6566
NUMBER OF PATENTS	173	228
NUMBER OF PATENTING PROJECTS	62	58
PATENTING PROJECTS (%)	16.5	3.9
MAXIMUM NUMBER OF PATENT PER PROJECT	24	31
PATENTS PER PROJECT	0.46	0.15
PATENTS PER PARTICIPANT	0.074	0.035
TOTAL EU CONTRIBUTION TO PATENTING PROJECTS (€)	276 752 506	241 698 948
TOTAL EU CONTRIBUTION TO ALL PROJECTS (€)	1 813 012 005	4 989 341 276
TOTAL EU CONTRIBUTION TO PATENTING / ALL PROJECTS (%)	15.3	4.8
AVERAGE EU TOTAL CONTRIBUTION FOR ONE PATENT (€) (based on total contributions to patenting projects / based on total contributions to all projects)	1 556 501 / 10 479 838	1 060 083 / 21 883 076

It is observed that in spite of the increased number of projects and participants in H2020 compared to FP7 Energy programmes, the number of patents did not increase much or at least to the same extent (from 173 to 228); the number of patenting projects has even decreased (from 62 to 58). The number of patents per project and per participant have also decreased (from 0.46 to 0.15 and from 0.074 to 0.035, respectively). This observation needs obviously explanation (Ertan and Gökalp, 2023a). We shall provide below correlations between the number of patents and a number of explanatory variables. In chapter 4, we shall conduct a regression analysis of the patenting behaviour in FP7 and H2020 Energy programmes.

Table 3-6 also contains data on the EU contributions to FP7 Energy projects. The total EU contribution to FP7 Energy projects is about 1.8 billion euros. But only less than 0.3 billion euros were spent to support patenting projects, i.e. 15.3% of the total EU contribution for FP7 Energy projects. Table 3-6 also indicates that the cost of one

patent[17] in the FP7 Energy projects was above 1.5 million euros if calculated based on the EU contributions received by patenting projects, but about 10.5 million euros based on the total EU contribution to all FP7 Energy projects. We are not able to compare these figures with data from other highly patenting regions such as USA, China, Japan, Corea etc. but this certainly needs to be done in the future.

We can however perform a diachronic comparison between the FP7 and H2020 Energy programs based on Table 3-6. The total EU contribution in H2020 to Energy projects is about 5 billion euros, but only less than 0.250 billion euros were spent to support patenting projects, i.e. less than 5% of the total EU contribution for H2020 Energy projects. This figure is three times less than that of FP7. Table 3-6 also indicates that the cost of one patent in the H2020 projects is about 1 million euros if calculaed based on the EU contributions received by patenting projects, but about 22 million euros based on the total EU contribution to all FP7 Energy projects. Obviously, the global average cost of one patent in H2020 Energy projects has doubled compared to FP7. This dynamics is difficult to explain with the data in our disposal and needs more detailed analysis in future work (Ertan and Gökalp, 2023b).

In order to provide more insight into analysis of patenting dynamics in FP7 Energy projects, Figures 3-17 to 3-22 below present the numbers of patent versus three variables: EU contribution to the patenting projects; the number of the participants in the patenting project and the coordination frequency of the patenting project coordinator. In these figures, projects with zero patent are not represented. In order to detect some trends in the patent number data with respcet to these three variables, we also represented on the figures several trendlines such as a second order polynomial, a linear and an exponential trendline. Obviously, these trendlines do not give satisfactory results; this will be checked in chapter 4 by performing a regression analysis.

[17] Defined as the ratio between the EU contribution to the program and the number of patents

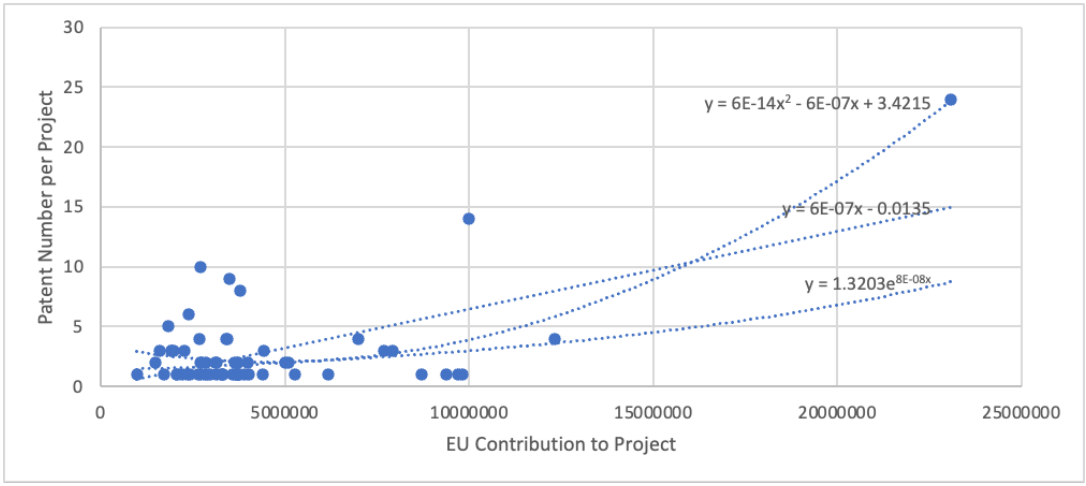


Figure3.17 : Number of patents per project vs the EU contribution to the project for FP7 Energy projects (excluding 0 patent projects)

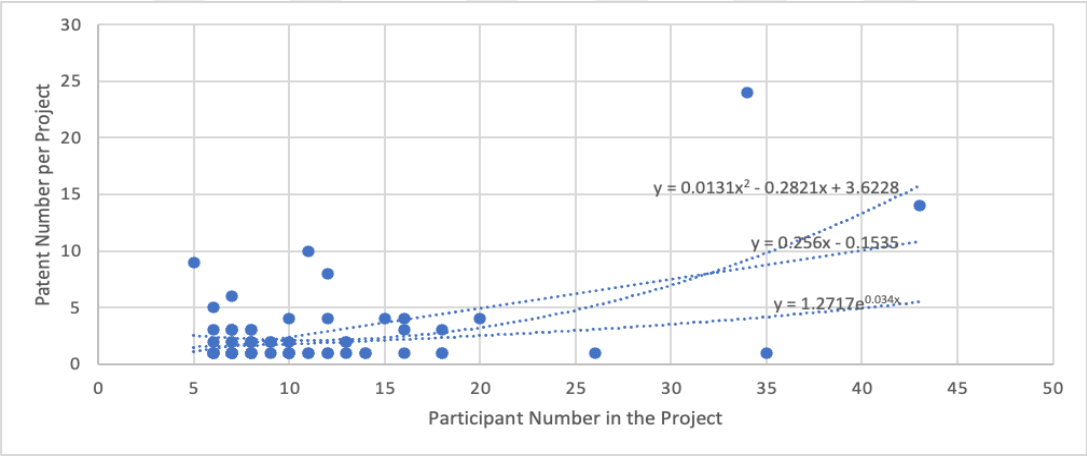


Figure 3.18: Number of patents per project vs the number of participantsin the project for FP7 Energy projects (excluding 0 patent projects)

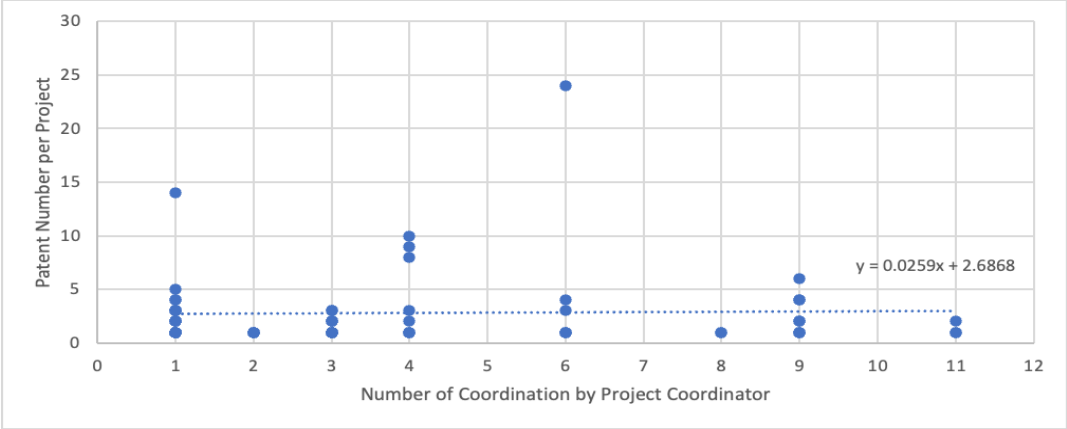


Figure 3.19: Number of patents per project vs the coordination requency of the

project's coordinator in the project for FP7 Energy projects (excluding 0 patent projects)

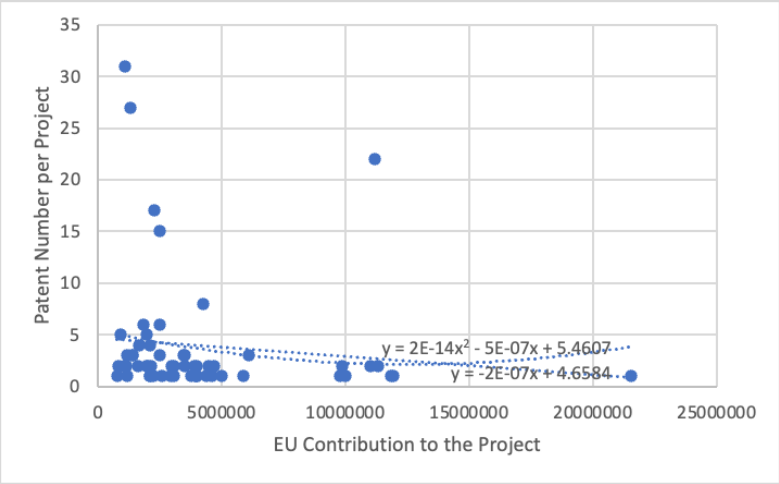


Figure3.20: Number of patents per project vs the EU contribution to the project for H2020 Energy projects (excluding 0 patent projects)

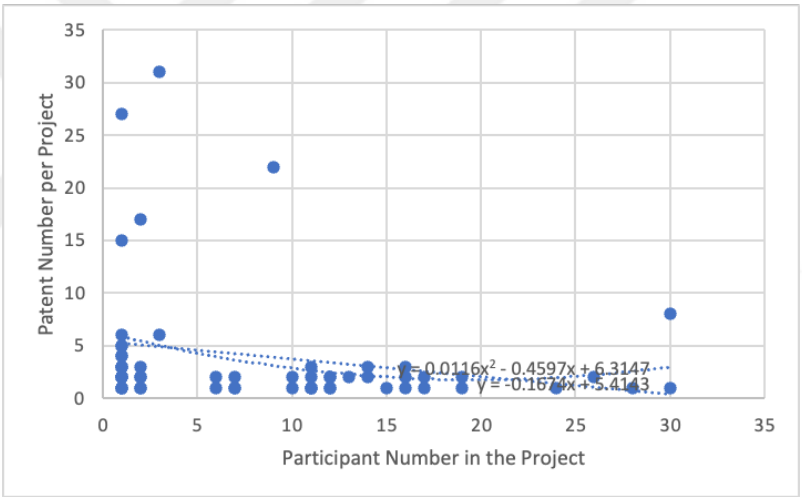


Figure3.21: Number of patentsper project vs the number of participants in the project for H2020 Energy projects (excluding 0 patent projects)

3.2.2. Publication indicators in FP7 & H2020 Energy projects

Table 3-7 shows the global publishing statistics for FP7 & H2020 Energy projects. We would like to restate here that we used the CORDIS publications datasets without knowing precisely the sources used in this dataset, the type of publications included, the controls applied for authorship etc. This analysis should be carried out in future works. Here we base our analysis on the raw publications per project from CORDIS datasets. We observe in Table 3-7 that the number of total publications has increased

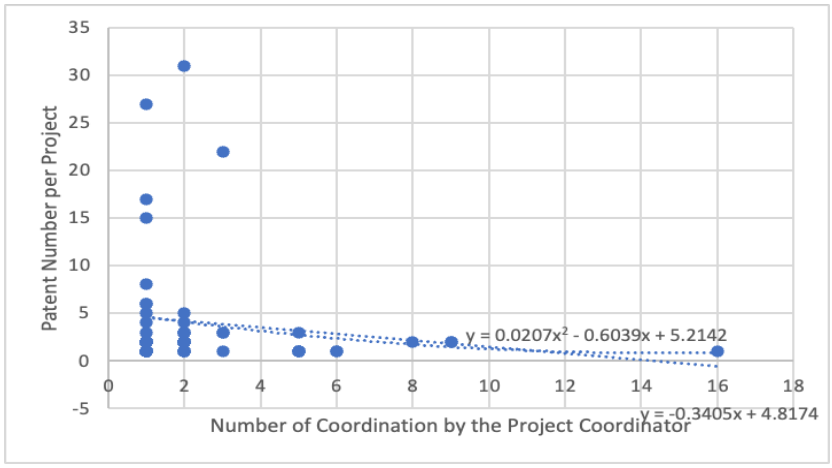


Figure 3.22: Number of participants per project vs the coordination frequency of the project's coordinator in the project for H2020 Energy projects (excluding 0 patent projects)

about 3 fold (3.05) from FP7 to H2020. The number of publishing projects has also increased about 4 times (3.96). But in spite of these increased absolute numbers, there is a striking similarity between the normalized publications indicators of FP7 and H2020.

For example, the percentage of publishing projects are close to 50% for both programmes. However, we observed a four fold decrease in the patenting projects percentage from FP7 to H2020. The publications per project and per participant indicators are also close to each other, as also the maxinmum publication number per project.

Again, for H2020 there were 2 to 3 fold decreases for the corresponding patenting indicators. It appears therefore that normalized publications' patterns stayed quite similar between the two Energy programs, but the patenting dynamics were much lower in H2020 and this is dispite the innovation focus of the H2020 programme. It is important to verify in future work if this is a general trend for H2020 topics and a peculiarity of the H2020 Energy projects. This behaviour is also depicted in the last line of Table 3-7 which shows the publications number per patent and indicating a doubling from 19.2 to 44.3 between FP7 and H2020.

Despite several biases likely to be present in the patent and publication datasets, this seems to prove that the patenting efficiency in H2020 is lower compared to FP7. Table

3-6 also showed a similar result in terms of the average cost of a unit patent; this means that the ratio between the unit cost of a patent and of a publication also increased in the same proportions from FP7 to H2020 (Ertan and Gökalp. 2023b).

Table 3-7: Summary table of the global publishing indicators for FP7 & H2020 Energy projects

ENERGY PROGRAMME	**FP7**	**H2020**
NUMBER OF PROJECTS	376	1476
NUMBER OF PARTICIPANTS	2347	6566
NUMBER OF PUBLICATIONS	3316	10100
NUMBER OF PUBLISHING PROJECTS	187	741
PUBLISHING PROJECTS (%)	49.7	50.2
MAXIMUM PUBLICATIONS PER PROJECT	229	202
PUBLICATIONS PER PROJECT	8.82	6.82
PUBLICATIONS PER PARTICIPANT	1.41	1.54
PUBLICATIONS PER PATENT	19.2	44.3
EU TOTAL CONTRIBUTION TO PUBLISHING PROJECTS (€)	758 146 664	3 780 594 231
TOTAL EU CONTRIBUTION TO ALL PROJECTS (€)	1 813 012 005	4 989 341 276
TOTAL EU CONTRIBUTION TO PUBLISIHING / ALL PROJECTS (%)	41.8	75.8
AVERAGE EU TOTAL CONTRIBUTION FOR ONE PUBLICATION (€) (based on total contributions to publishing projects / based on total contributions to all projects)	228 633 / 546 747	374 316 / 493 994

As for the patents datasets, we provide below the graphs corresponding to the variations of the publications numbers for FP7 & H2020 Energy projects versus the same three variables as for the patents dataset. As for the patent dataset, there is no emerging trendline for the publication numbers for both programmes. The clustering of the data towards lower EU contributions and lower participants numbers seems to

indicate that the datasets for these projects should be carefully evaluated. In addition, there seems to be no correlation between the coordination frequency of the project coordinator (its centrality) and the publication performance of the project, especially if we exclude single participant projects (SMEs).

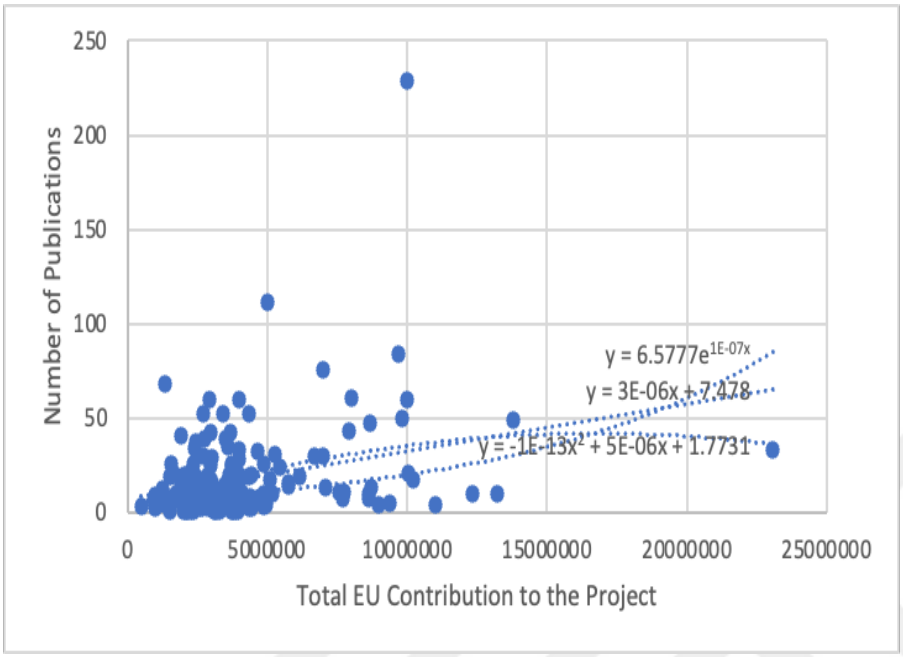


Figure 3.23: Number of publications per project vs the EU contribution to the project for FP7 Energy projects (excluding 0 publication projects)

3.3 SNA framework for analyzing the Quantitative FP7 and H2020 Energy projects data

3.3.1 Social Network Analysis of FP7 and H2020 Energy Projects

1-mode networks are based on 1-to-1 relationships in which each node is associated with the other node. For instance, in this dissertation NUTs2 region networks can be given as examples to 1-mode network. In the network diagram, each region relates to another region if they are enrolled in the same project. However, in a 2-mode network, nodes belong to two different sets (actors set and events set) and nodes are related to nodes in the other set. An example can be given to better explain 2-mode networks. For example, in a conference, the actor set is the researchers, and the event set is the sessions of the conference that they attend. Figure 3-29 below illustrates the 2-mode network of researchers and sessions of the conference. As illustrated in Figure 3-29, there is no connection between researchers and conference sessions in 2-mode networks; hence , 2-mode networks are created by connecting actors and

event sets which arise through affiliations (Kadry et al., 2014: 12).

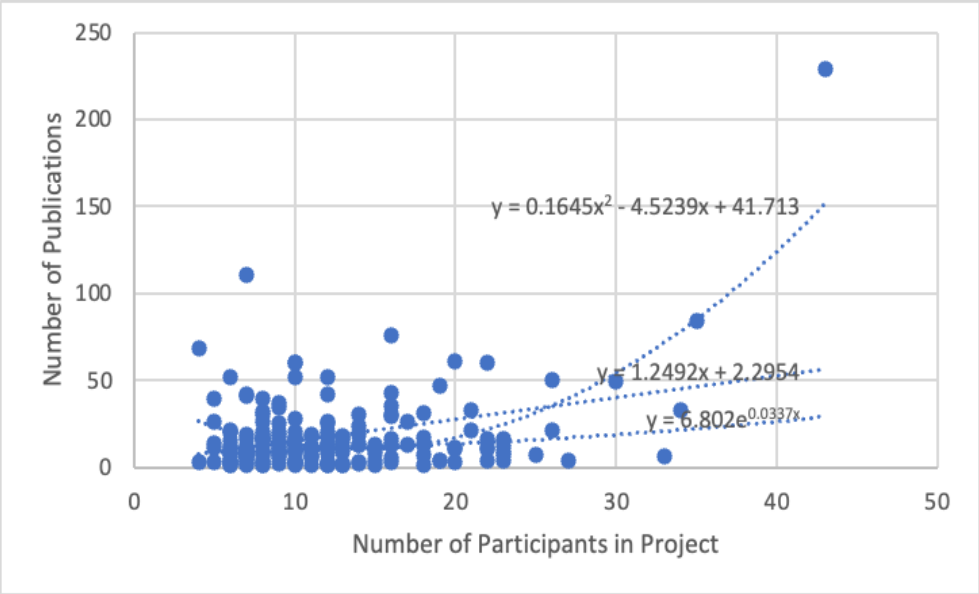


Figure 3.24: Number of publications per project vs the number of project participants for FP7 Energy projects (excluding 0 publication projects)

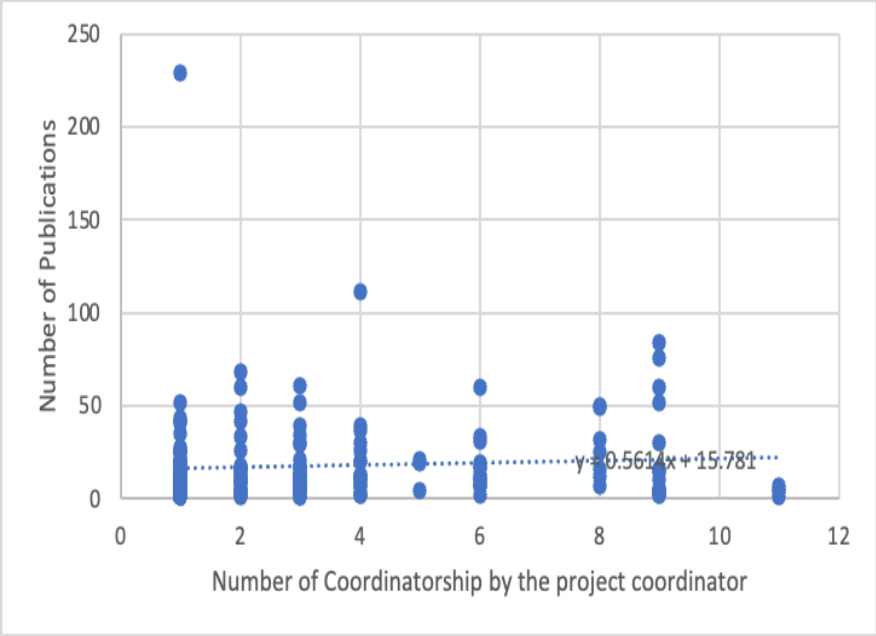


Figure 3.25: Number of publications per project vs the coordination frequency of the project coordinator for FP7 Energy projects (excluding 0 publication projects)

Moreover, 2-mode networks can be easily transformed into 1-mode networks. In Figure 3-29, if we want to create a 1-mode network of researchers among themselves, The meaning of their ties is explained as attending the same conference sessions. In other words, if researchers attend the same conference sessions, then there is a tie

between them.

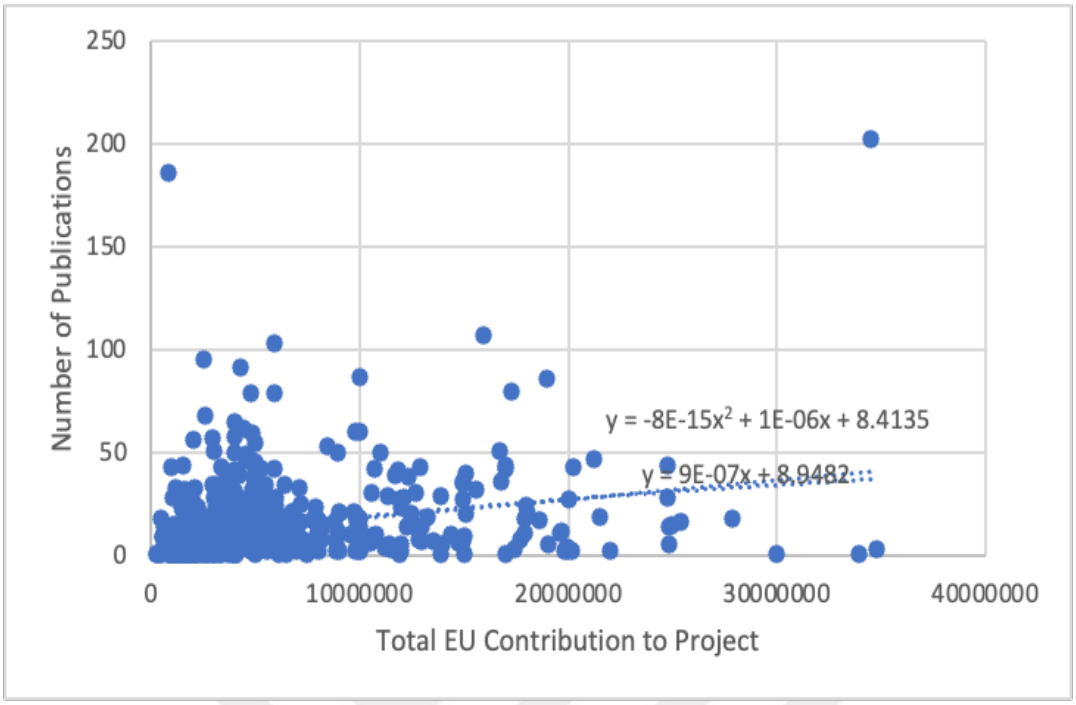


Figure 3.26: Number of publications per project vs the EU contribution to the project for H2020 Energy projects (excluding 0 publication projects)

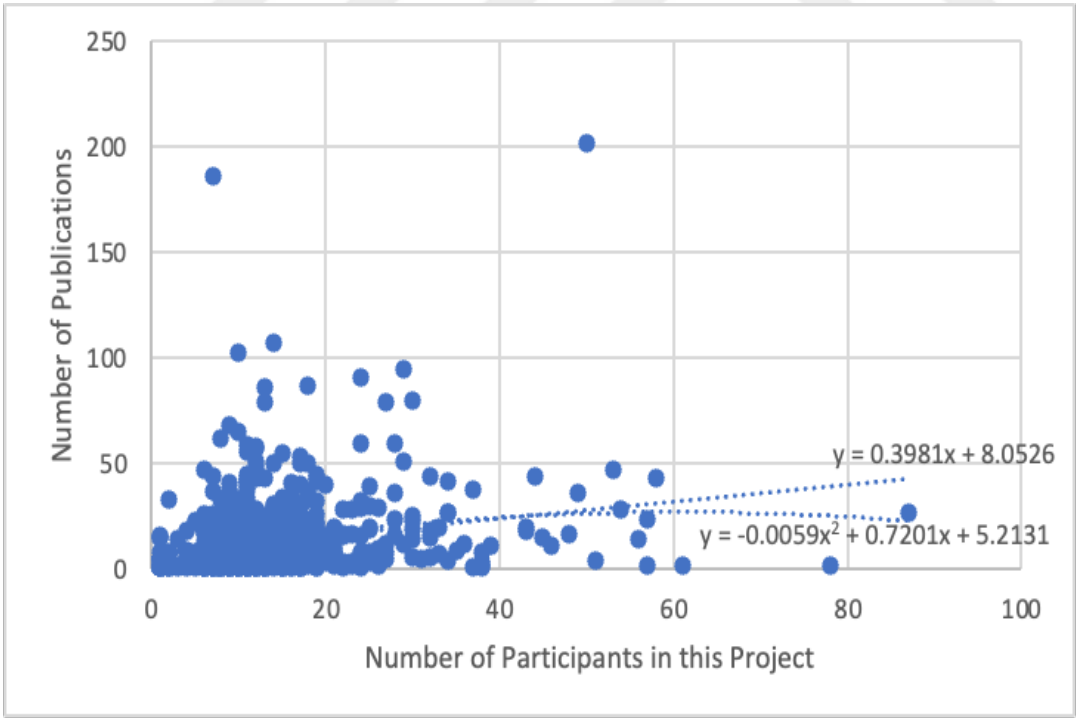


Figure 3.27: Number of publications per project vs the number of project participants For H2020 Energy projects (excluding 0 publication projects)

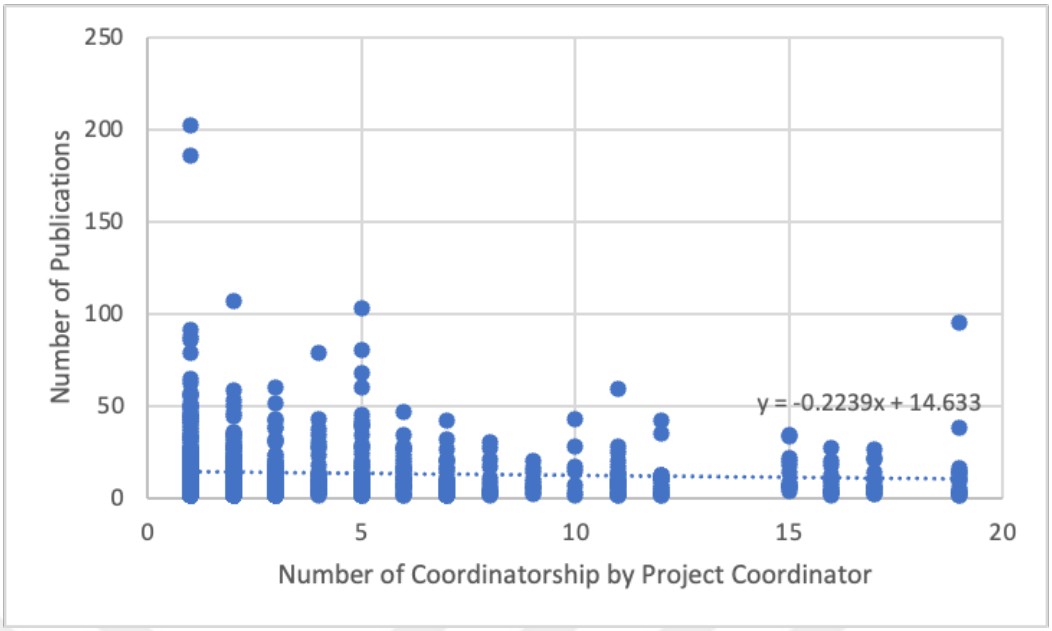


Figure 3.28: Number of publications per project vs the coordination frequency of the project coordinator for H2020 Energy projects (excluding 0 publication projects)

There are many more examples of 2-mode networks. For example, citing papers (the authors represent the actor set and the articles represent the event set) or supporting an election candidate (the supporters represent the actor set and the election candidates represent the event set) can be analyzed through 2-mode networks. In our thesis, 2-mode network analysis will be used to combine participant and project networks in FP7 and H2020. NUTs2 networks will be represented as a 1-mode network for both FP7 and H2020. Figures 3-30 and 3-31 represent the 2-mode networks of participants and projects in FP7 and H2020 energy programmes, respectively.

There is a tie between the participant and the project if the participant is enrolled in the project. 1-mode and 2-mode networks will be elaborated more in Chapter 4 when discussing the NUTS2 networks.

SNA Metrics

There are certain network properties which can facilitate the effective knowledge transfer between network participants. For example, a high number of connections in a network can improve transfer of information.

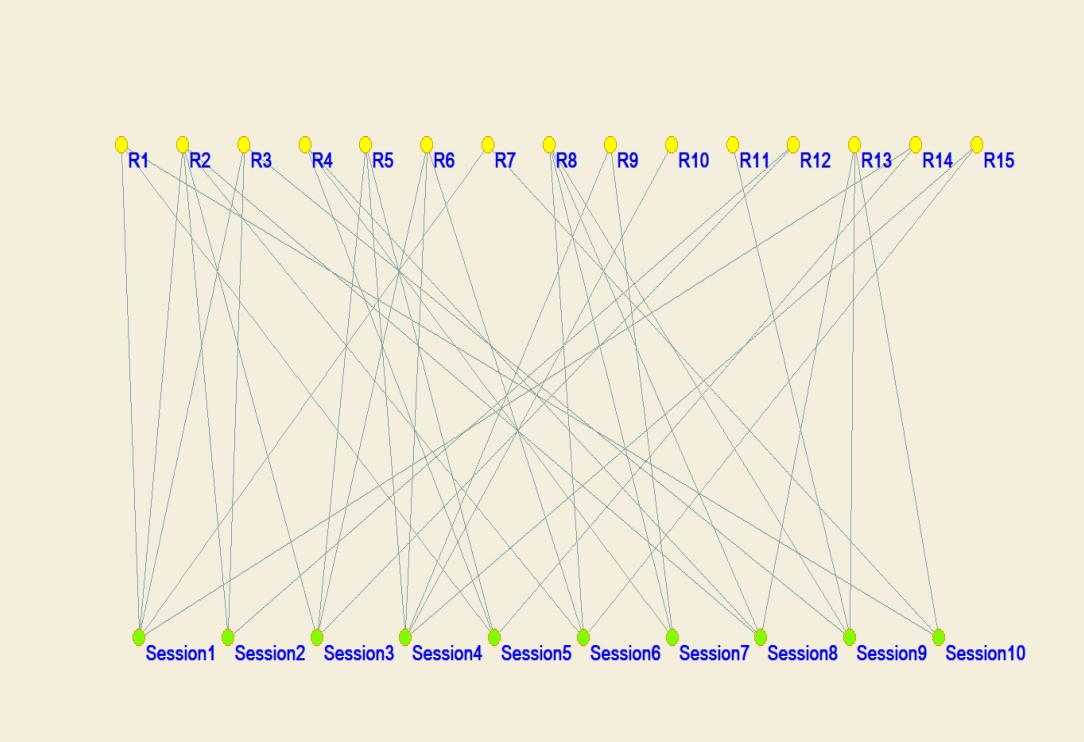


Figure 3.29: 2-mode network of researchers and sessions in a conference

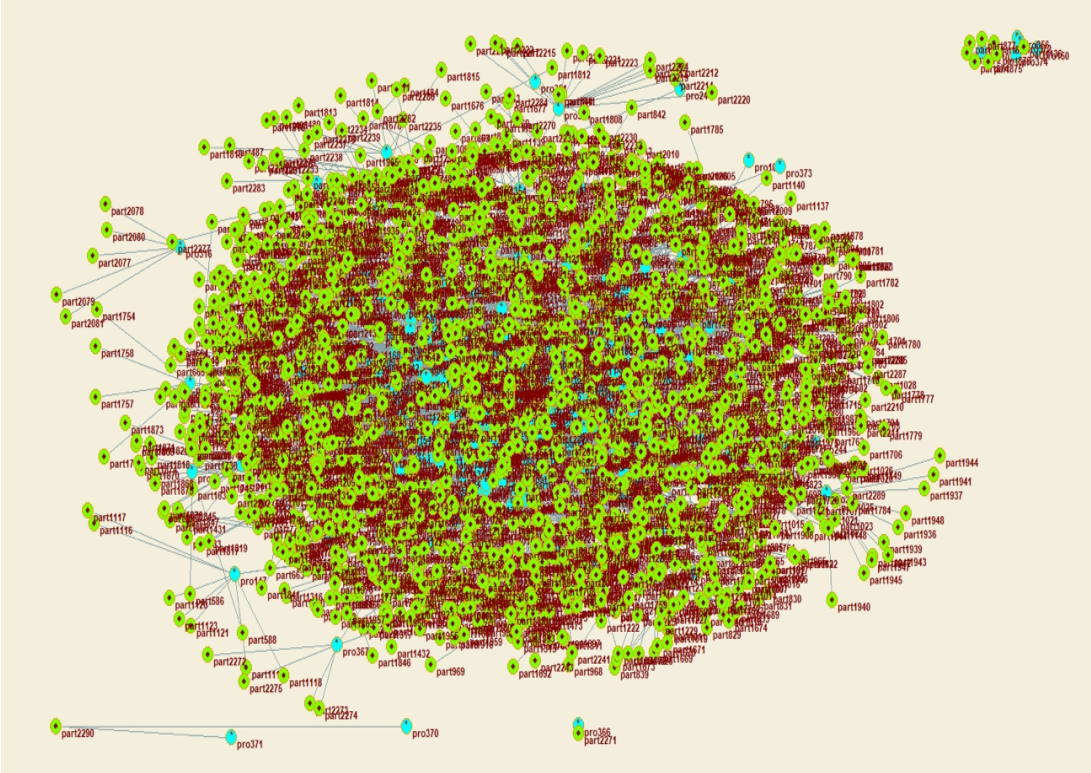


Figure 3.30: 2-mode representation of project – participants network of the FP7 energy programme (Blue nodes: projects; green nodes: participants. There is a tie if the participant is involved in the project)

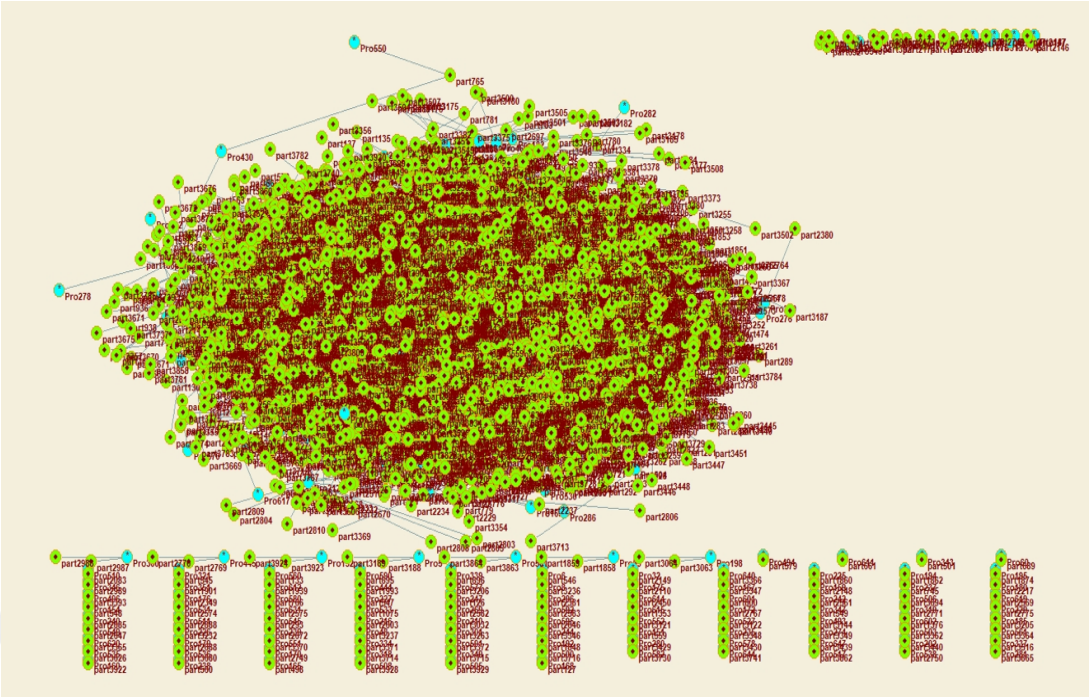


Figure3.31: 2-mode representation of project – participants network of the H2020 energy programme

(Blue nodes: projects, green nodes: participants. There is a tie if the participant is involved in the project)

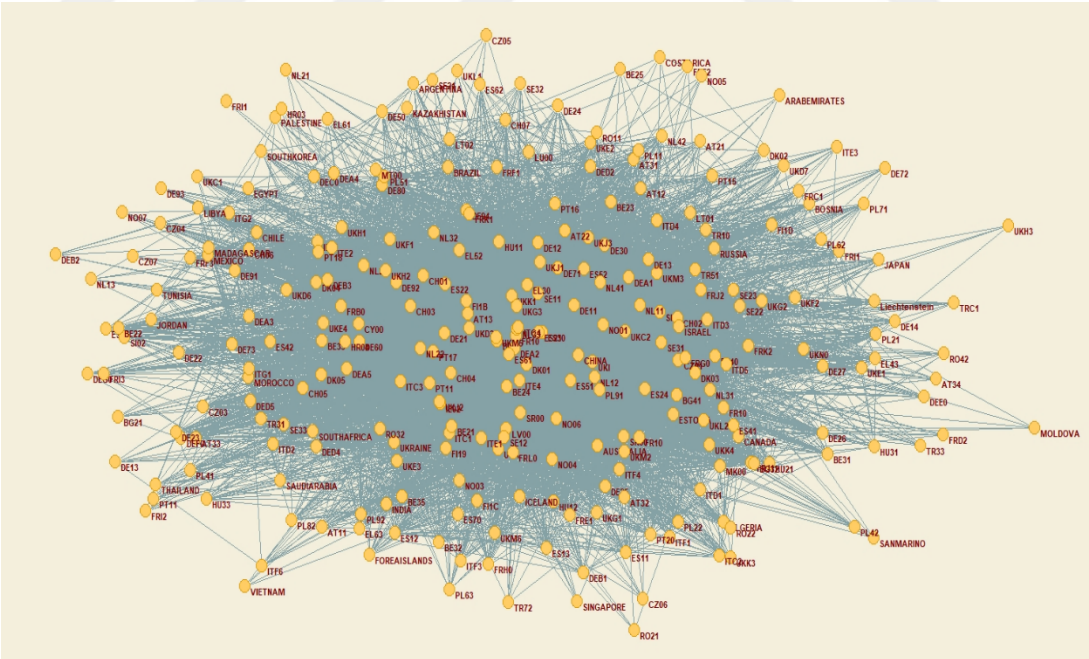


Figure 3.32: 1-mode representation of NUTS2 network of the FP7 energy programme

(Nodes: NUTS2 regions; there is a tie between 2 regions if they are enrolled in the same project)

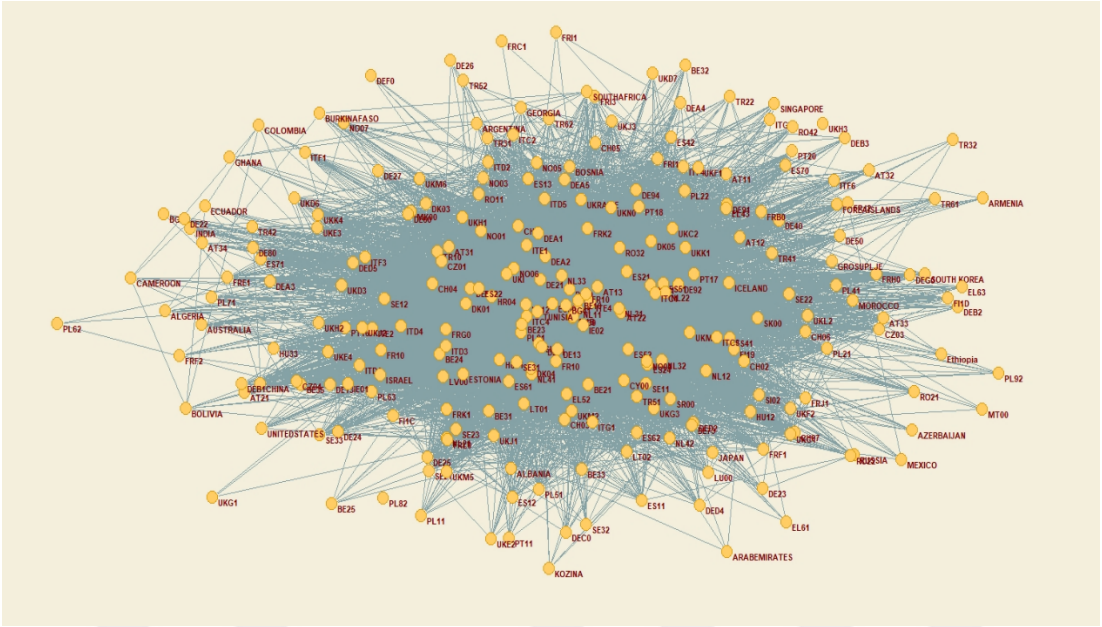


Figure 3.33: 1-mode representation of NUTS2 network of the H2020 energy programme

(Nodes: NUTS2 regions; there is a tie between 2 regions if they are enrolled in the same project)

Frequent number of connections are desirable for trust; on the other hand, weak or a smaller number of connections facilitate novel information transfer (Gogaladze, 2020). Therefore, we will compare the network structures of FP7 and H2020 programmes in the field of energy in terms of centrality metrics (degree, betweenness and closeness), clustering coefficient and density of the overall network[18].

2-mode network between participants and projects

First, remember that degree centralization of network is provided by the variation in the degree of vertices divided by the maximum variation in the degree that is possible given the number of vertices in the network. In a simple network of a particular size, the star-network has a maximum degree variation which is 1.

Table 3-8: Comparison of FP7 and H2020 Networks in terms of Centralization, Clustering Coefficient and Density

Programme	Degree Centralization	Betweenness Centralization	Closeness Centralization	Clustering Coefficient	Density
FP7	Participants: 0.211	0.13	N/A	Participants: 0.289	0.00123

[1818] See chapter for these metrics.

	Projects: 0.50			Projects: 0.465	
H2020	Participants: 0.164 Projects: 0.234	0.127	N/A	Participants : 0.388 Projects: 0.426	0.000611

Source: CORDIS data base and our own calculations for 1-mode networks (undirected and unweighted networks)

The division by the maximum degree variation provides degree centralization ranges from 0 (no variation) to 1 (maximum variation) in the case of a star network. In a star network, every node is connected to a central hub. In its simplest form, one central hub acts as a conduit to transmit messages or information in general. 2 mode network's degree centralization can be computed by transposing network in two sets (participants and projects). Table 3-8 shows that there is a significant reduction in the value of this metric in H2020which indicates that, compared to FP7, nodes become less central and less likely to connect to a central hub. This can be a sign that there is more than one central hub in the H2020 energy network structure.

Second, when we compare the betweenness centralization which shows the existence of structurally favorable positions to act as brokers, we do not observe a significant difference between the two programmes, but it is also lower in H2020. In return, we can assume that fewer nodes are on the shortest paths in H2020. Closeness centralization indicator cannot be computed since both networks are not strongly connected.

Third, clustering coefficient refers to how well connected is the neighborhood of the node. If the neighborhood is fully connected, the clustering coefficient is 1 and a value close to 0 means that there are hardly any connections in the neighborhood. This coefficient gets higher in the participants of H2020 compared to FP7. This finding indicates that participants' alters also tend to connect with each other, which shows they are in similar projects. When we compare this metric based on projects, we observe a slight fall in H2020 which means that participants built similar consortia for different projects. Thus, the transitivity of the H2020 network is less than that of FP7.

In the SNA context, transitivity refers to the extent to which the relation that relates two nodes in a network that are connected by an edge is transitive. More specifically, transitivity is a relation between three elements such that if it holds between the first and second and it also holds between the second and third it must necessarily hold between the first and third.

When looking at network density, which measures how many actual connections exist compared to how many possible connections there could be, we see that a higher density usually means there's more potential for collective action. In simpler terms, the more interconnected the network, the easier it is for people to work together.

From the data, we notice that network density has dropped significantly from the FP7 network to the H2020 network. This drop means that in the H2020 network, there are many projects and participants that are more isolated and not connected to the main, central parts of the network.

This change has several important effects:

- **Less Collaboration**: With fewer connections, people and projects aren't interacting as much. This can slow down the exchange of ideas and hinder collaborative efforts.
- **Weaker Team Efforts**: For collective action to be effective, strong, interconnected relationships are necessary. A less dense network means it's harder to organize and mobilize people towards common goals.
- **More Vulnerability**: Dense networks can handle disruptions better because the loss of one connection doesn't have a big impact. In a sparser network, losing key connections can cause significant problems and break down the network's functionality.
- **Unequal Access**: Those on the outskirts of the network may not have the same access to information and resources as those in the core, leading to imbalances and potential inequalities.

In short, the decrease in network density from the FP7 to H2020 networks suggests a

move towards a more fragmented and less cohesive structure.

This makes it harder for the network to support collaboration, collective action, and resilience, while also creating disparities in access to resources and information. It can be also observed as can be observed from the network diagrams for each program (previously provided please see Figure 3-30 and Figure 3-31), in H2020 there are many projects and participants in the periphery that are not connected to the core components.

1-mode network between NUTs2 regions

On the other hand, if we compare the two programs in terms of the performance of the NUTS2 regions, we observe that the network is not strongly connected, since closeness centralization cannot be calculated for H2020. Other metrics except degree centralization are slightly higher in H2020.

Closeness centralization reaches its maxium value of unity when one actor has geodesics of length 1 to all other actors, and other actors have geodesics of length 2 to the remaining actors.

Table 3-9: Network Statistics of NUTs2 Regions

NUTs2	Degree Centralization	Betweenness Centralization	Closeness Centralization	Clustering Coefficient	Density
FP7	0.595	0.0467	0.563	0.51	0.21
H2020	0.557	0.0481	N/A	0.564	0.250

Source: CORDIS data base and our own calculations

3.3.2 NUTS2 Analysis for FP7 and H2020 projects: the regional perspective

FPs are the main instruments for fostering research and innovation in the European Research Area and they have been analyzed extensively in the member states level to determine the main beneficiaries at national levels. Since FP programs' allocation rationality is mainly based on scientific excellence and industrial leadership, neither

of which does not address regional cohesion, the analysis of the geographical distribution of projects and funds is a key to identify regions are the main beneficiaries of these programs (Varela-Vázquez et al. 2019).

Since we adopt a geographical perspective here, we are interested in the regions involved in research production and collaboration. Therefore, in our thesis all the participants in both programmes (FP7 and H2020) are assigned into regions, according to the NUTS 2013 classification at level 2. CORDIS database does not contain NUTS2 codes of participants, so each participant was regionalized based on the geolocation information available in the organization dataset. While there are 4402 participants from 252 different NUTS2 regions in the FP7 energy projects, there are 11087 participants from 263 different NUTS2 regions in H2020 programme.

Going into the details of the specific regional data at NUTS2 level, concerning the total breakdown between coordination and participation in the FP7 and H2020, Table 3-10 displays the descriptive statistics regarding the total and the average number of coordinators and participations in projects, as well as the corresponding standard deviation and maximum and minimum values. Maximum numbers are identified for the highest per capita income regions, such as FR10, ES30, BE10, DE21, ITE4, DK01, ES21, EL30, UKI, NL33, ITC4 and FI1B.

Table 3-10: Summary statistics of the granted Energy projects in the FP7 and H2020

	Sum	Mean	Std. Dev.	Min.	Max.
Coordinated FP7	376	1.3	2.9	0	24
FP7 signed contracts	4536	14.0	21.0	0	170
Coordinated H2020	1476	5.2	22.2	0	335
H2020 signed contracts	14378	37.0	134.0	0	2067

Source: Own elaboration based on CORDIS data

There are participants outside the NUTS2 regions in both programs; since exclusion of these participants may cause structural holes in the network, they will be included in the analysis with their countries in the social network analysis. The average funding

of NUTS2 regions has substantially increased over the years as shown on Table 3-11, The total number of signed contracts also increased.

Table 3-11: Average funding of NUTS2 regions in FP7 and H2020 energy projects

Program	Signed contracts	Number of NUTS2 regions	Average Funding[19]
FP7	4536	252	3 556 985
H2020	14378	263	6 844 568

3.4 Statistical Network Analysis: Regression Analysis

In our thesis, we will use the ordinary least square estimation to investigate the determinants of the outputs of projects in FP7 and H2020. We will conduct two different analysis: first analysis is used estimate the number of patents resulted from energy projects in FP7 and H2020. In the second analysis, the network performance of NUTS2 regions is estimated whether regions characterized by higher energy demand or vulnerability or innovation driven to play a marginal role in the EU energy network. **The first regression model** we use for the patent data of FP7 and H2020 projects' empirical analysis is as follows:

$$\boldsymbol{y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \beta_4 X_{i4} + \beta_5 X_{i5} + \beta_6 X_{i6} + \varepsilon_i}$$

where y_i represents the outcome of project i and the outcome is measured either by the number of patents or publications, X_i is a set of project's properties for the project (i) its SNA metrics (degree, betweenness and closeness), (ii) EU funding contribution, (ii) duration of the project and (ii) the number of participants in the project. Finally, ε_i is the error term.

Table 3-12: List of independent and dependent variables

Variables	Description
Dependent Variables	
Number of Patents	Total number of patents originating from the project
Independent Variables	
Number of Publications	Total number of publications from the project

[19] Computed by dividing the total EU contribution by the number of NUTS2 regions

Number of participants in projects	Consortium size of the project: number of participants including the coordinator
Betweenness centrality of projects	Shows the node's importance in the overall connectivity of the network which is defined as the fraction of the shortest paths between any pair of nodes in the network, which pass through the nth node
EUMax Contribution	Funding amount of a project received from the EU
Network hub (dummy variable)	Dummy variable refering hub position in the network
Funding Scheme	Specific categories for type of support provided, the eligibility criteria, and the rules for participation and funding distribution
Cluster category	Being in part of core cluster or not

Dependent Variables:

Number of patents of the project

This refers to the total number of patents that resulted from the project.

Independent Variables:

Number of publications of the project:

Hoekman et al. (2013) randomize models by including the total number of publications of a region as independent variables to test its effect on the number of funded participations in FP6. However, we are aware that the publications number may also be considered as a dependent variable in the evaluation of the projects output and in that case should not be used as an independent variable for the estimation of the patents originating from the same project. We shall also discuss this issue in Chapter 4.

Number of participants in projects:

Hoekman et al. (2013) measure the effects of FP funding on the occurrence of scientific collaboration networks between region i and j and use the number of funded participations of region i in FP6 as one of the independent variables.

Betweenness centrality of projects:

Betweenness centrality refers to the node's presence in shortest paths of the network; the nodes with highest betweenness centrality may have the power to better control the

information flows. Calignano (2021) used these two-centrality metrics to determine the region's absolute and relative innovation capability in his study. The projects with the highest degrees are considered the most important and "central" and those with the highest betweenness centralities as the most influential "influential" ones whose removal from the network might cause disruptions in the knowledge flow (Calignano, 2021:8).

EUMax Contribution:

This means the financial contribution from the EC in accordance with the Grant Agreement.

Network hub:

In a similar study, Balland et al. (2019) uses network hub as a dummy variable (0/1) that takes value 1 if a participant belongs to the top 2% of both the degree and betweenness centrality distribution while measuring FP's participants' collaboration performance. Basically, hubs represent highly connected nodes in a network. We can assume that hubs exist between nodes with high degree and betweenness centralities. Farahani et al. (2019) also confirm that the easiest way to detect hubs in a network is to calculate the nodal degree which can be calculated through centrality metrics since high degree nodes in scale-free networks is accompanied by power-law distribution. The results of this regression analysis are discussed in Chapter 4.

Cluster Category:

Cluster category is used as independent variables in regression analysis to understand the impact of belonging to different network clusters on specific outcomes. This approach helps to identify how the characteristics and dynamics within these clusters influence overall network behavior, such as performance, collaboration, or innovation. Belonging to a core component of a cluster is particularly important as it often signifies a higher degree of influence, access to resources, and connectivity. By analyzing cluster membership, it is possible to pinpoint the contribution of each cluster to the dependent variable, providing insights into the role of network structures in shaping outcomes.

Funding Scheme:

The Funding Scheme in the EU Framework Programmes (FP7, Horizon 2020) refers to the specific mechanisms through which the EU allocates financial resources for research and innovation projects. These schemes, such as Collaborative Projects, Marie Skłodowska-Curie Actions, and SME Instruments, define the types of support, eligibility criteria, and participation rules. As an independent variable, the Funding Scheme is important because it influences project success rates and research outcomes, affects the distribution of financial support across disciplines and sectors, shapes collaboration patterns, and helps evaluate and improve the effectiveness of EU funding policies. Additionally, it drives regional development, reduces disparities, and impacts the diversity and inclusion of participants in funded projects.

The second basic regression model we use for the NUTS2 regions performance analysis is as follows:

$$\boldsymbol{y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \beta_3 X_{i3} + \beta_4 X_{i4} + \beta_5 X_{i5} + \beta_6 X_{i6} + \varepsilon_i}$$

where y_i represents the eigenvector centrality metric of region i X_i is a set of NUTS2 regions' properties, (i) Regional Innovation Scoreboard category, (ii) GDP, (iii) duration of the project and (iv) Heating and Cooling Degree Days, (v) Maximum EU funding amount, (vi) Human resources in science and technology. Finally, ε_i is the error term.

Eigenvector centrality:

Eigenvector centrality of a NUTS2 region is a measure used in network analysis to determine the influence of a region within a network. In regression analysis, it represents the importance of a region not just by its own connections but also by the connections of its neighbors,

Table 3-13: List of independent and dependent variables

Variables	Description
Independent Variables	
Eigenvector Centrality	Eigenvector centality measure of NUTS2 region
Dependent Variables	

RIS	Regional Innovation Scoreboard Group
GDP	Gross domestic product of region
Heating Cooling Degree Days	
ecMaxContribution	Maximum funding amount
HRST	Human resource in Science and Technology

reflecting the overall connectivity and influence of the region in the network. Balland, Boschma, and Frenken (2019) demonstrated that regions with high eigenvector centrality within the European research collaboration network tend to exhibit higher innovation outputs. Their study underscored the significance of network positions in driving regional innovation performance, highlighting how central regions can leverage their connections to access diverse knowledge and resources, thereby enhancing their innovation capacity.

Regional Innovation Scoreboard (RIS):

RIS is a categorical variable, meaning that it classifies each NUTS2 region into distinct categories or groups based on their innovation performance. These categories could be labels such as "highly innovative," "moderately innovative," or "less innovative," helping policymakers and researchers understand and analyze the innovation capabilities and needs of different regions.

Gross domestic product of region (GDP):

The regional gross domestic product (GDP) is used in order to measure and compare the economic activity of regions. It is the most important indicator for the selection of regions eligible for support under the investment for growth and jobs goal of the EU's regional policy. Regional gross domestic product data is annually available in Eurostat and it is calculated as harmonized production activity based on output, expenditure and income approach. The GDP data between 2007 and 2016 of NUTS2 regions is used as dummy variable and categorized into 3 groups: small for less than 30000, medium for between 30000 and 40000 and high for larger than 40000.

Heating Cooling Degree Days (HDD and CDD):

HDD and CDD of a NUTS2 region are measures used in regression analysis to quantify the demand for energy needed to heat or cool buildings. HDD indicates how

much heating is needed when the temperature drops below a certain threshold, while CDD indicates how much cooling is needed when the temperature rises above a certain threshold. These metrics help in analyzing energy consumption patterns in different regions. Regions with high energy vulnerability may face greater challenges in maintaining economic stability and growth, which can impact their network centrality. Day and Karali (2014) emphasized the importance of degree days in analyzing regional energy consumption patterns. Their research highlights how energy vulnerability can affect economic performance and, consequently, the centrality of regions within a network.

EC MaxContribution:

It is the total funding amount of the participants in that region in FP7 and H2020 energy projects.

Human resources in Science and Technology (HRST):

HRST database is based on a Canberra Manual of the measurement of human resources devoted to science and technology field. HRST statistics is downloaded from Eurostat regional science and technology statistics[20]. An HRST stock is defined as "the number of people at a particular point in time who fulfil the conditions of the definition of HRST," which satisfies the conditions stated in the following:

- Who successfully completed a tertiary education and are employed in any kind of job; or
- Who are not formally qualified as above but employed in a S&T occupation where the above qualifications are normally required.

HRST data is calculated as annual data of specific NUT 2 region and its unit of measure is shown in number of persons in thousands whose age group is between 15 and 74 years. The median of the HRST data between 2007 and 2017 of NUTS2 regions is used as dummy variable and categorized into 3 groups: small for less than 300, medium for between 300 and 400 and high for larger than 400.

[20] https://ec.europa.eu/eurostat/cache/metadata/en/hrst_esms.htm

The selected variables collectively provide a robust framework for analyzing regional performance within the scope of social network analysis. Eigenvector centrality serves as the primary dependent variable, capturing the influence and connectivity of regions within the network. The independent variables—RIS, GDP, HDD and CDD, EC MaxContribution, and HRST—cover key dimensions of economic activity, innovation capacity, energy vulnerability, financial resources, and human capital.

This comprehensive approach ensures that the regression model accounts for the complex interplay of factors that drive regional performance. By understanding these interactions through the lens of SNA, policymakers and researchers can identify leverage points to enhance regional development and innovation.

3.5 Some conclusions for chapter 3

This chapter described data sources used, data collection and retrieval processses and the quantitative analysis techniques aimed at the investigation of research questions of the dissertation. The purpose of this chapter was to provide insights about the chapter 4 which will offer in-depth analysis and evaluations of the changes in the network structure and performance from FP7 to H2020 using SNA metrics.

In the present chapter 3, a methodological strategy comprising descriptive statistical analyses, social network analysis (SNA), graph visualization, and econometrics (ordinary least square model) was adopted to conduct empirical analysis in the context of the energy networks funded by the EU under the FP7 and H2020 programmes. We used SNA measures, such as degree, betweenness and closeness centrality metrics and hub detection to map the performances of the energy projects in the targeted networks and determine the possible associations among the dependent variables and two main independent variables, project publications and patents as project outcomes.

The first part of the chapter presented the sources and data collection processes used in the descriptive statistical analyses and SNA for FP7 and H2020 energy projects. The second part presented the results of a preliminary statistical analysis of the data to prepare the SNA section. The third part summarized the SNA approach we used and presented some preliminary results preparing chapter 4.

Chapter 3 of the thesis provides important and surprising findings on the analysis of data sources and the methodologies employed to investigate EU-funded energy projects under the FP7 and H2020 programmes. One significant finding is the marked difference in patenting behavior between FP7 and H2020. Despite the increased number of projects and participants in H2020, the number of patents did not increase proportionally. In fact, the number of patenting projects decreased, and the cost of generating patents doubled from FP7 to H2020. This indicates a potential decline in patenting efficiency and highlights the need for a more detailed examination of the factors influencing patenting outcomes .

Another surprising observation is the strong preference of certain partners for the participant role rather than the coordinator role, particularly in the FP7 program. This preference was not observed in the H2020 program, suggesting an evolution in the roles and dynamics of participants between the two frameworks. The use of Social Network Analysis (SNA) revealed that large research institutes like Fraunhofer and CNRS frequently played coordinator roles in multiple projects, underlining their pivotal role in shaping the research networks. Additionally, the chapter outlines the methodological strategy adopted, which includes descriptive statistical analyses, SNA, and econometric models to map the performance and interactions within the energy project networks. These preliminary findings set the stage for a more in-depth analysis in Chapter 4, where the focus will be on the detailed SNA results and their implications for regional innovation and development. .

CHAPTER 4

SNA ANALYSIS OF THE FP7 AND H2020 ENERGY PROJECTS

This chapter presents the findings related to the research questions outlined in Chapter 1. These results include the outcomes from the Social Network Analysis (SNA) of the networks examined in Chapter 3, specifically focusing on the energy projects in FP7 and H2020. The Pajek software package has been utilized to examine the network structure and performance of these energy projects, allowing us to discover and visualize the relationships between projects and participants. This analysis is also performed at the regional NUTS2 level to assess how regions' performances have evolved between the two programs.

Additionally, we conduct an econometric analysis to provide a deeper understanding of the underlying factors influencing the structure and dynamics of these energy projects. Our objective is to analyze the structure and dynamics of the energy projects in FP7 and H2020, identifying the key determinants that drive regional performance within these programs.Regression analysis is employed to quantify the relationships between the dependent variables output of energy projects and NUTS2 performance and multiple independent variables. By controlling for other variables, this approach isolates the specific effects of each factor, providing a robust and comprehensive analysis. Understanding these interactions through the lens of SNA and econometric analysis enables policymakers and researchers to identify leverage points to enhance regional development and innovation. This comprehensive approach ensures that the regression model accounts for the complex interplay of factors driving regional performance, offering valuable insights for improving policy interventions and regional strategies. Basically, this chapter aims to use following tools to investigate research questions:

- Exploration of the performance of NUTS2 regions in FP7 and H2020 programmes by using *network centrality metrics* with the aim of comparing

the network structure in these programmes.

- Exploratin of *network centrality metrics* of FP7 and H2020 with an aim to identify network hubs.
- Exploration of *structural holes and brokerage roles* in the project and participant networks and making a comparison between FP7 and H2020, the focus here being uncovering important nodes.
- Conducting regression analysis in order to examine how projects differ from each other in terms of independent variables
- Conducting regression analysis to investigate NUTS2 regions whether innovativeness ('innovation-driven' participation) or energy demand/vulnerability ('challenge-driven' participation) determine different degrees of participation in the context of the energy programmes

4.1 Regional Network Analysis based on Energy Projects in FP7 and H2020

In this section, the performance of regions at NUTS2 level is analyzed based on network analysis of energy projects in FP7 and H2020[21]. 2-mode network is built between NUTS2 regions and projects in both programs. These networks are provided below in Figure 4.1 and Figure 4.2, respectively. Subsequently, 2-mode network is transformed into 1-mode network of NUTS2 regions: this simply means that there is a tie between two regions if they have at least one participant in the same project.

Network metrics show that the FP7 network has more structural holes compared to H2020 because the length of the ties between regions and projects is longer when the nodes have low aggregate constraints. As discussed in Chapter 2, nodes with low aggregate constraints achieve better performance. This is because they are often in pivotal positions where they can effectively resolve conflicts within projects or successfully capitalize on knowledge transfer opportunities to serve their interests (Wang et al., 2022).

[21] For the NUTS classification, see https://ec.europa.eu/eurostat/documents/345175/629341/NUTS2021-NUTS2024.xlsx

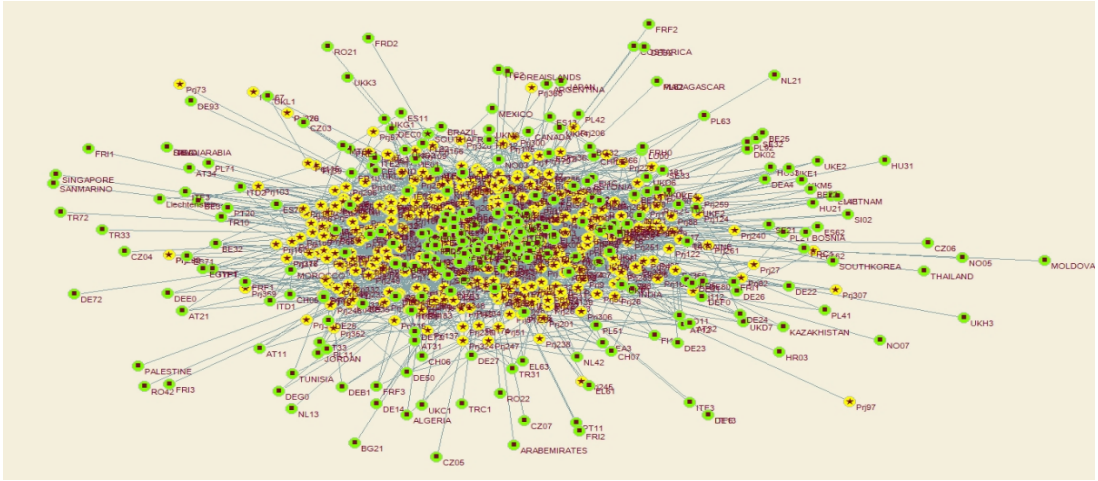


Figure 4.1: 2-mode network of FP7 energy projects and NUTS2 regions

Color of nodes: Yellow represents the projects and green represents the NUTS2 regions
Source: Author's calculations based on CORDIS data.

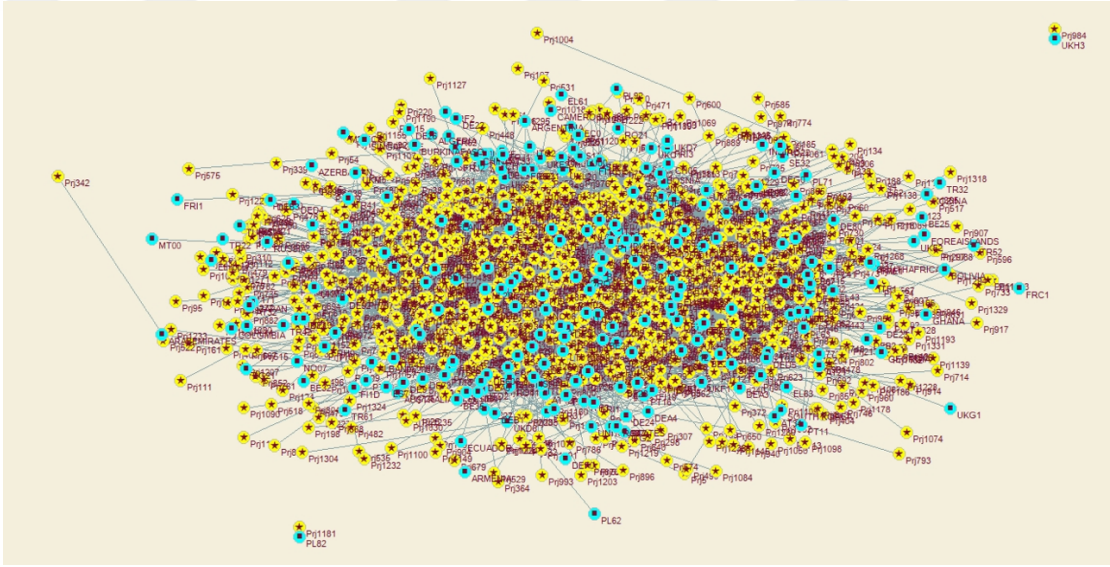


Figure 4.2: 2-mode network of H2020 energy projects and NUTS2 regions

Color of nodes: Yellow represents the projects and blue represents the NUTS2 regions
Source: Author's calculations based on CORDIS data.

Regions centrally located with high betweenness centrality benefit from the presence of structural holes, as the flow of knowledge between peripheral regions frequently passes through them.

Table 4.1 shows the network statistics of NUTS2 regions in FP7 and H2020. The average degree slightly increases in H2020, indicating that the regions have enhanced their capacity to maintain links with others. According to Akçomak et al. (2018), the ratio of self-loop value in each Framework Programme (FP) to the number of edges

can be used to understand whether there is regional favoritism. The lower self-loop ratio and average geodesic distance in the H2020 network suggest that regions are more positively inclined towards cooperation with other regions. Additionally, we observe a decrease in betweenness centrality and an increase in connected components, indicating that several regions control different paths.

In the FP7 programme, there is one component that is significantly larger than those in H2020, suggesting that there is only one dominant information flow in FP7. This means that the majority of information transmission and collaboration predominantly occurs through this single large component. Essentially, there is a central hub or a dominant cluster in the FP7 network that controls and facilitates the bulk of information flow among regions. In contrast, the H2020 network is characterized by multiple smaller components, indicating a more decentralized structure where information flow is distributed across various paths and regions.

Moreover, in the H2020 programme, newcomers are connected to different core components compared to FP7. The path length decreases and the clustering coefficient increases in H2020, demonstrating that the network of NUTS2 regions exhibits small-world properties. This implies high efficiency in knowledge creation and diffusion between regions, fostering a more interconnected and collaborative environment.

Table 4-1: General statistics of NUTs2 regions in FP7 and H2020 programmes

Graph Metric	**FP 7**	**H2020**
Vertices	280	257
Unique Edges	8904	8305
Total Edges	8904	8747
Self-Loops	156	156
Connected Components	1	3
Single-Vertex Connected Components	0	2
Maximum Vertices in a Connected Component	280	255
Maximum Edges in a Connected Component	8904	8747
Maximum Geodesic Distance (Diameter)	3	3
Average Geodesic Distance	1.795	1.758

Graph Density	0.224	0.253
Average Degree	63.600	66.078
Average Betweenness Centrality	111.743	96.400
Average Closeness Centrality	0.563	0.572
Average Eigenvector Centrality	0.049	0.051
Average Clustering Coefficient	0.711	0.757

Source: Author's calculations based on CORDIS data

Based on comparative statistics of NUTS2 regions in the FP7 and H2020 programmes, despite the increased funding in H2020, certain metrics such as the number of vertices (regions) and unique edges (connections) decreased, indicating a more concentrated network. The number of connected components rose, suggesting a more fragmented network, possibly due to more isolated regions receiving funding.

A slight decrease in the average geodesic distance indicates improved overall connectivity among regions. However, the drop in average betweenness centrality suggests a reduction in the influence of individual regions within the network, potentially indicating a more equitable distribution of influence. Increased graph density and clustering coefficient reflect a denser and more tightly-knit network, which may enhance collaboration and innovation diffusion among regions. Overall, while funding increased, the network became more concentrated and cohesive, with a potential shift towards more inclusive and widespread regional development.

In Table 4.2, the Top10 regions are ranked based on their network degree, which represents the number of direct connections a region has with other regions. To illustrate, in FP7, the region with the highest degree is FR10 Île de France, indicating that FR10 is directly connected to 233 out of the 251 available regions. In Table 4.3, we present the Top10 EU regions based on their network betweenness, and in Table 4.4, we rank the regions according to their eigenvector centrality which takes into account the centralities of the connected nodes. Betweenness centrality measures a region's significancy in the flow of knowledge within the network. In general, a region with a high degree is also highly central in the network by connecting critical nodes.

The rankings of the Top10 regions are rather stable in these centrality lists. Some changes can be noted however such as Oberbayern losing its place to Attica in the eigenvector rankings in H2020. In addition, Hovedstaden and Köln, which were among the Top10 regions in FP7, are not in the Top10 in H2020 for the eigenvector centrality list. They are replaced by the Vienna and Lisboa regions.

Table 4-2: Comparison of degree centralities of Top10 NUTS2 Regions in FP7 and H2020

FP7			**H2020**		
FR10	Ile de France	233	BE10	Brussels	212
DE21	Oberbayern	221	ES30	Madrid	211
BE10	Brussels	211	FR10	Ile de France	208
ES30	Madrid	207	DE21	Oberbayern	206
ITE4	Lazio	198	ITE4	Lazio	192
DK01	Hovedstaden	191	EL30	Attica	187
DEA2	Köln	185	ES51	Catalonia	185
EL30	Attica	180	UKI7	London	183
ES21	Basque Community	174	NL33	South Holland	179
UKI7	London	172	AT13	Vienna	177

Source: Author's calculations based on CORDIS data.

Our decision to focus on betweenness centrality is grounded in its capacity to illuminate a node's pivotal role within a network. Betweenness centrality quantifies the extent to which a node lies on the shortest paths connecting other nodes, thereby indicating its influence over network connectivity. A node with high betweenness centrality serves as a crucial intermediary; its removal would either fragment the network or necessitate longer alternative paths for interaction.

In the context of regional innovation performance, regions with high betweenness centrality are especially significant. These regions act as key hubs that facilitate the exchange of ideas, resources, and knowledge across the innovation network. By linking otherwise disconnected regions, they enhance the integration of diverse innovative inputs, creating opportunities for the cross-fertilization of ideas and collaborative ventures.

This interconnectedness fosters a more dynamic innovation ecosystem, driving regional innovation by enabling regions to leverage external knowledge and resources. The strategic positioning of such regions within the network thus underpins their ability to catalyze and sustain innovation through improved connectivity and collaborative potential.

Table 4-3: Comparison of betweenness centralities of Top10 NUTS2 Regions in FP7 and H2020

FP7			**H2020**		
FR10	Ile de France	0.0494	DE21	Oberbayern	0.0509
DE21	Oberbayern	0.0417	BE10	Brussels	0.0463
ES30	Madrid	0.0406	ES30	Madrid	0.0378
BE10	Brussels	0.0312	FR10	Ile de France	0.0364
DK01	Hovedstaden	0.0292	EL30	Attica	0.0254
ITE4	Lazio	0.0285	AT13	Vienna	0.0218
DEA2	Köln	0.0242	ITE4	Lazio	0.0214
EL30	Attica	0.0188	ES51	Catalonia	0.0201
DE11	Stuttgart	0.0178	UKI7	London	0.0182
ES61	Andalusia	0.0166	FI1B	Helsinki-Uusimaa	0.0179

Source: Author's calculations based on CORDIS data.

After analyzing two different centralities in our network, we look at their neighbors.

Table 4-4: Comparison of eigenvector centralities of top NUTS2 Regions in FP7 and H2020

FP7			H2020		
FR10	Ile de France	0.137	BE10	Brussels	0.358
DE21	Oberbayern	0.132	ES30	Madrid	0.334
BE10	Brussels	0.131	FR10	Ile de France	0.261
ES30	Madrid	0.127	EL30	Attica	0.238
ITE4	Lazio	0.126	ITE4	Lazio	0.228
DK01	Hovedstaden	0.122	AT13	Vienna	0.220
EL30	Attica	0.121	DE21	Oberbayern	0.175
DEA2	Köln	0.119	PT17	Lisboa	0.165
UKI	London	0.118	UKI	London	0.162
ES21	Basque Community	0.117	ES21	Basque Community	0.155

Source: Author's calculations based on CORDIS data.

We conducted a statistical analysis using the independent variables described in chapter 3 in order to estimate how regions differ in terms of determinants of eigenvector centrality. Eigenvector centrality refers to the importance of a node in a network based on node's connections and nodes with high eigenvector centrality fill in the structural holes by setting links with important actors. These actors have more access to codified knowledge in the network. Calignano and Trippl (2020) explored the relationship between cross-country research flows and energy efficiency in FP7. They used energy intensity as independent variable and network centrality metrics as dependent variables in their econometric model. The aim of thistudy research was to investigate whether innovativeness ('innovation-driven' participation) or energy demand/vulnerability ('challenge-driven' participation) lead to a different degree of participation in the context of the energy programme funded under FP7 by conducting SNA and econometric analyses. It is found that the more innovative EU regions hold a central or key position, while the regions characterized by higher energy demand or vulnerability play a marginal role in the EU energy network.

We used Stata software (version 15.0) to predict the eigenvector centrality metrics based on the Regional Innovation Scoreboard category, GDP, Heating Cooling Degree Days, EU financial contribution and Human resources in Science and Technology index in this multiple regression model which are explained in Chapter 3. The alteration in the eigenvector centrality of a NUTS2 region can be attributed to independent variables such as EU contribution and Heating Cooling Degree Days in FP7. On the other hand, when predicting changes in H2020, significant factors include the independent variables such as EU contribution, Regional Innovation Scoreboard category, and Human resources in Science and Technology index. As expected, all three indicators in H2020 are positively associated with the eigenvector centrality. The results of the estimation of eigenvector centrality in FP7 and H2020 are given in Table 4.5. The model for FP7 demonstrates that several factors significantly influence eigenvector centrality.

Table 4-5: Results of the estimations of eigenvector centrality in FP7 and H2020

Outcome		
Ind.Variables	**Eigenvector**	**Eigenvector**

	Centrality (FP7)	Centrality (H2020)
GDP	1.87e-07 (2.651e-07)	0.0000 (0.0000)
RIS	-0.003698 (0.001317)**	0.0137 (0.0042)*
Heating Cooling Degree Days	-7.408e-06 (1.939e-06)***	-0.0000 (0.0000)
ecMaxContribution	2.944e-09 (2.836e-10)***	0.0000 (0.0000)*
HRST	0.0008702 (0.0003008)**	0.0020 (0.0005)*
_const	0.0245 (0.01041)*	-0.1009 (0.0279)*
No. of obs.	173	123
R^2	0.627	0.528

Standard errors reported in the parenthesis. The signs ***, **, * indicate the statistical significance at the 1, 5, and 10 percent significance levels, respectively.

Specifically, RIS, Heating Cooling Degree Days, ec max contribution, and HRST are significant predictors, while GDP is not. The positive coefficients for ec max contribution and HRST suggest that regions with higher maximum contributions to the economy and higher proportions of human resources in science and technology have higher centrality. Conversely, higher RIS categories and more degree days are associated with lower centrality. These findings offer insights into the structural factors that influence the centrality of regions within a network, which can inform policy decisions aimed at fostering regional development and innovation.

However, the model in H2020 shows that the large condition number (1.6e+08) indicates potential multicollinearity issues among the independent variables, which could affect the reliability of the coefficient estimates. It is found that RIS, ec_max_contribution, and HrST have significant positive effects on eigenvector centrality. GDP and Heating/Cooling Days do not have statistically significant effects on eigenvector centrality in this model. So, we conducted The multicollinearity analysis using the Variance Inflation Factor (VIF) for each independent variable and we deleted HrST since its VIF is the highest and rerun the regression model. We found that Removing HrST addressed the multicollinearity issues, leading to more reliable coefficient estimates. The refined model suggests that GDP and ec_max_contribution are the primary drivers of eigenvector centrality in this analysis.

4.2 Project-based analysis of energy networks in FP7 and H2020 programme

4.2.1 Social Network Analysis

In this section, we present and analyse the SNA network indicators computed at the project level. Through the development of an analysis on diverse nodes and their positions within the network, it becomes feasible to pinpoint the projects that significantly enhance network integration. To achieve this goal, three primary centrality measures, degree, betweenness and closeness metrics, will be examined for FP7 and H2020.

In Tables 4.7-4.8 and Tables 4.10-4.11, we present the Top10 projects ranked according to values of these three centrality measures for the FP7 and HH2020, respectively. These tables also include project-level informations such as topic description, coordinator's name, coordinator's participant type and NUTS2 region. Projects are ranked in descending order of centrality.

Table 4.6 displays the Top10 projects ranked according to degree centrality in FP7 that contribute to the advancement of innovative solutions in photovoltaics, smart grids, wind energy, concentrated solar power, offshore applications, carbon capture and storage, aerodynamic modeling, renewable energy conversion platforms, electric vehicle-grid interaction, and offshore wind farm clusters. On the other hand, the subject of Top10 projects in H2020 presented in Table 4-8 are based on smart grids and storage, EU-Africa partnership for renewable energy, public authorities' support for implementing the Energy Union, modeling for a low-carbon energy system, and advancements in materials and manufacturing processes for solid oxide cells. The projects in both programs are coordinated by organizations located in various NUTS2 regions, showcasing a geographic spread across Europe.

This reflects a paneuropean effort to address common challenges and promote innovation in the energy sector. In H2020, several projects emphasize sustainability by supporting the implementation of the SET Action Plan, enhancing the capacity of public authorities for sustainable energy policies, and demonstrating system integration with smart technologies for increased renewable energy utilization. For example, projects like "NewSOC" and "GreenDiamond" highlight a focus on new

materials, architectures, and technologies. This finding points to the importance of innovation and technological advancements in achieving sustainable energy goals. In addition, the projects align with broader goals of sustainability, smart energy systems, and the transition to a low-carbon future.

As indicated in Tables 4-9 and 4-10, the maximal value of this metric for FP7 projects is larger than the value calculated for H2020. In contrast, H2020 shows a concentration in lower degree centrality values, suggesting a different distribution of project involvement. H2020 generally exhibits higher average funding, especially in the higher degree centrality ranges. Frequency distribution of degree centrality of projects and their average funding in FP7 and H2020 are provided in Table 4.9 and Table 4.10 respectively.

Table 4-6: FP7 - Top10 Projects according to degree centrality

Project Acronym	**Topic Description**	**Coordinator's Name**	**Part. Type**	**Coordinators NUTS2 region**
CHEETAH	Integrated research programme in the field of photovoltaics	STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND	REC	Noord-Holland
ELECTRA	Integrated research programme on smart grids	RICERCA SUL SISTEMA ENERGETICO - RSE SPA	REC	Lombardia
IRPWIND	Integrated research programme in the field of wind energy	DANMARKS TEKNISKE UNIVERSITET	HES	Hovedstaden
STAGE-STE	Integrated Research Programme in the field of Concentrated Solar Power (CSP)	CENTRO DE INVESTIGACIONES ENERGETICAS, MEDIOAMBIENTALES Y TECNOLOGICAS-CIEMAT	REC	Comunidad de Madrid
INNWIND.EU	Innovative wind conversion systems (10-20MW) for offshore applications	DANMARKS TEKNISKE UNIVERSITET	HES	Hovedstaden
MACPLUS	Efficiency increases in existing and new build pulverised coal power plants with a view to CCS	CENTRO SVILUPPO MATERIALI SPA	PRC	Lazio

AVATAR	Advanced aerodynamic modelling, design and testing for large rotor blades	STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND	REC	Noord-Holland
ORECCA	Coordination action on off-shore renewable energy conversion platforms	FRAUNHOFER-GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V	REC	Oberbayern
COTEVOS	Enhanced interoperability and conformance testing methods and tools for interaction between grid infrastructure and electric vehicles	FUNDACION TECNALIA RESEARCH & INNOVATION	REC	País Vasco
EERA-DTOC	Development of design tools for Offshore Wind farm clusters	DANMARKS TEKNISKE UNIVERSITET	HES	Hovedstaden

Source: Author's calculations based on CORDIS data. REC = research organizations, PUB = public bodies, PRC = private sector, HES = higher education institutions, OTH = other participants

Table 4-7: FP7 - Top10 Projects according to degree centrality

Project Acronym	**Topic Description**	**Coordinator's Name**	**Participant Type**	**Coordinators NUTS2 region**
INSHIP	European Common Research and Innovation Agendas (ECRIAs) in support of the implementation of the SET Action Plan	Fraunhofer Gesellschaft Zur Forderung Der Angewandten Forschung Ev	REC	Oberbayern
IntEnSys4EU	Support to R&I strategy for smart grid and storage	Zabala Innovation Consulting Sa	PRC	Comunidad Foral de Navarra
LEAP-RE	Long Term EU-Africa Partnership for Research and Innovation actions in the area of renewable energy	Lgi Sustainable Innovation	PRC	Ile-de-France
ODYSSEE-MURE2	Supporting public authorities to implement the Energy Union	Agence De L'environnement Et De La Maitrise De L'energie	Public bodies	Pays de la Loire
Open ENTRANCE	Modelling in support to the transition to a Low-Carbon Energy System in Europe	Sintef Energi As	REC	Trøndelag
NewSOC	New materials, architectures and manufacturing processes for Solid Oxide Cells	Danmarks Tekniske Universitet	HES	Hovedstaden

EU-SysFlex	Demonstration of system integration with smart transmission grid and storage technologies with increasing share of renewables	Eirgrid Plc	PRC	Eastern and Midland
ODYSSEE-MURE1	Enhancing the capacity of public authorities to plan and implement sustainable energy policies and measures	Agence De L'environnement Et De La Maitrise De L'energie	Public bodies	Pays de la Loire
POCITYF	Smart Cities and Communities	Labelec Estudos Desenvolvimento E Actividades Laboratoriais Sa	HES	Área Metropolitana de Lisboa
GreenDiamond	New knowledge and technologies	Centre National De La Recherche Scientifique Cnrs	REC	Ile-de-France

Source: Author's calculations based on CORDIS data.

When we compare the top ten energy projects in FP7 and H2020 based on betweenness centrality metric in Tables 4.11 and 4.12, respectively, notable differences emerge

Table 4-8: FP7 - Frequency distribution of degree centrality of projects and their average funding

Vector Values	**Frequency**	**Freq %**	**CumFreq**	**CumFreq(%)**	**Average Funding (€)**
0- 0	2	0.5348	2	0.5348	1 057 264
0- 80.6667	285	76.2032	287	76.738	4 417 096
80.6667-161.3333	81	21.6578	368	98.3957	6 363 601
161.3333-242.0000	6	1.6043	374	100	10 668 298

Source: Own calculation based on Pajek calculations and CORDIS project database

In FP7, the dominant subject areas encompass photovoltaics, wind energy, concentrated solar power, and bio-energy carriers.

Table 4-9: H2020 - Frequency distribution of degree centrality of projects and their

average funding

Vector Values	Frequency	Freq%	CumFreq	CumFreq%	Average Funding (€)
0-0	112	17.2573	112	17.2573	1,036,165
0.0000-61.3333	397	61.171	509	78.4284	3,372,750
61.3333-122.6667	121	18.6441	630	97.0724	6,214,342
122.6667- 184	19	2.9276	649	100	7,781,083

Source: Own calculation based on Pajek calculations and CORDIS project database

Conversely, H2020 projects exhibit a broader spectrum, emphasizing renewable energy partnerships, smart grids, sustainable energy policies, and system integration with storage technologies. FP7 demonstrates a more focused approach, concentrating on specific technologies, while H2020 projects point to a greater diversity, spanning long-term partnerships, smart grids, energy policies, and system integration. Another significant difference between them lies in the project coordination structures. FP7 projects are primarily coordinated by research organizations, whereas H2020 projects involve a mix of private for-profit entities, public bodies, and research organizations. Furthermore, FP7 coordinators are distributed across regions like Noord-Holland, Lombardia, and Comunidad de Madrid, while H2020 coordinators are situated in regions such as Ile-de-France, Oberbayern, and Pays de la Loire. This geographical distinction reflects the evolving landscape of renewable energy research and innovation, with H2020 projects embodying a broader scope and engaging a diverse array of entities.

The shift from specific technology-focused projects in FP7 to a broader spectrum in H2020 suggests a significant strategic evolution in the EU's approach to energy research and innovation. H2020 projects, which emphasize renewable energy partnerships, smart grids, sustainable energy policies, and system integration with storage technologies, reflect a move towards comprehensive solutions that address policy and systemic challenges alongside technological advancements.

This broadening of focus indicates a recognition that sustainable energy goals require a multifaceted approach, integrating various aspects of the energy system to promote

synergy and efficiency.

The diversification of project coordination structures, from primarily research organizations in FP7 to a mix of private for-profit entities, public bodies, and research organizations in H2020, underscores a more collaborative and interdisciplinary approach. This integration fosters innovation through diverse perspectives and expertise, enhancing the potential for groundbreaking solutions and facilitating the commercialization of new technologies. Public-private partnerships, in particular, play a critical role in translating research into practical applications, driving the market deployment of innovative solutions.

Geographically, the distribution of project coordinators has shifted from regions like Noord-Holland, Lombardia, and Comunidad de Madrid in FP7 to regions such as Ile-de-France, Oberbayern, and Pays de la Loire in H2020. This reflects the expansion of research and innovation hubs across Europe, promoting balanced regional development and the dissemination of best practices. Such a geographic spread fosters a cohesive European research area, where all regions contribute to and benefit from collective innovation efforts.

In summary, the evolution from FP7 to H2020 projects highlights the importance of comprehensive, collaborative, and regionally inclusive strategies. By embracing a wider range of initiatives and engaging diverse entities, H2020 is better positioned to develop resilient and sustainable energy systems, driving the EU towards its long-term energy and climate goals.

In a similar way to Top10 projects according to betweennes centrality, ranking according to closeness centrality (Tables 4.13 and 4.14) show that FP7 projects exhibit a larger prevalence of research organizations assuming the role of coordinators, in contrast to H2020 where a more diverse mix, including private for-profit entities, takes the lead. Interestingly, a distinctive pattern emerges in the geographic dispersion of FP7 coordinators, particularly notable in the concentration within Noord-Holland

and Hovedstaden, each overseeing two projects. This localized clustering suggests the presence of specific strengths or focal areas of expertise in these regions during the

FP7.

Conversely, H2020 projects demonstrate a shift towards stronger industrial partnerships, as evidenced by a higher representation of private for-profit entities taking on coordinator roles. This shift signifies a move towards a more collaborative approach involving the active participation of commercial entities in driving research initiatives.

For the current study, one of the two community detection methods provided by Pajek, the Louvain method, was employed. The Louvain community detection algorithm is a modularity optimization method provided in Pajek. The clusters/groups are stored and executed by using partitions in Pajek. We use Chi-square and Cramer's V values to analyze the strength of the association between partition on communities and partition on topic description of projects.

that drive interactions and collaborations. By employing the Louvain method, I can optimize the modularity of the network, resulting in the identification of dense clusters that are highly connected internally but sparsely connected externally. This capability is crucial for analyzing the strength of associations between different network partitions and understanding how topics of projects relate to community structures. Furthermore, statistical measures like Chi-square and Cramer's V provide a quantitative assessment of these associations, validating the detected communities and offering insights into their significance.

Table 4-10: FP7 - Top10 Projects according to betweenness centrality

Project Acronym	**Topic Description**	**Coordinator's Name**	**Participant Type**	**Coodinators NUTS2 region**
CHEETAH	Integrated research programme in the field of photovoltaics	STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND	REC	Noord-Holland
S2BIOM	Support to the sustainable delivery of non-food biomass feedstock at local, regional and pan-European level	Fachagentur Nachwachsende Rohstoffe e.V.	Other	Mecklenburg - Vorpommern
ELECTRA	Integrated	RICERCA SUL SISTEMA	REC	Lombardia

	research programme on smart grids	ENERGETICO - RSE SPA		
IRPWIND	Integrated research programme in the field of wind energy	DANMARKS TEKNISKE UNIVERSITET	HES	Hovedstaden
STAGE-STE	Integrated Research Programme in the field of Concentrated Solar Power (CSP)	CENTRO DE INVESTIGACIONES ENERGETICAS, MEDIOAMBIENTALES Y TECNOLOGICAS-CIEMAT	REC	Comunidad de Madrid
INNWIND.EU	Innovative wind conversion systems (10-20MW) for offshore applications	DANMARKS TEKNISKE UNIVERSITET	HES	Hovedstaden
MACPLUS	Efficiency increases in existing and new build pulverised coal power plants with a view to CCS	CENTRO SVILUPPO MATERIALI SPA	PRC	Lazio
SECTOR	Development of new or improved sustainable bio-energy carriers	DBFZ DEUTSCHES BIOMASSEFORSCHUNGSZENTRUM GEMEINNUETZIGE GMBH	REC	Leipzig
ORECCA	Coordination action on off-shore renewable energy conversion platforms	FRAUNHOFER-GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V	REC	Oberbayern
EUROBIOREF	Sustainable Biorefineries	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	REC	Ile-de-France

Source: Author's calculations based on CORDIS data.

Table 4-11: H2020 - Top10 Projects according to betweenness centrality

Project Acronym	**Topic Description**	**Coordinator's Name**	**Part. Type**	**Coodinators NUTS2 region**
LEAP-RE	Long Term EU-Africa Partnership for Research and Innovation actions in the area of renewable energy	LGI SUSTAINABLE INNOVATION	PRC	Ile-de-France
INSHIP	European Common Research and Innovation Agendas (ECRIAs) in support of the implementation of the SET Action Plan	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	Oberbayern
	Support to R&I	ZABALA INNOVATION	PRC	Comunidad

IntEnSys4EU	strategy for smart grid and storage	CONSULTING SA		Foral de Navarra
ODYSSEE-MURE1	Enhancing the capacity of public authorities to plan and implement sustainable energy policies and measures	AGENCE DE L'ENVIRONNEMENT ET DE LA MAITRISE DE L'ENERGIE	Public bodies	Pays de la Loire
ODYSSEE-MURE2	Supporting public authorities to implement the Energy Union	AGENCE DE L'ENVIRONNEMENT ET DE LA MAITRISE DE L'ENERGIE	Public bodies	Pays de la Loire
RESPONSE	Smart Cities and Communities	EIFER EUROPAISCHES INSTITUT FUR ENERGIEFORSCHUNG EDF KIT EWIV	REC	Karlsruhe
ARV	Building and renovating in an energy and resource efficient way	NORGES TEKNISK-NATURVITENSKAPELIGE UNIVERSITET NTNU	HES	Trøndelag
OneNet	TSO – DSO – Consumer: Large-scale demonstrations of innovative grid services through demand response, storage and small-scale (RES) generation	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	Oberbayern
OSMOSE	Demonstration of system integration with smart transmission grid and storage technologies with increasing share of renewables	RTE RESEAU DE TRANSPORT D'ELECTRICITE	PRC	Ile-de-France

Source: Author's calculations based on CORDIS data.

Table 4-12: FP7 - Top10 Projects according to closeness centrality

Project Acronym	**Topic Description**	**Coordinator's Name**	**Participant Type**	**Coodinators NUTS2 region**
CHEETAH,	Integrated research programme in the field of photovoltaics	STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND	REC	Noord-Holland
ELECTRA	Integrated research programme on smart grids	RICERCA SUL SISTEMA ENERGETICO - RSE SPA	REC	Lombardia
IRPWIND	Integrated research programme in the field of wind energy	DANMARKS TEKNISKE UNIVERSITET	HES	Hovedstaden
STAGE-STE	Integrated Research Programme in the field of Concentrated Solar Power (CSP)	CENTRO DE INVESTIGACIONES ENERGETICAS, MEDIOAMBIENTALES Y TECNOLOGICAS-	REC	Comunidad de Madrid

		CIEMAT		
INNWIND.EU	Innovative wind conversion systems (10-20MW) for offshore applications	DANMARKS TEKNISKE UNIVERSITET	HES	Hovedstaden
MACPLUS	Efficiency increases in existing and new build pulverised coal power plants with a view to CCS	CENTRO SVILUPPO MATERIALI SPA	PRC	Lazio
AVATAR	Advanced aerodynamic modelling, design and testing for large rotor blades	STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND	REC	Noord-Holland
ORECCA	Coordination action on off-shore renewable energy conversion platforms	FRAUNHOFER-GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V	REC	Oberbayern
EERA-DTOC	Development of design tools for Offshore Wind farm clusters	DANMARKS TEKNISKE UNIVERSITET	HES	Hovedstaden
COTEVOS	Enhanced interoperability and conformance testing methods and tools for interaction between grid infrastructure and electric vehicles	FUNDACION TECNALIA RESEARCH & INNOVATION	REC	País Vasco

Source: Author's calculations based on CORDIS data.

Table 4-13: H2020 - Top10 Projects according to closeness centrality

Project Acronym	**Topic Description**	**Coordinator's Name**	**Participant Type**	**Coodinators NUTS2 region**
INSHIP	European Common Research and Innovation Agendas (ECRIAs) in support of the implementation of the SET Action Plan	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	Oberbayern
IntEnSys4EU	Support to R&I strategy for smart grid and storage	ZABALA INNOVATION CONSULTING SA	PRC	Comunidad Foral de Navarra
LEAP-RE	Long Term EU-Africa Partnership for Research and Innovation actions in the area of renewable energy	LGI SUSTAINABLE INNOVATION	PRC	Ile-de-France
Open ENTRANCE	Modelling in support to the transition to a Low-Carbon Energy System in Europe	SINTEF ENERGI AS	REC	Trøndelag
ODYSSEE-MURE2	Supporting public authorities to implement	AGENCE DE L'ENVIRONNEMENT	Public bodies	Pays de la Loire

	the Energy Union	ET DE LA MAITRISE DE L'ENERGIE		
NewSOC	New materials, architectures and manufacturing processes for Solid Oxide Cells	DANMARKS TEKNISKE UNIVERSITET	HES	Hovedstaden
EU-SysFlex	Demonstration of system integration with smart transmission grid and storage technologies with increasing share of renewables	EIRGRID PLC	PRC	Eastern and Midland
POCITYF	Smart Cities and Communities	LABELEC ESTUDOS DESENVOLVIMENTO E ACTIVIDADES LABORATORIAIS SA	PRC	Área Metropolitana de Lisboa
ODYSSEE-MURE1	Enhancing the capacity of public authorities to plan and implement sustainable energy policies and measures	AGENCE DE L'ENVIRONNEMENT ET DE LA MAITRISE DE L'ENERGIE	Public bodies	Pays de la Loire
OneNet	TSO – DSO – Consumer: Large-scale demonstrations of innovative grid services through demand response, storage and small-scale (RES) generation	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV	REC	Oberbayern

Source: Author's calculations based on CORDIS data.

4.2.2 Econometric analysis of the determinants of patents originating from the energy-related projects in FP7 and H2020 programmes

Community detection allows for the identification of naturally occurring groups within a network, which is essential for understanding the underlying patterns and dynamics Through pairwise comparisons of partitions, I can ensure the reliability and consistency of the community detection outcomes. Ultimately, integrating community detection into my research not only enhances the depth and robustness of my findings but also provides practical implications for understanding innovation ecosystems and collaborative networks. It allows me to identify key players, understand the flow of information, and assess the impact of collaborative efforts, thereby contributing significantly to the field of social network analysis and innovation studies.

In order to compare different clusters gained from the dissimilarity scores, a pairwise comparison between partitions is conducted by using the “Partitions>Info>Cramer’s

V, Rajski" command in Pajek. Community detection analysis is used to detect and define if any natural community is present in the network. A value larger than 0.60 indicates a strong association, with a range from 0 to 1. According to Cramer's V measure, there is a strong association between the two classifications in FP7 but there is no association in H2020. According to Rajski's measure, the topics of projects can be predicted quite well from the communities partition. In fact, high modularity results in compact groups within the network that are highly connected within the group but loosely connected between groups. All these results show that information flow was unified around one big group, indicating a cohesive structure within the network. Table 4.15 gives the results for the FP7 and H2020.

Table 4-14: ChiSquare, CramersV,_ and Rajski Results based on communities and regions in FP7 and H2020

FP7	**H2020**
Chi-Square: 2429.66897367 Cramer's V: 0.80385854 --- Rajski(C1 <-> C2): 0.26253840 Rajski(C1 -> C2): 0.74717831 Rajski(C1 <- C2): 0.28813478 --- Adjusted Rand Index: 0.00603974	Chi-Square: 15990.20213600 Cramer's V: 0.18815817 --- Rajski(C1 <-> C2): 0.20010010 Rajski(C1 -> C2): 0.38610849 Rajski(C1 <- C2): 0.29346572 --- Adjusted Rand Index: -0.05130878

The results from social network analysis unveil a compelling link between the collaborative structures within energy projects and their tangible outcomes in the form of patents in many studies. Researchers often use a mix of social network analysis and regression analysis to understand the dynamics of innovation ecosystems, identify key players, and explore the factors influencing patenting behavior within social networks. The presence of patents not only signifies successful knowledge transfer mechanisms and collaborative efforts but also serves as a tangible metric for assessing the overall impact of energy projects. It underscores the practical applicability of the developed technologies and their potential for commercialization.

For instance, in innovation networks to investigate the relationship between the centrality of organizations in a collaborative innovation network and their patenting activity, SNA centrality metrics (e.g., degree centrality, betweenness centrality) of

organizations in a patent citation network are used. It is found that organizations with higher centrality scores are more likely to be prolific patent holders, suggesting that their position in the innovation network is correlated with the innovation output.

Other studies reveal that researchers with higher centrality in collaboration networks tend to produce more patents, and their patents may have a broader impact, highlighting the importance of social networks in innovation. In addition, firms with higher centrality metrics in collaborative networks tend to generate more patents, and this patent output contributes to improved firm performance.

In our regression analysis, the dependent variable measures the number of patents associated with each project. Project-specific explanatory variables are as follows: number of scientific publications originating from a given project, number of participants, betweenness centrality, the duration of the project, a binary variable indicating the the presence of a hub, presense in core cluster and EU financial contribution. Table 4.15 provide estimation results for energy projects in FP7 and H2020, respectively.

Table 4-15: Results of estimations of number of patents in FP7 and H2020

Outcome		
Ind.Variables	**Number of Patents (FP7)**	**Number of Patents (H2020)**
Number of Publications	0.0415 (0.0050)***	-0.0018 (0.0028)
Betweenness Centrality	32.5745 (17.3708)*	-68.9940 (26.1823)***
Hub or Not	-1.4648 (0.5527)***	0.3566 (0.3946)
Funding sheme	-0.0897 (0.0688)	
ecMaxContribution	0.0000 (0.0000)*	8.93e-08 (3.01e-08)**
Core cluster	-0.0096 (0.0057)*	-0.0002 (0.0002)
_const	0.3587 (0.3113)	0.5693 (0.2350)**
No. of obs.	374	649
R^2	0.21	0.17

In FP7, the analysis of factors influencing patent variable in various projects reveals that the number of publications is a highly significant predictor of patent output, with more publications leading to more patents ($p < 0.001$). Being a hub, however,

negatively impacts patent production, indicating that hubs might prioritize coordination over direct innovation ($p < 0.01$). Betweenness centrality shows a marginally positive effect on patent numbers, suggesting that projects with strategic positions in the network might facilitate patenting, though this effect is less robust ($p < 0.1$). Overall, research output and network positioning significantly influence patent generation, while the role of hubs suggests a different strategic focus within innovation networks. In H2020, the significant positive effect of EC Max Contribution indicates that funding is crucial for patent production. The interaction between betweenness and duration suggests that projects with central roles and specific durations have nuanced impacts on patent outcomes. Despite these findings, the model still fails to capture the majority of variance in patent numbers, indicating that additional factors or non-linear relationships might need further exploration.

4.3 Participant-based analysis of energy networks in FP7 and H2020 programmes

SNA provides powerful methodologies for discovering and visualizing the relationships between actors. SNA has been used from two perspectives in this part of our thesis: (i) to evaluate the characteristics of the investigated networks and (ii) to analyze the roles of individual nodes within the network, considering them as active components of the system.

We computed indicators of projetcs' liaison brokerage roles[22] according to participant type and NUTS2 regions clusters in order to uncover which participants are crucial when it comes to connect different regions. This facilitates the assessment of the evolution of a participant's role between the two periods – i.e. FP7 (2007–2013) and H2020 (2014–2020) - and its relation to the change in the network performance.

The following participants' network graphs are drawn by transforming the network to 1-mode participant network; line values lower than 2 are removed. To obtain the final diagram, the size of the network is reduced by removing isolates which have component size of 1. It is important to understand which participants occupy central

[22] See "structural holes and brokerages roles" part in section 2.1.

positions in the network. Figure 4.3 and Figure 4.4 show that the core of the networks is mainly composed of research centers and higher education institutions.

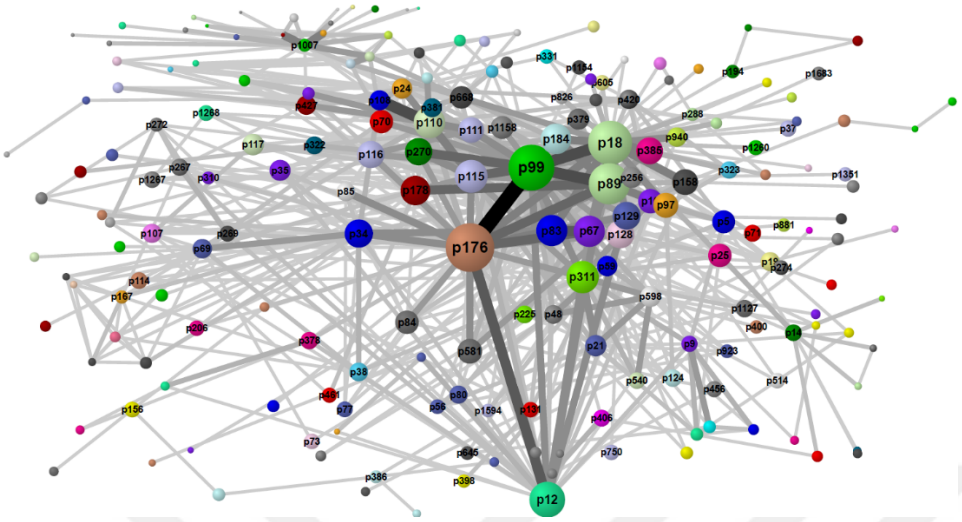


Figure 4.3: 1-mode Participant Network Diagram in FP7 energy projects

(**Nodes**: Participants of projects; **Tie:** There is a tie between participants if they participate in the same project; **Size of nodes**: Degree centrality of nodes; **Color of nodes**: Nodes have the same color if they are in the same NUTs2 region)

Table 4.18 and Table 4.19 present Top10 participants in Liaison Role according to NUTS2 regions and participant type clusters in FP7 and H2020, respectively. Most research centers have been identified in this role in both programs; universities are also included in the Top10 lists. Participant part176 (Frauhhofer) seems to be the most important according to several criteria in FP7. There is only one private sector participant in the Top10 lists for the liaison role in H2020 which is Rina Consulting.

Table 4-16:Top10 Participants in Liaison Role in FP7

Participant Number	**Participant Name**
part176	FRAUNHOFER-GESELLSCHAFT ZUR FOERDERUNG DER ANGEWANDTEN FORSCHUNG E.V
part12	FUNDACION TECNALIA RESEARCH & INNOVATION
part99	DANMARKS TEKNISKE UNIVERSITET
part89	STICHTING ENERGIEONDERZOEK CENTRUM NEDERLAND
part34	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE
part311	RICERCA SUL SISTEMA ENERGETICO - RSE SPA
part18	TEKNOLOGIAN TUTKIMUSKESKUS VTT

part178	IMPERIAL COLLEGE OF SCIENCE, TECHNOLOGY AND MEDICINE
part83	COMMISSARIAT ENERGIE ATOMIQUE CEA
part184	KENTRO ANANEOSIMON PIGON KE EXIKONOMISIS ENERGEIAS
part110	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK - TNO

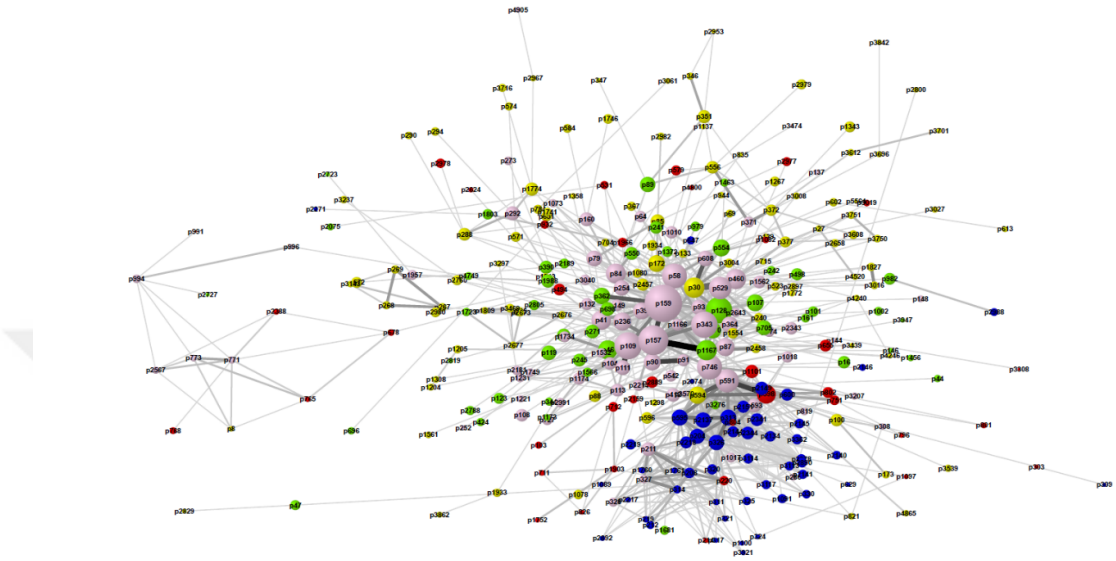


Figure 4.4: 1-mode Participant Network Diagram in H2020 energy projects

Nodes: Participants of projects; **Tie:** There is a tie between participants if they participate in the same project; **Size of nodes**: Degree centrality of nodes; **Color of nodes**: Nodes have the same color if they have the same participant type)

Table 4.19: Top10 Participants in Liaison Role in H2020

Participant Number	**Participant Name**
part159	FRAUNHOFER GESELLSCHAFT ZUR FORDERUNG DER ANGEWANDTEN FORSCHUNG EV
part109	NEDERLANDSE ORGANISATIE VOOR TOEGEPAST NATUURWETENSCHAPPELIJK ONDERZOEK TNO
part58	FUNDACION TECNALIA RESEARCH & INNOVATION
part529	ETHNIKO KENTRO EREVNAS KAI TECHNOLOGIKIS ANAPTYXIS
part343	TEKNOLOGIAN TUTKIMUSKESKUS VTT OY
part157	COMMISSARIAT A L ENERGIE ATOMIQUE ET AUX ENERGIES ALTERNATIVES
part30	RINA CONSULTING SPA
part128	DANMARKS TEKNISKE UNIVERSITET
part460	FUNDACION CIRCE CENTRO DE INVESTIGACION DE RECURSOS Y CONSUMOS ENERGETICOS
part554	AALBORG UNIVERSITET

Tables 4.20 and 4.21 indicate that the degree centrality of research organizations (REC) and higher education institutions (HES) in both programs are similar, while degree centrality of public bodies (PUB) in the FP7 is significantly larger than in H2020. As shown in Tables 4.20 and 4.21, research organizations are the hubs of both networks. They present significantly higher centrality measures compared to other types of participants in both programs.

The centrality measures of private sector (PRC) have decreased over time. Participants from private sector have been less central in the H2020 network compared to other group of participants. According to our findings, there is significant increase in average funding, but findings show that there is little change in the ranking between participant types.

Table 4-17: FP7 -Degree and Betweenness Centralities & Average Funding of Participant Types

Participant Type	Degree Centrality	Betweenness Centrality	Numbre of Participants	Average Funding (€)
REC	0.259	0.082	292	305 919
HES	0.236	0.131	358	279 712
PRC	0.090	0.138	1101	228 119
PUB	0.251	0.113	140	148 948
OTH	0.035	0.008	399	158 710

Source: Author's calculations based on CORDIS data. Note: REC = research organizations, PUB = public bodies, PRC = private sector, HES = higher education institutions, OTH = other participants

Table 4-18: H2020 -Degree and Betweenness Centralities & Average Funding of Participant Types

Participant Type	Degree Centrality	Betweenness Centrality	number of Participants	Average Funding
REC	0.209	0.134	501	423 324
HES	0.205	0.088	501	364 841
PRC	0.055	0.107	2270	372 907
PUB	0.140	0.136	277	322 902
OTH	0.045	0.031	387	214 470

Source: Author's calculations based on CORDIS data. Note: REC = research organizations, PUB = public bodies, PRC = private sector, HES = higher education institutions, OTH = other participants.

4.4 Conclusions for chapter 4

In this chapter, the research findings related to the SNA have been presented and analyzed. The results presented are derived from the social networks constructed by using different SNA metrics and methods. Overall, SNA results included centralization values of the networks, brokerage role detections to find which participants are crucial to connect different regions and community detection analysis findings.

Despite concerted efforts to integrate marginal actors, our study indicates that peripheral regions exhibit lower rates of collaboration in H2020, attributed to extensive SME involvement. The observed high clustering coefficient underscores the presence of closed triangles, limiting interaction with other groups. Consequently, bridges become pivotal in facilitating knowledge transfer. Notably, NUTS2 regions in H2020 demonstrate Small World characteristics, indicating that knowledge creation and diffusion are more streamlined due to the presence of hubs. The high clustering coefficient suggests that NUTS2 regions group together in densely connected clusters, making it less likely to easily reach other nodes. Furthermore, the closeness centralization in FP7 indicates fewer steps required to reach all others. Although existing studies did not generally address the comparison of energy projects in FP7 and H2020 since they examined the networks at the country level, it can be deduced from their network analyses that the findings presented in our thesis are in line with the previous work.

For example, Calvo-Gallardo et al. (2021) determined the SNA metrics for the FP7 Energy domain projects. This is one of the very few studies where the research questions are close to those investigated in our thesis. It is therefore important to compare some of our results with those presented in this study, especially the various centrality rankings of the participants such as degree, closeness, eigenvalue and betweenness centralities and ranked the Top20 participants. Their results show that the same participants generally appear on all the four lists, albeit with slightly different rankings (see their Table 12 in Calvo-Gallardo et al. (2021). The ranking of the Fraunhofer Gesellschaft at the top of the four lists is particularly striking. Because of the proximity of the rankings for all four centralities, we only compared

our degree centrality results with those of Calvo-Gallardo et al. (2021) (see our Table 3-4 in Chapter 3). We should note here that there are some differences between the data sets we used for SNA computations and the ones used in Calvo-Gallardo et al. (2021). We used the entire FP7 Energy projects dataset from the CORDIS base, whereas Calvo-Gallardo et al. (2021) used the same base without the projects under the Coordination and Support Action (CSA) type calls. Therefore, our database contains 376 projects, 2347 participants and 4536 project participations - since of the participants' multiple participations to more than one project. The corresponding numbers for Calvo-Gallardo et al. (2021) are respectively 311, 2061 and 3816. There is therefore about 17% projects less than ours in Calvo-Gallardo et al. (2021). Despite this difference, our Table 3-4 shows that in the Top20 ranking for degree centrality, 19 participants are both in the Calvo-Gallardo et al. (2021) list and in our list, with some ranking changes. But the four first highest ranks are occupied by the same participants. Only the 20th rank is occupied by two different UK universities.

The Top20 degree centrality values calculated in Calvo-Gallardo et al. (2021) and in our study are also close to each other, ranging between 523 and 200 in our case and between 719 and 231 for Calvo-Gallardo et al. (2021). This comparison confirms therefore, first, the validity of our calculations and, second, the solidity of such rankings (Asli and Gökalp, 2023b).

We can also add that Calvo- Gallardo et al. (2021) obtained similar cohesion metrics which presents networks with a low density and a high level of clustering. This effect may occur because research consortia are repeatedly established with the same partners, who form a core within the network, consisting mainly of by project coordinators and research organizations in the Energy Theme.

Our examination of the energy projects data in FP7 and H2020 focused on the structure of research networks at the NUTS2 level within the energy theme. A meticulous exploration of FP7 and H2020 Energy projects was conducted to gain insights into the progression of the energy Research, Development, Innovation (RDI) ecosystem. Our investigation leads to identify optimal collaboration levels by considering diverse participant types and their interregional collaboration patterns.

CHAPTER 5

CONCLUSION

This thesis aimed to analyze the structure and dynamics of a sub-domain of the European Commission Framework Programmes. The sub-domain we selected concerns the energy area. Our main motivation to focus specifically on the energy programs of FPs is due to the critical importance of the energy sector, its connections to global environmental issues, and its sensitivity to regional and geopolitical conditions. Another motivation is the uniform nature of the EU FP approach to innovation. We addressed these issues through detailed quantitative and descriptive analyses, aiming to contribute to the broader field of innovation studies.

Our analysis covers the evolution of collaboration networks through examination of statistics on patents and publications, and average funding changes of projects between FP7 and H2020. This thesis provides comprehensive comparisons with prior works and focuses on the collaboration patterns within the energy theme at the European regional level. To this end, our thesis utilizes various SNA metrics and methods to construct social networks composed of the energy projects funded by FP7 and H2020 and their participant institutions. These metrics include centralization values, brokerage role detections, and network analysis. The findings regarding NUTS2 regional distributions for energy projects and participants in FP7 and H2020 provide a comprehensive assessment of regional innovation system’s dynamics. The analysis of the energy sector's RDI dynamics under the EU energy-related FPs is expected to make valuable contribution in providing insights into innovation dynamics in other sectors as well.

As discussed in Chapter 2, the FPs for Research and Technological Development have served as the primary funding instrument for the EU's research and development policy since their initiation in the early 1980s. Previous studies employing SNA within the context of FPs, especially for Horizon 2020, are examined in the last section of this

chapter. These studies highlight the formation of collaborative research networks, their role in establishing the European Research Area, the presence of network characteristics like scale-free and small-world structures, and the identification of hubs and gatekeepers. Notably, network centrality emerges as a crucial factor influencing participation and funding approvals in EU research initiatives. Public organizations and universities often act as gatekeepers, underscoring the significance of their role in collaborative networks. These findings establish the groundwork for the research in Chapter 4 to examine the structure, dynamics, and impact of collaborative research networks.

Chapter 3 describes the data sources and methodologies we used for the descriptive statistical analysis and for the implementation of SNA methodology. Moreover, we reported some preliminary results therein. This chapter describes the global characteristics of FP7 and H2020 energy project structures, introduces SNA tools as well as the regression analysis elements to be used in Chapter 4.

The empirical analysis of chapter 4 aims to identify and explore collaboration networks in the energy domain by using SNA as the analytical framework. The unit of analysis and relational links are defined, and network metrics are used in order to classify actors based on their positions in the network. NUTS2 regions and projects are analyzed by using several centrality measures to identify top performers. Liaison roles of participants are investigated to observe which participants are crucial to connect different regions. The graphical visualization tools further illustrate collaboration patterns. A comparative analysis between FP7 and H2020 energy projects is conducted to discern their evolution and assess if structural and performance dynamics align with the EU Commission's expectations for RDI evolution in the energy sector. To this end, together with SNA findings, a regression analysis is conducted to assess which variables explain the patenting behavior of the projects in the two programmes.

This conclusion chapter is organized as follows: Section 5.1 presents overall findings of the preliminary analysis in Chapter 3 and SNA results in Chapter 4. In Section 5.2 we discuss the RDI policy implications of the overall research and some policy tools

to improve the network performances of future FPs. Section 5.3 presents the limitations of the research; and finally, discusses some directions for further research.

5.1 Overall Findings

The main objective of this study was to develop and implement a methodological framework for assessing the characteristics and effectiveness of energy projects networks formed in FP7 and H2020 in supporting the competitiveness of the European Research Area (ERA).

We used SNA tools and information available in the European Commission CORDIS databases to examine the characteristics and performances of the projects that has been funded during 2007–2013 in FP7 and 2014-2020 in H2020 in the energy field. For all organizations involved in these collaborative projects, we also collected data on the NUTS2 European regions to perform a regional analysis.

Using this information, the study has undertaken three types of analyses as explained below.

First, the projects are examined quantitatively in terms of various statistical indicators such as

- the number of participants in projects and the financial contribution received from the European Commission, the participation and coordination frequencies of the participants and their dynamics between the FP7 and H2020 programs, the patenting and publication patterns of the participants and the projects.

- a difference in patenting behavior between FP7 and H2020 is detected and the need for a regression analysis is highlighted, which is performed in chapter 4.

- one striking observation is a fourfold fall in the proportion of patenting projects in H2020 compared to FP7, suggesting lower patenting dynamics despite the H2020 programme’s strong focus on innovation.

- a doubling in the publications per patent ratio, suggesting a decrease in patenting efficiency in H2020 compared to FP7, also supported by similar findings regarding the average cost of a unit patent, showing an increase from FP7 to H2020.

Second, we adopted the techniques and methods of SNA to conduct a systematic analysis of the structural properties of the investigated networks and of the positioning of European organisations in those networks. We analyzed the following features of the EU energy research networks funded under the FP7 and H2020 programs:

- the network positioning of the participants, projects and NUTS2 regions
- the identification of core organizations (hubs) and their effectiveness in creating and diffusing knowledge
- the identification of participant's liaison roles in connecting projects and regions
- the distribution of various centralities metrics of participants and projects and their positioning in funding gathering
- the collaboration patterns between central and peripheral regions

Third, we performed two distinct regression analyses using the patent data, SNA findings, and the performance of NUTS regions:

- the first regression model highlights the relationship between the total number of patents associated with the projects and SNA metrics, including, betweenness centralities, as well as whether a region serves as a hub or not.
- the second regression model, explores whether innovativeness

(measured by 'innovation-driven' participation) or energy demand/vulnerability (measured by 'challenge-driven' participation) influences varying levels of engagement within the context of energy programs.

- correlations between the eigenvector centrality of NUTS2 regions and factors such as regional innovation scoreboard group, GDP, heating and cooling degree days, human resources in science and technology, and maximum EC contribution are established.

- correlations between the patent number and factors such as the number of publications, closeness centrality, and whether an entity functions as a hub are established for FP7 and H2020 projects.

- regional characterization in terms of higher energy demand or vulnerability or by innovation driven is established.

5.2 Policy Implications

The policy implications are determined by formulating policy recommendations to solve the policy problems. For this purpose, the policy design model proposed is used. In this model, to address policy problems, policy recommendations are specified at three different levels: macro-, meso- and micro-levels based on three dimensions.

First of all, policy aim is specified as to improve the efficiency of support mechanisms within structural network change in FP7 & H2020. To achieve this aim, policy recommendations are developed within the context of increasing project participant diversity and creating a favorable environment for regions.

There are five policy recommendations: (i) collaborative networks, (ii) enhancing innovation of different support mechanisms (iii) eliminating regional disparities through FP methods (iv) enhancing diversity of participants through structural change induced by FP7 & H2020 and (v) rising the competitiveness of the European energy

sector through inclusive, sustainable frameworks. These policy recommendations are summarised at three levels including definitions, tools, and policy targets in Table 5.1.

Table 5.1: Policy Implications to Improve the Efficiency of Support Mechanisms within Change through FP7 to H2020

Policy Problem: Increase project participant diversity and create a favorable environment for regions				
At	Policy Recommendations	Policy Description	Policy Tools	Responsible STI Actor
Micro Level	Enhancing diversity of participants through structural change induced by FP7 & H2020	Structural changes in FP7 & H2020 to increase participant diversity.	-Incentivize Private Sector Participation - Strengthen Broker Roles - Promote Inclusivity in Project Consortia - Support Capacity Building Enhance Information Dissemination	Participant Networks
Meso Level	Fostering collaborative networks	Promote collaboration among different projects and regions	-Incentivizing transnational collaborations by offering additional funding and support for projects that involve multiple countries. -Encouraging private sector participation by providing grants and tax incentives for industry-led research initiatives. -Supporting the establishment of collaborative platforms and networks to facilitate communication and partnership among diverse stakeholders. - Developing regional innovation hubs to centralize and amplify regional expertise. - Enhancing cross-border collaboration	Project and Regional Networks

			through funding incentives and collaborative platforms. - Encouraging participation from underrepresented regions to ensure a diverse and inclusive network.	
Meso Level	Eliminating regional disparities through FP methods	Use FP methods to reduce regional disparities.		Project and Regional Networks
Macro Level	Enhancing innovation of different support mechanisms	Improve and innovate support mechanisms to better serve participants.	-Development of Innovation Hubs and thematic innovation centers -Enhanced Collaboration Platforms -Capacity Building and Training Programs especially mentoship programs	EU Commision
Macro Level	Raising the competitiveness of the European energy sector through inclusive, sustainable frameworks	Develop frameworks to improve the competitiveness and sustainability of the European energy sector.	-Inclusive Policy Frameworks: Diverse Stakeholder Engagement and Equity-Based Funding Allocation for funding based on regional needs and disparities to ensure all regions have access to resources necessary for competitive development -Sustainable Investment Incentives and supporting	EU Commision

			sustainability Standards and Certification -Fostering Public Prive Partnershis to combine public funding with private sector expertise in developing sustainable energy solutions. -Launching campaigns to raise awareness about the benefits of sustainable energy and the importance of inclusivity in the energy sector.	

Micro-level

At the micro level, policy recommendations are developed for participant networks. This policy recommendation is aimed at enhancing diversity of participants through structural change induced by FP7 & H2020. The FP7 and H2020 programs recorded significant shifts in participant demographics. Universities and research institutions remained the most active participants, demonstrating substantial involvement across various projects. Notably, there was a 30% increase in participation from private companies in H2020 compared to FP7, reflecting a growing interest from the private sector in collaborative research initiatives. As for the role of key actors, several institutions and individuals emerged as significant brokers or liaisons within the network. For instance, the University of Cambridge played a pivotal role as a key broker, facilitating numerous collaborations across different regions and projects. These brokers were instrumental in connecting disparate network parts, ensuring smooth information flow and resource sharing.

Key actors in these programs included universities, national energy agencies, and large

multinational corporations. Universities were central to generating innovative ideas and conducting groundbreaking research. National energy agencies were vital in disseminating information, fostering innovation, and ensuring the alignment of projects with national and regional policies. Multinational corporations provided crucial resources and industry expertise, bridging the gap between academic research and market applications.

The diversity and connectivity of participants had a profound impact on network performance and innovation outcomes. Networks that included a diverse mix of universities, private companies, and government agencies demonstrated higher performance in terms of innovation output and project success rates. For example, networks with well-connected participants exhibited greater innovation outputs, evidenced by a higher number of patents and publications. Additionally, these networks reported higher project success rates, reflecting the effective collaboration and resource utilization among participants.

To enhance the diversity of participants through structural change in FP7 & H2020, the following policy tools can be implemented:

- **Incentivize Private Sector Participation**: Provide financial incentives and support mechanisms to encourage greater participation from private companies, thereby enriching the diversity of the network and fostering innovation through cross-sector collaborations.
- **Strengthen Broker Roles**: Identify and support key brokers or liaisons within the network. These brokers should be provided with resources and recognition to facilitate collaborations and connect different network parts effectively.
- **Promote Inclusivity in Project Consortia**: Encourage the formation of consortia that include a mix of universities, research institutions, private companies, and government agencies. This inclusivity ensures a wide range of expertise and perspectives, leading to more comprehensive and innovative solutions.
- **Support Capacity Building**: Implement training and capacity-building programs for less experienced participants, particularly from smaller

institutions or countries with lower participation rates. This support helps level the playing field and enables a more diverse range of participants to contribute effectively.

- **Enhance Information Dissemination**: Utilize national and regional agencies to disseminate information about funding opportunities, best practices, and successful project outcomes. This dissemination ensures that all potential participants are well-informed and can engage effectively.

Meso-level

At the meso level, policy recommendations are developed for projects and regional networks. Policy recommendations include fostering collaborative networks and eliminating regional disparities through FP methods. For the project networks, associated with FP7, the top 10 projects based on degree centrality accounted for 20% of the total network ties. In H2020, this figure increased to 25%, indicating a more concentrated network. The project 'EnergyNet' emerged as the most central in both FP7 and H2020, playing a crucial role in bridging different research areas in bridging different research areas. Projects with higher centrality were associated with a higher number of patents and publications, reinforcing the importance of strategic network positioning.

Collaboration patterns shifted from predominantly national partnerships in FP7 to more transnational collaborations in H2020, reflecting the EU's emphasis on cross-border cooperation. This shift towards more diverse and international collaborations has contributed to a richer exchange of knowledge and innovation.

There was an increase in project coordination by private sector entities in H2020 compared to FP7, indicating a shift towards industry-led innovation. This change highlights the growing role of industry in driving research and development within the EU framework programs.

Projects with higher centrality were associated with a higher number of patents and publications, reinforcing the importance of strategic network positioning. The concentrated network in H2020 facilitated more impactful and innovative project

outcomes, demonstrating the value of well-connected projects. In FP7, based on the regression analysis it is found that publications are strong predictor of patent output. However surprisingly, being a hub status has negative impact, implying suggesting coordination over innovation. Betweenness Centrality has a positive effect on patent numbers.

Therefore, to enhance collaboration networks among different projects and regions, the following policy tools are recommended:

- Incentivizing transnational collaborations by offering additional funding and support for projects that involve multiple countries.
- Encouraging private sector participation by providing grants and tax incentives for industry-led research initiatives.
- Supporting the establishment of collaborative platforms and networks to facilitate communication and partnership among diverse stakeholders.

At the meso level, for the regional networks to enhance collaborative networks, the

analysis revealed that 50 NUTS2 regions participated in FP7, with an average degree centrality of 0.35. In H2020, 55 regions were involved, with a slightly higher average degree centrality of 0.40. Regions in Western Europe, such as Île-de-France and Bavaria, exhibited high centrality, acting as major hubs in the network. Regions with higher centrality were found to produce more patents and publications, indicating a positive correlation between network position and innovation output. There was a noticeable increase in collaboration among Eastern European regions in H2020 compared to FP7, suggesting a growing inclusivity in the network.

Regions with higher centrality were found to produce more patents and publications, indicating a positive correlation between network position and innovation output. The network structures of these regions contributed significantly to innovation outcomes by facilitating knowledge transfer and collaboration among key players. Within the context of regression analysis of eigenvector centrality of NUTSs regions, in FP7 program significant predictors included RIS category, Heating/Cooling Degree Days, ecMaxContribution, and HRST. GDP is not found significant. ecMaxContribution and

HRST had positive impacts on centrality, while RIS and Heating/Cooling Degree Days had negative impacts. In H2020, RIS category, ecMaxContribution, and HRST are significant predictors, with GDP and Heating/Cooling Degree Days not being significant. After removing HRST, GDP and ecMaxContribution as the primary drivers of eigenvector centrality. So as an important conclusion, regions with higher energy demand or vulnerability in FP7 have lower eigenvector centrality in the network. In addition, there is a statistically meaningful inverse relationship between eigenvector centrality and regional innovation scoreboard category of the region. In FP7 policies were built to support basic science and technology, however our findings show that although a region is highly innovative but poor in energy demand surprisingly were absent in collaborations with powerful participants. For eliminating regional disparities through FP methods, policies should be developed to support the regions with higher energy demand.

There was a noticeable increase in collaboration among Eastern European regions in H2020 compared to FP7, suggesting a growing inclusivity in the network. This shift indicates a more balanced and diverse participation across different regions, enhancing the overall innovation potential of the network.

To promote collaboration networks among different regions, policies aimed at fostering regional hubs and bridging peripheral regions to central nodes could enhance overall network efficiency and innovation. These policies should focus on the following tools:

- Developing regional innovation hubs to centralize and amplify regional expertise.
- Enhancing cross-border collaboration through funding incentives and collaborative platforms.
- Encouraging participation from underrepresented regions to ensure a diverse and inclusive network.
- Create a fund dedicated to supporting projects from regions with lower centrality and fewer innovation outputs.
- Require projects to include partners from a mix of high and low centrality regions to qualify for funding.

- Launch initiatives that recognize and reward excellence in research and innovation in underrepresented regions, providing additional support and visibility.

Macro-level

At the macro level, policy recommendations are developed for the European Commission aimed at enhancing innovation of different support mechanisms and raising the competitiveness of the European energy sector through inclusive, sustainable frameworks.

The analysis of the European energy sector indicates a disparity in innovation levels across various regions and projects. Notably, regions with robust support mechanisms, such as substantial R&D funding and well-established collaboration networks, demonstrate significantly higher innovation outputs. Conversely, regions with insufficient support mechanisms lag in innovation, underlining the necessity for a more equitable distribution of resources. To enhance innovation, it is crucial to implement a suite of targeted support mechanisms that address these disparities.

One of the primary strategies to bolster innovation involves the establishment of targeted R&D grants. These grants should specifically focus on underrepresented regions and sectors within the energy field, directing resources to high-potential but underfunded areas. Complementing these grants, matching funds programs could be introduced, where public funds match private investments in energy innovation, thereby encouraging greater private sector involvement.

Additionally, the development of regional innovation hubs is essential. These hubs should provide resources, mentorship, and collaboration opportunities to energy innovators, particularly in regions with lower innovation outputs. Strategically placed hubs can help balance regional disparities. Thematic innovation centers, focusing on specific aspects of the energy sector such as renewable energy, energy storage, and smart grids, would further foster specialized innovation.

Enhanced collaboration platforms are also pivotal. Virtual collaboration platforms that facilitate communication and resource sharing between researchers, industry

stakeholders, and policymakers across Europe can significantly enhance collaborative efforts. These platforms should include comprehensive tools for project management, resource sharing, and networking. Moreover, providing incentives for cross-border collaborations can leverage diverse expertise and resources, fostering a more integrated and innovative energy sector.

Capacity building and training programs play a vital role in this context. Implementing training programs for researchers and innovators in underrepresented regions can build their capacity for high-impact research and development. Establishing mentorship networks that connect experienced innovators with newcomers can provide essential guidance and support, further nurturing the innovation ecosystem. Policy tools are summarised for enhancing Innovation through different support mechanisms stated below:

- Development of Innovation Hubs and thematic innovation centers
- Enhanced Collaboration Platforms
- Capacity Building and Training Programs especially mentorship programs

The competitiveness of the European energy sector is heavily influenced by regulatory frameworks, market access, and sustainability initiatives. Regions and projects that prioritize sustainability and inclusivity tend to exhibit more resilience and competitiveness. Therefore, inclusive and sustainable frameworks are critical for long-term success and competitiveness in the energy sector.

Developing inclusive policy frameworks that mandate the engagement of diverse stakeholders, including small and medium enterprises (SMEs), local communities, and marginalized groups, in energy projects and decision-making processes is fundamental. Additionally, an equity-based approach to funding allocation, ensuring that resources are distributed based on regional needs and disparities, can level the playing field and promote equitable development across all regions.

Sustainable investment incentives are another crucial element. Establishing green investment funds can provide financial support for sustainable energy projects, particularly those that employ renewable energy sources and innovative technologies.

Implementing sustainability standards and certification programs can encourage best practices in energy projects, enhancing their market competitiveness.

Regulatory and market reforms are necessary to streamline processes and facilitate innovation. Simplifying regulatory processes for energy projects can reduce barriers to entry, making it easier for new and innovative projects to get off the ground. Additionally, developing market access programs can help innovative energy solutions gain traction, supporting export initiatives and fostering international collaborations.

Investing in sustainable technology development through R&D tax incentives can stimulate private sector investment in sustainable energy innovations. Furthermore, fostering public-private partnerships (PPPs) can combine public funding with private sector expertise, driving the development of cutting-edge sustainable energy solutions.

Finally, education and awareness campaigns are essential to raise public awareness about the benefits of sustainable energy and the importance of inclusivity in the energy sector. Integrating sustainability and energy innovation topics into educational curricula can prepare the next generation of leaders in the energy sector, ensuring that they are equipped with the knowledge and skills needed to drive future innovations.

By implementing these comprehensive policy tools, the European Commission can significantly enhance innovation across different support mechanisms and raise the competitiveness of the European energy sector. An inclusive and sustainable approach will ensure that all regions and stakeholders benefit, fostering a resilient and forward-thinking energy sector that meets the needs of the future.

Policy tools are summarised for Raising the Competitiveness of the European Energy Sector through Inclusive, Sustainable Frameworks below:

- Inclusive Policy Frameworks: Diverse Stakeholder Engagement and Equity-Based Funding for allocating funding based on regional needs and disparities to ensure all regions have access to resources necessary for competitive development
- Sustainable Investment Incentives and supporting sustainability Standards and Certification

- Fostering Public Prive Partnershis to combine public funding with private sector expertise in developing sustainable energy solutions.
- Launching campaigns to raise awareness about the benefits of sustainable energy and the importance of inclusivity in the energy sector.

5.3 Limitations of this work and future research orientations

This study has a number of limitations. By its nature our study heavily depends on the reliability of the datasets we used. CORDIS data of the FP projects is strongly reliable, and we consider that no bias or error is introduced in our calculations originating from this essential part of our data inputs. However, we have some reservations about the reliability of the output data, such as those on the patents and publication statistics.

For the patents data we observed very high numbers of patents issued from very small projects, in terms of the number of participants and the financial contribution received from the European Commission. When we looked at the details of the patenting patterns of a sample of projects and participants, we observed that the total number of patents were highly inflated as the same initial patents were recounted several times, without any significant changes in its technological content but due its resubmission for extending its geographical validity range. A very detailed screening of the patents databases was outside of the scope of this thesis. Therefore, we used the raw patent databases; but it should be noted that the patent data of the FP7 and H2020 Energy projects is most probably highly inflated. If we remember that one of our conclusions was the lowering of the patenting efficiency of the energy projects in H2020, the non-accuracy of the patent data appears to potentially worsen this finding and increase the average cost of the patenting efficiency.

It is more difficult to appreciate the accuracy of the patent data we used for judging the efficiency of this output. To do this we need to perform a detailed analysis of the publication's sources included in the CORDIS database. For instance, we shall certainly obtain different publication numbers per project if we include only publications in Q1 and Q2 journals or if we exclude presentations in national conferences etc. To remedy this situation is outside of the scope of this thesis;

therefore, we used the publications data as it is. But, again as for the patents data, the proper evaluation of the publications output of the FP7 and H2020 energy related projects will most probably diminish the publication efficiency of the investigated FP programs.

These limitations of our work could be eliminated if dedicated investigations were performed for cleaning up the output datasets or at least if some critical analyses are provided to estimate the extent of the biases we suspect.

In a similar vein, one limitation for the proper analysis of the regional impact of FP7 and H2020 energy related programs and of the NUTS2 network analysis applied to them is due to the domination of these networks by large scale research institutions (RECs) whose general administrations are centralized and use the same administrative address even when the research is accomplished in one of the regional sub-units of this REC. It is obvious that this situation introduces an important bias in the ranking of NUTS2 regions. One of the best examples of this bias is the one introduced by the presence of the general administrative locations of the CNRS in Paris, boosting therefore the Région Ile de France at the top of the NUTS2 regions for energy programs both for FP7 and H2020 programs (Ertan, 2023b).

There are other limitations of our study not directly related to the statistical reliability of the datasets or to some research administration organizational issues (such the one related to the centralized nature of the RECs). We focused intentionally in this work on the energy related FP programs. This choice enabled us to conduct a detailed understanding of the structure of the projects and their networks in this sub-domain. However, to fully assess the generality or the peculiarity of this RDI sub-domain within the ERA, we need to perform some comparisons with other sub-domains. We were not able to perform this exercise because of the lack of comparable studies. Therefore, this lack of comparison with other sub-domains of the FP approach of the European Commission also limited the general character of our policy recommendations. We may also note that a temporal extension of this study to the beginning of the FP approach, i.e. to FP1 and onwards, could have permitted to perceive the dynamics of the construction of the ERA more clearly and fully appreciate

this journey of 40 years.

A final limitation of our work is related to the limited access we had to the experts in the energy domain having experience of FP projects to critically assess our findings. In the continuation of this research program, using the expertise and knowledge about energy-related issues we gained during this investigation, we intend to confront our findings with several European “stars” in the energy domain, especially the coordinators of high degree centrality projects, from various member states and belonging to various institution types.

In conclusion, this thesis explored a number of methods and approaches aimed at understanding in detail how FP type project networks in the energy domain are constructed: It also made use of the SNA framework for investigating collaboration networks. Therefore, we believe that this thesis has made an important contribution to science and technology policy research regarding FPs in the energy field and also opened up new perspectives about collaboration networks in these programs.

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APPENDICES

A. CURRICULUM VITAE

1. **Family name :** ERTAN
2. **First names :** ASLI
3. **Nationality :** Turkish
4. **Education :**

Institution[Date from - Date to]	Degree(s) or Diploma(s) obtained:
Middle East Technical University [2011-2023 expected]	Science and Technology Policy Studies – PhD Degree
Institut Mines-Télécom Business School [February 2018- June 2018]	ICT Business Management
University of Cologne [October 2017-December 2017]	Economics and Social Sciences
Middle East Technical University [2009-2011]	Science and Technology Policy Studies – Master's Degree
Bilkent University [2001-2007]	Computer Engineering - Bachelor Degree

5. **Language skills: Indicate competence on a scale of 1 to 5 (1 - excellent; 5 - basic)**

Language	Reading	Speaking	Writing
Turkish	Mother Tongue		
English	1	1	1

6. **Other skills:** (e.g. Computer literacy, etc.) Full computer literacy and excellent command of office equipment, Programming Tools such as SPSS, R-Project and SAS Enterprise Guide
7. **Present position:** Senior Associate
8. **Key qualifications:**

- Good written and oral communication skills, report-writing skills (in English)
- More than 7 years of working experience in research innovation and technology management, innovation systems
- Knowledge of developing questionnaires for quantitative and qualitative analysis.
- Experience in project management in the field of **EU Technical Assistance, Framework Programme, H2020** Projects
- Research on academic fields described in the below:
  - Master's project titled "The Determinants of Social Capital on Facebook": **Conducted online surveys using SurveyMonkey to target group and analysed the data with SPSS** to generate results to determine factors related with social capital.
  - PhD thesis titled "Social Network Analysis of Energy Projects in EU 7th Framework and their impacts on regional development": **Conducted data analysis on 7th FP and H2020 projects in the energy field by social network analysis and statistics with the tools Pajek and SPSS and suggest renewable energy policy for EU Commission.**

- Experienced project coordinator on the projects given in the below:
  -**IPA Projects:** TA Project for Conducting Chemical Safety Assessment under REACH Regulation and for Strengthening the Management Capacity of the DoEUFR -Ministry of Urban and Environment for the Second Implementation Period and Capacity Building for the End-Recipients"

- **METU Academic Policy Workshop** (Registrar's Office Admission Sub-Committee Member) Developed Strategic Plan for Registrar's Office Admissions (March-May 2011)
- **Strategic analysis of the innovation capacity of the ICT sector in Ankara**, worked on project's Reports, Documentation, Implementation Processes, Needs Assessment and prepared report for Ankara Development Agency (February-April 2011)
- **Kazan Defence and Aeronautical Cluster**, Conducted interviews for the participants of projects and Prepared Needs Assessment Report for Under secretariat for Defence Industries, 2012

9. Specific experience in the region:

Country	Date from – Date to
Turkey	2008-Present

10. Professional Experience

Date from - Date to	Location	Company	Position	Description
July 2022 – March 2023	Ankara/ Turkey remote	PwC Turkiye	**Senior Associate**	Responsible for the following activities: • Delivering consultancy services for EU funded calls (Horizon Europe, EUREKA, ERA-Nets, IraSME etc.) to large firms and SMEs ▪ Creating mappings for client's R&D expertise, following b2b meetings ▪ Building consortia and supporting proposal writing and submission stages • Applying as a coordinator to the Horizon Europe EIE and WIDERA calls • Organization workshops for EIT RIS Hub Turkiye and preparation interim reports • Preparation of motivation letter for TUBITAK 1515 program • Following application stages to IPA funds and preparation mapping of national funding system for Turkiye
September 2021- July 2022	Ankara/ Turkey	E-CO Consulting &Coaching	**Senior Consultant**	Responsible for the following activities: • Business development with high-tech start-ups. • Consulting on project applications of national fund programs such as TÜBİTAK, KOSGEB, Ministry of Commerce. • Taking part in the creation of project consortia (EU Technical Assistance Projects, Eurostars, etc.) • Supporting companies' market and competitor research • Organizing awareness, information days and trainings for open calls. • Ensuring up-to-date information flow by communicating with funding institutions, research centers and firms.
May 2021- September 2021	Ankara/ Turkey	ANKEY Consulting and Trade	**Project Manager**	Responsible for the following activities: • Building a merit based consortium that chooses proven experience over connections and be preparation for changes in the consortium. • Checking references and budget of all parties before joining consortium. • Providing management tools (e.g. guides, templates, etc.) for the consortium. • Preparing and monitoring all contractual obligations (Grant Agreement, Consortium Agreement and other legal reference documents) and draft additional agreements • Providing support in proposal writing for follow-up research initiatives • Following up the coordination and management of the EU project titled: **"Technical Assistance for Strengthening the Management Capacity of the DoEUFR -Ministry of Urban and Environment for the Second Implementation Period and Capacity Building for the End-Recipients" (EUROPEAID/139348/IH/SER/TR)**

				• Searching Key and Non-Key experts for the projects and evaluating their CV's regarding to selection criteria.
November 2019-March 2020	Ankara/ Turkey	KMO Information Systems and Consulting	**Project Coordinator**	Responsible for project administration and coordination in the project given below: **Technical Assistance Project for Conducting Chemical Safety Assessment under REACH Regulation (EuropeAid/139595/IH/SER/TR)** • Responsible for activities and objectives Stated in the Terms of Reference • Playing key role in managing relationships with beneficiary and international experts. • Preparing meeting minutes and steering committee presentations • Responsible for preparation of inception report. • Conducting online surveys, analysing results and preparing **training needs assessment report.** • Organizing opening seminar and training activities. • Translating all reports and training materials.
July 2018 – January 2019	Ankara/ Turkey	VL Media	**Data Analyst**	• Responsible for identifying firm's KPI's to monitor performance and quality control plans on daily, weekly and monthly basis. • Creative at analysing business problems to generate solutions by preparing reports and graphs. Skilled understanding of data analysis to interpret quantitative results by using tools such as Google Analytics, Firebase, Facebook Analytics and firm's in-house generated other applications. • Providing expertise in data cleansing and data storage structures for coming up with understandable documentation to present to the firm's managerial team.
October 2017-July 2018	Cologne/ Germany - Paris/ France	University of Cologne-Institut Mines-Télécom Business School	**Exchange Researcher**	In line with my dissertation, I have been in two different universities in Europe as an exchange researcher with Erasmus scholarship.
December 2010 – October 2017	Ankara/ Turkey	Middle East Technical University	**Research Assistant/ Researcher**	Experienced project coordinator on the projects given below: • **METU Academic Policy Workshop** (Registrar's Office Admission Sub-Committee Member) Developed Strategic Plan for Registrar's Office Admissions (March-May 2011) • **Strategic analysis of the innovation capacity of the ICT sector in Ankara (TEKPOL)**, Collected data from Start-ups in ICT sector based on techno parks for benchmarking innovation level, organized workshop for needs assessment and prepared final report for Ankara Development Agency (February-April 2011) • **Kazan Defence and Aeronautical Cluster (TEKPOL)**, Conducted interviews for the participants of projects and Prepared needs assessment and final report for Under secretariat for Defence Industries, (2011-2012) • **EU Sharing KnowledgE Assets: InteRregionally Cohesive NeigHborhoods (FP7-SSH-SSH-2010.2.2.1-266834)**, Prepared Working Paper

March 2008-January 2009	İstanbul/ Turkey	Yapı Kredi Pension Ltc.	**System Analyst/ Project coordinator**	• Prepared flow charts to demonstrate department's decision making processes. • Responsible for collaboration of projects between Information Technology department and company's other departments. • Responsible for project monitoring, testing, deployment. And troubleshooting before delivering to the third parties. • Prepared project implementation plan and final report. • Experienced in managing multiple projects with cross-functional teams and concurrent deadlines. • Created SQL queries to retrieve data needed for generating daily reports and monitoring.

11. Other relevant information

Certificates:

- Global Energy and Climate Policy (University of London through Coursera, 3 April 2023)
- Social Network Analysis (University of California, Davis through Coursera, 21 November 2022)
- Chris Freeman Centenary Lecture Series – Innovation Systems, (CRIS-IS.ORG, 7 January – 7 April 2021)
- Inclusive Leadership: The Power of Workplace Diversity (University of Colorado through Coursera, 27 April 2021)
- Microsoft 2793 Implementing and Maintaining Microsoft SQL Server 2005 (Bilge Adam Kurumsal, 16th July .2008)
- Personal and Institutional Communication Skills (Gelişim Atölyesi, 9th August 2008)
- Project Management and Contract Administration (Istanbul Technical University, Project Management Center, 23th August 2008)
- Information Technology Project Management (İstanbul Kurumsal Gelişim, 20th July 2008)
- Customer Relation Management (BIYMED Danışmanlık, 16th June 2008)
- Microsoft Report Builder (Bilge Adam Kurumsal, 9th May 2008)
- Requirement Management on IT Projects (Icon, 12th May 2008)

Trainings delivered:

Beneficiery	Topic	Description
Uludağ University TTO	Horizon Europe Applied Project Writing Training	Training was given for 2 days with more than 100 participants between 19-20 October 2021
Erciyes University	Horizon Europe Applied Project Writing Training	Training was given for 1 days with more than 50 participants on 22 October 2021

Conference Presentations:

- Ertan, Aslı (2021, August 25). *Social network analysis of publications from Turkey regarding infectious diseases.* Paper presented at 22nd RSEP International Economics, Finance & Business Conference, İstanbul, ONLINE/VIRTUAL.
- Ertan, Aslı (2021, August 25). *Hot topic analysis of foreground publications funded by TÜBİTAK between 2019 and 2020.* Paper presented at 22nd RSEP International Economics, Finance & Business Conference, İstanbul, ONLINE/VIRTUAL.
- Ertan, Aslı (2016, April 28-29). *Comparison between Social Network Analysis of 7th Framework*

Programmes on ICT and Energy Projects. Paper presented at 1st RSEP International Conference on Politics, Economics, Finance & Interdisciplinary Studies, Prague.

- Ertan, Aslı (2011, April 15). *Identity Construction in Social Networking Sites & Online Fantasy Role-Playing Games*. Paper Presented at International Conference on eBusiness and eGovernment, İzmir

Papers:

- Ertan, A. (2019). Social Network Analysis of European Union Energy Projects and their Impacts of on Regional Development. Review of Socio-Economic Perspectives RSEP, 10(January), 57–70. (ISSN: 2149-9276)
- Ertan, Aslı (2016, June). Comparison between Social Network Analysis of 7th Framework Programmes on ICT and Energy Projects. Review of Socio-Economic Perspectives, 1(1), 83-106. (ISSN: 3275792)
- Ertan, Asli and Tunç Medeni (2011, July). "Identity Construction in Social Networking Sites & Online Fantasy Role-Playing Games", International Journal of eBusiness and eGovernment Studies, Vol.3, No:2, http://www.sobiad.org/eJOURNALS/journal_IJEBEG/arhieves/2011_2/03asli_ertan.pdf

Book Chapters:

- Erden, Y., Durukan, C., Ertan, A. and Doğan, M. (Eds.), (2014), Ulusal İnovasyon Girişimi 2006- 2013 Dönemi Değerlendirme Raporu TÜSİAD-Sabancı Üniversitesi Rekabet Kurumu, İstanbul

Working Papers:

- Yalciner,U. G. Durukan, C. and Ertan, A. (2013) "Legal framework for intangible assets in Turkey", SEARCH Working Paper Series, WP5.26 https://ideas.repec.org/p/met/stpswp/1305.html
- Ertan, Aslı (2011). The Determinants of Social Capital on Facebook. Science and Technology Policies Research Center (TEKPOL) Working Paper Series, WP 11/08, 2011 http://stps.metu.edu.tr/sites/stps.metu.edu.tr/files/1108.pdf

B. TURKISH SUMMARY / TÜRKÇE ÖZET

Bu doktora tezi, Avrupa Birliği'nin 7. Çerçeve Programı (FP7) ve Ufuk 2020 (H2020) programlarında yürütülen enerji projelerinin sosyal ağ analizini (SNA) ele almaktadır. Tez, Avrupa Birliği'nin araştırma ve yenilik politikalarının enerji projelerine etkisini ve bu projelerdeki işbirliği ağlarının yapısını anlamayı amaçlamaktadır. Bu bağlamda, sosyal ağ analizinin temel kavramları, merkeziyetçilik ölçütleri ve ağ performansı gibi konular derinlemesine incelenmiştir.

Avrupa Birliği, enerji politikalarında yenilikçiliği teşvik etmek ve sürdürülebilir enerji çözümleri geliştirmek amacıyla FP7 ve H2020 programlarını hayata geçirmiştir. Bu programlar, enerji projelerinin finansmanını sağlayarak, yenilikçi araştırma ve geliştirme faaliyetlerinin desteklenmesini amaçlamaktadır. Tezin odak noktası, bu projelerdeki işbirliği ağlarının yapısını ve dinamiklerini analiz ederek, Avrupa Birliği'nin enerji politikalarına nasıl katkıda bulunduğunu ortaya koymaktır.

Araştırmanın Amacı ve Önemi

Bu araştırmanın temel amacı, FP7 ve H2020 programları kapsamında yürütülen enerji projelerindeki işbirliği ağlarının yapısını ve dinamiklerini analiz etmektir. Avrupa Komisyonu'nun beklentilerine uygun olarak bu projelerin bölgesel performanslarını değerlendirmek, yenilikçilik ve enerji talebi/vulnerabilite gibi faktörlerin ağ yapısına etkilerini ortaya koymak hedeflenmiştir. Araştırmanın sonuçları, politika yapıcılar için önemli çıkarımlar sunmakta ve gelecekteki araştırmalar için yeni perspektifler açmaktadır.

Enerji projelerinin başarısı, projelerde yer alan aktörlerin (üniversiteler, araştırma merkezleri, özel sektör ve kamu kurumları) işbirliği düzeyine ve ağ yapısına bağlıdır. Sosyal ağ analizi, bu işbirliklerinin nasıl oluştuğunu ve hangi aktörlerin ağın merkezinde yer aldığını belirlemek için kullanılır. Bu analiz, enerji projelerinin daha etkili ve yenilikçi olmasına katkı sağlayacak stratejilerin geliştirilmesine

yardımcı olur.

Araştırmanın önemi, AB'nin enerji politikalarının etkinliğini değerlendirmek ve bu politikaların iyileştirilmesi için öneriler sunmaktır. Özellikle, küçük ve orta ölçekli işletmelerin (KOBİ) projelere katılımının teşvik edilmesi, yenilikçi bölgelerin desteklenmesi ve enerji talebi yüksek olan bölgelerin daha fazla fon almasının sağlanması gibi öneriler, enerji projelerinin başarısını artırabilir.

Tezde belirtilen ana araştırma sorusu şudur:

- **FP politikalarında inovasyonun pazar boyutuna öncelik verilmesi, enerji projelerindeki ağ yapısını nasıl etkilemektedir?**

Bu araştırma sorusu, FP7 ve H2020 programları kapsamında finanse edilen enerji projelerinin işbirliği ağlarının nasıl evrildiğini ve bu değişikliklerin inovasyon sonuçlarına olan etkilerini incelemeyi amaçlamaktadır. Bu bağlamda, Sosyal Ağ Analizi (SNA) kullanılarak bu projelerdeki işbirliği ağlarının yapısal ve dinamik özellikleri analiz edilmiştir.

Bu araştırma sorusu, tezin temel hedefleriyle yakından ilişkilidir. Tez, FP7 ve H2020 programları altında finanse edilen enerji projelerinin sosyal ağ dinamiklerini ve bu projelerin Avrupa Birliği'nin enerji politikası hedeflerine katkısını incelemektedir. Bu bağlamda, araştırma sorusu, enerji projelerinin işbirliği ağlarının yapısını anlamak ve bu ağların inovasyon sonuçlarına olan etkilerini değerlendirmek için kritik öneme sahiptir. Araştırma, FP politikalarının pazar odaklı inovasyon stratejilerinin, enerji projelerinde işbirliği ağlarının nasıl şekillendiğini ve bu yapıların projelerin başarısına nasıl katkıda bulunduğunu ortaya koymayı amaçlamaktadır.

Bu analiz, Avrupa Birliği'nin enerji politikası hedeflerine ulaşmak için inovasyon politikalarının nasıl tasarlanması ve uygulanması gerektiğine dair önemli içgörüler sağlamayı hedeflemektedir. Ayrıca, bu çalışma, enerji projelerinin bölgesel inovasyon sistemleri üzerindeki etkilerini anlamak ve gelecekteki politika müdahaleleri için önerilerde bulunmak açısından da değerli katkılar sunmaktadır .

Yöntem ve Veri Kaynakları

Tezde kullanılan veri kaynakları, Avrupa Komisyonu'nun CORDIS veritabanından elde edilmiştir. FP7 ve H2020 programları kapsamında gerçekleştirilen enerji projelerine dair veriler toplanmış ve sosyal ağ analizi (SNA) yöntemleri kullanılarak değerlendirilmiştir. SNA, ağ yapısını anlamak için kullanılan merkeziyet, kümelenme katsayısı ve yoğunluk gibi ölçütler üzerinden yapılmıştır. Ayrıca, projelerin patentleme ve yayın performansları da incelenmiştir.

Veri toplama sürecinde, projelerde yer alan aktörler, bu aktörler arasındaki işbirliği ilişkileri ve projelerin çıktıları (patentler, yayınlar vb.) analiz edilmiştir. Bu veriler, projelerin yenilikçilik düzeyini ve ağ yapısını değerlendirmek için kullanılmıştır. Sosyal ağ analizi, bu verilerin görselleştirilmesi ve ağdaki önemli aktörlerin belirlenmesi için etkili bir yöntem sunar.

Ayrıca, tezde kullanılan verilerin güvenilirliği ve geçerliliği, çeşitli doğrulama yöntemleri ile sağlanmıştır. Verilerin analizinde, çeşitli istatistiksel yöntemler ve sosyal ağ analizi araçları kullanılmıştır. Bu araçlar, ağ yapısının ve projelerin performansının değerlendirilmesinde önemli bir rol oynamıştır.

Bulgular

Tezde elde edilen bulgular, FP7 ve H2020 programları kapsamında yürütülen enerji projelerinin ağ yapılarının önemli ölçüde farklılık gösterdiğini ortaya koymaktadır. H2020 programında daha fazla proje ve katılımcı bulunmasına rağmen, patent sayılarında önemli bir artış gözlemlenmemiştir. FP7 döneminde 173 patent alınmışken, H2020 döneminde bu sayı sadece 228'e yükselmiştir. Bu durum, H2020 programında projelerin daha çok sayıda olmasına rağmen, patentleme performansının artmadığını göstermektedir. Araştırmanın bulguları, FP7 ve H2020 programları kapsamında yürütülen projelerin ağ yapısında önemli değişiklikler olduğunu göstermektedir. H2020 programında daha fazla proje ve katılımcı bulunmasına rağmen, patent sayılarındaki artışın beklenenden az olması, projelerin yenilikçilik düzeyinin istenilen seviyede olmadığını göstermektedir. Ayrıca, projelerde yer alan aktörlerin dağılımı ve ağ yapısı, yenilikçilik ve işbirliği düzeylerini etkileyen önemli

faktörler olarak belirlenmiştir.

Ağ Yapısının Analizi

Sosyal ağ analizinin sonuçlarına göre, FP7 ve H2020 programlarında bölgesel ağ yapıları incelenmiştir. Yenilikçi bölgeler ağın merkezinde yer alırken, yüksek enerji talebi veya vulnerabiliteye sahip bölgeler ağın kenarlarında kalmaktadır. Ayrıca, üniversiteler ve kamu kuruluşlarının ağ yapısında önemli bir rol oynadığı ve genellikle ağın merkezinde konumlandıkları tespit edilmiştir.

Ağ yapısının analizi, projelerde yer alan aktörlerin işbirliği düzeylerini ve ağdaki merkezi aktörleri belirlemek için kullanılmıştır. Yenilikçi bölgeler, ağın merkezinde yer alarak projelerin başarısında önemli bir rol oynamaktadır. Bu bölgeler, yüksek yenilikçilik ve işbirliği düzeyleri ile öne çıkmaktadır. Ayrıca, üniversiteler ve kamu kuruluşları, ağın merkezi aktörleri olarak önemli bir rol oynamaktadır.

Politika Önerileri

Bu araştırmanın bulguları doğrultusunda, Avrupa Komisyonu'nun enerji projelerinde yenilikçiliği artırmak ve bölgesel eşitsizlikleri azaltmak için çeşitli politika önerileri sunulmuştur. Özellikle, küçük ve orta ölçekli işletmelerin (KOBİ) projelere daha aktif katılımının teşvik edilmesi, yenilikçi bölgelerin desteklenmesi ve enerji talebi yüksek olan bölgelerin daha fazla fon almasının sağlanması önerilmektedir.

Politika önerileri, enerji projelerinin daha etkili ve yenilikçi olmasını sağlamayı amaçlamaktadır. KOBİ'lerin projelere daha aktif katılımı, yenilikçi çözümlerin geliştirilmesine katkıda bulunabilir. Ayrıca, yenilikçi bölgelerin desteklenmesi ve enerji talebi yüksek olan bölgelerin daha fazla fon alması, projelerin başarısını artırabilir. Bu öneriler, enerji projelerinin daha verimli ve yenilikçi olmasını sağlamayı amaçlamaktadır.

Sonuç ve Gelecek Araştırmalar

Bu tez, FP7 ve H2020 programları kapsamında yürütülen enerji projelerinin sosyal ağ yapısını analiz ederek önemli katkılar sağlamaktadır. Araştırma bulguları, enerji

projelerindeki işbirliklerinin nasıl yapılandırıldığını ve bu yapıların yenilikçilik üzerindeki etkilerini ortaya koymaktadır. Gelecek araştırmalar için, diğer araştırma alanlarıyla karşılaştırmalı analizler yapılması ve daha uzun dönemli verilerin incelenmesi önerilmektedir.

Gelecek araştırmalar için, enerji projelerinin sosyal ağ yapısının daha detaylı analiz edilmesi ve diğer araştırma alanlarıyla karşılaştırılması önerilmektedir. Ayrıca, uzun dönemli verilerin incelenmesi, projelerin başarısında etkili olan faktörlerin belirlenmesine katkıda bulunabilir. Bu tür çalışmalar, enerji projelerinin daha etkili bir şekilde yönetilmesine ve yenilikçi çıktılar elde edilmesine katkı sağlayacaktır.

Tezin ikinci bölümünde literatür çalışması yapılmıştır ve Sosyal Ağ Analizi ve Önceki Çalışmalar incelenmiştir. İlk öncelikle Sosyal Ağ Analizi (SNA): Nedir, Neden Kullanılır ve Nasıl Gelişmiştir kısmı anlatılmıştır.

Sosyal ağ analizi (SNA), araştırma ve teknolojik değişim çalışmalarında, aktörler arasındaki ağların ortak araştırma hedeflerine ulaşmada önemli bir mekanizma olduğunu öne sürer (European Commission 2015, s.10). Aktörlerin ağı, aktörlerin pozisyonları ve aralarındaki ilişkilerle tanımlanan bir grafik olarak temsil edilebilir. Aktörler, insanlar, organizasyonlar veya bunların birimleri, teknolojiler, ürünler, bölgeler ve ülkeler olabilir. Aktörler arasındaki ilişkiler, bilgi, bilgi ve yenilikler de dahil olmak üzere kaynakların transferi için kanallar olarak kabul edilir. Ağlar, bu nedenle, çoklu ilişkileri olan aktörler ve desenleri içeren karmaşık yapılar olarak tanımlanır.

SNA, bir ağdaki üyeler arasındaki ilişkilerin desenlerini çözmek, yorumlamak ve yönlendirmek için kullanılan bir metodolojidir. Bu, (i) ilişkisel bağlantıların yoğunluğunu ve karmaşıklığını ortaya çıkarmak, (ii) ağ aktörlerini bilgiye erişim seviyelerine ve bilgi akışlarını kontrol etme düzeylerine göre sınıflandırmak ve (iii) bilgi üretimi ve yayılımı için fırsatları ve potansiyel tıkanıklıkları belirlemek için kullanılır (Muniz ve Cuervo 2018: 1135).

SNA'nın kökeni 1920'lerde Harvard'da başlayan çalışmalarla başlar ve graf teorisi formalizmini geliştiren matematikçilerle devam eder. Mayo (1945), küçük gruplarda

her kişinin yalnızca bir bağla bağlı olduğunu öne süren graf teorisini kullanmıştır. En eski ve en bilinen SNA, Milgram'ın küçük dünya kavramıdır (1967), bu kavramda her kişi doğrudan bağlantılı olmasa da, tanıdıklar zinciri ile birbirine bağlıdır. 1930'larda Moreno (1937), insanların farklı mesafelerde ve kiminle zaman geçirmeyi seçtiklerine dair çalışmalar yapmıştır. Freeman'a (2004) göre, Moreno'nun çalışmaları SNA'nın kalbini oluşturmuştur, bu çalışmalarda "psikolojik coğrafya" terimi, insanların ağlarındaki davranışlarını ve hareketlerini araştırmak için kullanılmıştır.

Graf teorisi formalizminin gelişimi 1940'larda sosyal antropologlara ve psikolojik çalışmalara yayılmıştır. 1970'lerde sosyologlar ağı, alanın gelişimini yönlendirmiştir ve 1990'lardan sonra Burt, Borgatti, Wellman, Cross ve Freeman gibi akademisyenlerden oluşan bir ağ, sosyal ağ metodolojisine katkıda bulunmuştur. Ayrıca, Manchester antropologları Barnes, Bott ve Nadel, 1950'lerde kabile ve köy toplumlarındaki topluluk ilişkilerinin yapısını araştırmıştır. John A. Barnes, 1954'te "Norveç Adası Cemaati'ndeki Sınıf ve Komiteler" adlı etkili çalışmasını yayınlayarak antropolojide sosyal ağ kavramını tanıtmıştır. Elizabeth Bott'un "Aile ve Sosyal Ağ" adlı temel çalışması 1957'de yayınlanmış ve kentsel İngiltere'deki aile yapıları ve sosyal ağlar arasındaki bağlantıları incelemiştir. S.F. Nadel'in "Sosyal Yapı Teorisi" adlı katkısı 1957'de yayınlanmış ve çeşitli toplumların, kabile ve köy bağlamlarında, sosyal yapılar ve ilişkiler teorisi üzerine odaklanmıştır. Wambeke ve diğerleri (2012), orijinal çalışmaların bireyler arasındaki sosyal ve politik ilişkilere büyük ölçüde dikkat çektiğini ve "sosyal ağ" teriminin 1950'lerin sonlarında, sınırlandırılmış grup sosyal kategorilerine odaklanan sosyal bilimciler tarafından türetildiğini tartışmışlardır. Freeman (2004), 1940 ile 1960 yılları arasındaki dönemi, sosyal ağ analizi gelişiminin karanlık çağı olarak adlandırmış ve "yapısal paradigmayı barındıran tanınmış bir sosyal araştırma yaklaşımının eksikliği" nedeniyle bu dönemi tanımlamıştır (Zhang 2010:9).

Graf teorisine dayanan ve matematiksel hesaplamaları mümkün kılan çağdaş SNA, 1960'larda başlamıştır. Freeman (2004), bu dönemi SNA'nın Rönesansı olarak adlandırmış ve bu dönemde Harvard akademisyenleri, geleneksel yaklaşımlarla birleştirerek teori oluşturma ve araştırmada katkıda bulunmuşlardır.

Literatür kısmında temel kavramlar açıklanmıştır. Özet olarak açıklanan kavramlar

aşağıda listelenmiştir ve araştırma konusuyla ilgileri belirtilmiştir.

Düğüm (Node), sosyal ağ analizinin temel birimidir ve ağdaki bireyler, organizasyonlar, bölgeler veya ülkeler gibi aktörleri temsil eder. Bir ağ, düğümler ve bu düğümler arasındaki bağlantılardan (kenar veya yay) oluşur. Sosyal ağlarda düğümler, çeşitli ilişki türleri aracılığıyla birbirine bağlıdır. Bu ilişkiler akrabalık, arkadaşlık, bilgi paylaşımı gibi farklı türlerde olabilir.

Düğüm kavramı, sosyal ağ analizi için kritik öneme sahiptir çünkü ağdaki her bir düğüm, ağın genel yapısının anlaşılmasında temel bir rol oynar. Düğüm tanımları ve bunların ağdaki rolü, tezdeki enerji projelerinin analizinde de büyük önem taşımaktadır. Örneğin, enerji projelerinde yer alan üniversiteler, araştırma merkezleri ve şirketler gibi çeşitli aktörler, düğüm olarak tanımlanır ve bu düğümlerin birbirleriyle olan ilişkileri, ağ yapısını ve performansını anlamamıza yardımcı olur.

Jeodezik mesafe (Geodesic Distance), iki düğüm arasındaki en kısa yolu ifade eder. Bu kavram, ağ analizi için kritik bir öneme sahiptir çünkü ağın yapısal özelliklerini ve düğümler arasındaki ilişki dinamiklerini anlamada temel bir rol oynar. Jeodezik mesafe, iki düğüm arasındaki bağlantıların en az sayıda olduğu yolu ifade eder ve bu mesafe, ağın genel bağlanırlık düzeyini ve düğümler arasındaki etkileşim yollarını değerlendirmede kullanılır.

Jeodezik mesafe, sosyal ağ analizinde **yakınlık merkeziyeti (closeness centrality)** ve **aracılık merkeziyeti (betweenness centrality)** gibi merkeziyet ölçümlerinin hesaplanmasında kullanılır. Yakınlık merkeziyeti, bir düğümün diğer düğümlere olan ortalama mesafesini ölçer ve bu düğümün ağdaki bilgi akışı üzerindeki potansiyel etkisini değerlendirir. Aracılık merkeziyeti ise bir düğümün diğer düğümler arasındaki en kısa yollarda ne kadar sıklıkla yer aldığını gösterir ve bu düğümün bilgi akışındaki kritik rolünü belirler.

Merkeziyet Kavramları

Merkeziyet kavramları, sosyal ağ analizinde düğümlerin ağ içindeki önemini ve etkisini değerlendirmek için kullanılır. Bu kavramlar, düğümlerin ağdaki konumlarını ve diğer düğümlerle olan ilişkilerini analiz etmek için çeşitli ölçütler sunar:

1. **Derece Merkeziyeti (Degree Centrality):**
    - Bir düğümün doğrudan bağlı olduğu diğer düğümlerin sayısını ifade eder.
    - Yüksek derece merkeziyetine sahip bir düğüm, ağda çok sayıda bağlantıya sahip olduğu anlamına gelir ve genellikle önemli bir bilgi dağıtıcısı veya toplayıcısı olarak kabul edilir.
2. **Yakınlık Merkeziyeti (Closeness Centrality):**
    - Bir düğümün diğer tüm düğümlere olan ortalama mesafesini ölçer.
    - Yüksek yakınlık merkeziyetine sahip bir düğüm, diğer düğümlere hızlı bir şekilde erişebilir ve ağdaki bilgi akışını etkin bir şekilde yönetebilir.
3. **Aracılık Merkeziyeti (Betweenness Centrality):**
    - Bir düğümün diğer düğümler arasındaki en kısa yollarda ne kadar sıklıkla yer aldığını gösterir.
    - Yüksek aracılık merkeziyetine sahip bir düğüm, ağdaki bilgi akışında kritik bir rol oynar ve bilgi geçiş noktası olarak önemli bir konuma sahiptir.
4. **Özvektör Merkeziyeti (Eigenvector Centrality):**
    - Bir düğümün önemini, bağlı olduğu diğer düğümlerin merkeziyet değerleri ile ilişkilendirir.
    - Yüksek özvektör merkeziyetine sahip bir düğüm, yüksek merkeziyete sahip diğer düğümlerle bağlantılıdır ve bu nedenle ağın genel yapısında önemli bir rol oynar.

Bu kavramlar, tezdeki enerji projelerinin sosyal ağ yapısını anlamada ve değerlendirmede kritik öneme sahiptir. Örneğin:

1. **Düğüm Analizi:**
    - FP7 ve H2020 programları kapsamında yer alan enerji projelerindeki çeşitli aktörler (üniversiteler, araştırma merkezleri, şirketler) düğüm olarak tanımlanır. Bu düğümlerin ağdaki konumları ve birbirleriyle olan ilişkileri, projelerin işbirliği düzeyini ve yenilikçilik kapasitelerini anlamamıza yardımcı olur.
    - Ağdaki düğümlerin merkeziyet ölçümleri (yakınlık, aracılık, derece

merkeziyeti) kullanılarak, hangi aktörlerin ağın merkezi konumlarında yer aldığı ve bu aktörlerin bilgi akışındaki rolleri belirlenir.

2. **Jeodezik Mesafe ve Merkeziyet Analizi:**
    - Enerji projeleri kapsamında yer alan düğümler arasındaki en kısa yollar (jeodezik mesafeler) hesaplanarak, ağdaki bilgi akışının verimliliği ve düğümler arasındaki etkileşim yolları değerlendirilir.
    - Yakınlık merkeziyeti ölçümleri, düğümlerin ağdaki diğer düğümlere olan ortalama mesafelerini belirler ve bu düğümlerin bilgi akışındaki bağımsızlık düzeyini değerlendirir.
    - Aracılık merkeziyeti ölçümleri, düğümlerin ağdaki en kısa yollarda ne kadar sıklıkla yer aldığını gösterir ve bu düğümlerin bilgi akışındaki kritik rollerini belirler.

Bu analizler, tezdeki enerji projelerinin sosyal ağ yapısının anlaşılmasına ve projelerdeki işbirliği düzeylerinin değerlendirilmesine önemli katkılar sağlar. Özellikle, merkezi düğümler olarak tanımlanan aktörlerin ağdaki bilgi akışındaki rolleri, projelerin yenilikçilik kapasiteleri ve başarı oranları üzerinde önemli etkiler yaratabilir. Bu nedenle, düğüm, jeodezik mesafe ve merkeziyet kavramları, tezdeki sosyal ağ analizinin temel bileşenleridir ve enerji projelerinin performansının değerlendirilmesinde kritik bir rol oynar.

Granovetter'in "zayıf bağların gücü" teorisi (1973 ve 1983), ağdaki yeni ilişkilerin veya fırsatların kurulmasında gayri resmi kanalların önemini vurgulamıştır (verileri yeni işler bulma üzerine kuruludur). Zhang (2010), Granovetter'in çalışmalarının, sosyal faaliyetlerin sosyal yapılara gömülü olduğunu ve sosyal yapıların bireyin sosyal ağlarına gömülü olduğunu ifade eden "embeddedness" kavramını önerdiğini belirtmiştir. Ağ gömülülüğü, sosyal ağ yaklaşımı içinde, bireylerin veya varlıkların bir sosyal ilişkiler ağına ne derece bağlı ve entegre olduğunu ifade eden bir kavramdır. Bu kavram, sosyal aktörlerin izole varlıklar olmadığını, çeşitli kişilerarası bağlantılar ve etkileşimlerle karakterize edilen daha büyük bir sosyal yapının içine gömülü olduklarını vurgular. Sosyal ağ teorisi bağlamında "gömülülük" terimi, bireylerin sahip olduğu ilişkiler ve bağlantıları dikkate almanın önemini vurgular ve davranışlarını, karar alma süreçlerini ve sonuçlarını anlamada önemlidir. Bir kişinin

eylemleri ve seçimleri, yalnızca bireysel özelliklerinden değil, aynı zamanda gömülü oldukları sosyal bağlamdan da etkilenir. Bu kavram, sosyal olayların, bireyleri izole bir şekilde inceleyerek tamamen anlaşılamayacağını, daha geniş bir ağın incelenmesini gerektirdiğini vurgular. Dolayısıyla, gömülülüğün sosyal ağ yaklaşımına tanıtılması, bu alanı ana akım sosyal araştırmalara daha yakın hale getirmiştir.

Freeman (2014), sosyal ağ analizini dört önemli özellik açısından özetlemiştir: (1) sosyal aktörler arasındaki bağlantıların önemli olduğuna dair bir sezgi içerir; (2) aktörleri birbirine bağlayan sosyal ilişkileri kaydeden verilerin toplanması ve analizi üzerine kuruludur; (3) bu bağlantıların desenlerini ortaya çıkarmak ve göstermek için grafik görüntülerden yoğun bir şekilde yararlanır; ve (4) bu desenleri tanımlamak ve açıklamak için matematiksel ve hesaplamalı modeller geliştirir.

SNA, bir ağda bulunan bilgileri çıkarmak için graf teorisi, cebir, istatistik ve sosyometriyi kullanan temel metodoloji haline gelmiştir. Büyük veri boyutları ve ağlardaki ilişkileri anlama gereksinimi, sosyal ağ analizi metodolojisini ve uygulamalar için gerekli araçları oluşturmuştur.

Üçüncü bölümde tezde kullanılacak olan verisetleri anlatılmıştır. Bu tezde kullanılan veri kaynakları, Avrupa Komisyonu'nun CORDIS veritabanından elde edilmiştir. FP7 ve H2020 programları kapsamında gerçekleştirilen enerji projelerine dair veriler toplanmış ve sosyal ağ analizi (SNA) yöntemleri kullanılarak değerlendirilmiştir. SNA, ağ yapısını anlamak için kullanılan merkeziyet, kümelenme katsayısı ve yoğunluk gibi ölçütler üzerinden yapılmıştır. Ayrıca, projelerin patentleme ve yayın performansları da incelenmiştir.

Veri toplama sürecinde, projelerde yer alan aktörler, bu aktörler arasındaki işbirliği ilişkileri ve projelerin çıktıları (patentler, yayınlar vb.) analiz edilmiştir. Bu veriler, projelerin yenilikçilik düzeyini ve ağ yapısını değerlendirmek için kullanılmıştır. Sosyal ağ analizi, bu verilerin görselleştirilmesi ve ağdaki önemli aktörlerin belirlenmesi için etkili bir yöntem sunar.

İstatistiksel analiz, FP7 ve H2020 programları kapsamında enerji projelerinin performansını ölçmek ve karşılaştırmak için kullanılmıştır. Analizler, projelerin

çıktıları ile bağımsız değişkenler arasındaki olası ilişkileri belirlemek amacıyla çeşitli regresyon modelleri kullanılarak yapılmıştır. Bu modeller, projelerin patent sayıları, yayın sayıları, katılımcı sayıları, fonlama miktarları ve ağ merkeziyet ölçütleri gibi değişkenleri içermektedir.

Dördünce bölümde Çerçeve programlarından FP7 ve H2020'deki enerji projeleri verisetini kullanan analizler gerçekleştirilmiştir. Bu çalışmalar Sosyal ağ analizi ve istatisel hesaplamaları kullanarak hangi sonuçlar elde ettiklerine göre gruplanmıştır. Bu bölümde, SNA yaklaşımının temel kavramları ve ağ performansı, hangi organizasyonların kiminle işbirliği yaptığı ve ağların nasıl evrildiği gibi sorular açısından tartışılmaktadır. Son bölümde, SNA'yı kullanan FP7 ve H2020 programlarına dayalı çalışmalar incelenmiştir. Bu çalışmalar, Avrupa Birliği'nin Çerçeve Programları (FP) ve Ufuk 2020 (H2020) aracılığıyla oluşturulan işbirliği araştırma ağlarını araştırmaktadır. Ana bulgular arasında, Avrupa Araştırma Alanı'nın kurulmasında işbirliği ağının rolü, ölçekten bağımsız ve küçük dünya ağ karakteristiklerinin varlığı ve ağ analiz metriği kullanarak merkezler ve geçiş noktalarının tanımlanması yer almaktadır.

Çalışmalar, AB araştırma girişimlerinde katılım ve fon onaylarını etkileyen ağ merkeziyetinin önemini vurgulamaktadır. Güven, dil benzerlikleri ve yakınlık gibi faktörler, işbirliği eğilimlerini şekillendirmede hayati roller oynamaktadır ve bölgesel işbirlikleri daha gelişmiş bölgelerde yoğunlaşma eğilimindedir. Ayrıca, kamu organizasyonları ve üniversiteler, bu ağlarda genellikle geçiş noktaları olarak hareket etmektedir.

Bu bulgular, işbirlikçi araştırma ağlarının yapısı, dinamikleri ve etkisi hakkında değerli bilgiler sunmakta ve alandaki bilgiye dayalı politika kararları ve daha fazla araştırma için temel sağlamaktadır. Aşağıdaki tablo, veri, kavramsal çerçeveler, araştırma metodolojileri ve ilgili bulguların kapsamlı bir özetini sunmaktadır.

1. Katılımcılar Üzerine Ağ Analizi

Analizin Amacı ve Yöntemi: Katılımcılar üzerindeki ağ analizi, FP7 ve H2020 programları kapsamında enerji projelerine katılan kuruluşlar arasındaki işbirliği

yapısını anlamayı amaçlamaktadır. Bu analiz, katılımcıların projelerdeki rollerini (koordinatör veya katılımcı) ve bu rollerin ağ yapısındaki etkilerini incelemek için kullanılmıştır. Sosyal Ağ Analizi (SNA) kullanılarak, katılımcıların merkeziyet (degree centrality), arabuluculuk (betweenness centrality) ve yakınlık (closeness centrality) gibi ağ metrikleri hesaplanmıştır.

Sonuçlar:

- **Merkeziyet Analizi:** Katılımcılar arasındaki merkeziyet, belirli kuruluşların ağ içinde ne kadar merkezi bir konumda olduğunu gösterir. Örneğin, Fraunhofer-Gesellschaft gibi büyük araştırma enstitüleri, hem FP7 hem de H2020 programlarında yüksek merkeziyet değerlerine sahiptir.
- **Arabuluculuk Analizi:** Bu analiz, belirli katılımcıların ağ içinde ne kadar kritik bir bağlantı noktası olduğunu ortaya koyar. Örneğin, H2020 programında, Rina Consulting özel sektörden tek arabulucu olarak öne çıkmaktadır.
- **Katılım ve Koordinasyon:** Katılım ve koordinasyon frekansları, belirli katılımcıların projelerdeki rolleri hakkında bilgi verir. FP7'de yüksek koordinasyon frekansına sahip katılımcılar, H2020'de de benzer roller üstlenmiştir.

2. Projeler Üzerine Ağ Analizi

Analizin Amacı ve Yöntemi: Projeler üzerindeki ağ analizi, FP7 ve H2020 programları kapsamında finanse edilen enerji projelerinin genel yapısal özelliklerini ve projeler arasındaki bağlantıları incelemeyi amaçlamaktadır. Bu analiz, projelerin sayılarını, katılımcı sayılarını ve projelerin çıktıları üzerindeki etkilerini değerlendirmek için yapılmıştır.

Sonuçlar:

- **Proje Ağ Yapısı:** FP7'de daha merkezi ve tek bir büyük bileşen üzerinden bilgi akışı sağlanırken, H2020'de daha dağınık ve çok bileşenli bir yapı gözlenmiştir. Bu, H2020 programının daha kapsayıcı ve geniş bir işbirliği ağı oluşturduğunu göstermektedir.

- **Bağlantı ve Kümelenme:** H2020'de ortalama bağlantı uzunluğu azalmış ve kümelenme katsayısı artmıştır, bu da bölgeler arası bilgi akışının daha verimli hale geldiğini ve işbirliğinin arttığını göstermektedir.

3. NUTS2 Bölgeleri Üzerine Ağ Analizi

Analizin Amacı ve Yöntemi: NUTS2 bölgeleri üzerindeki ağ analizi, FP7 ve H2020 programları kapsamında enerji projelerine katılan bölgelerin performansını değerlendirmeyi amaçlamaktadır. Bu analiz, bölgeler arasındaki işbirliği ağlarını ve bu ağların bölgesel inovasyon üzerindeki etkilerini incelemek için yapılmıştır.

Sonuçlar:

- **Bölgesel Performans:** NUTS2 bölgelerinin performansı, merkeziyet ve bağlantı yoğunluğu gibi ağ metrikleri kullanılarak değerlendirilmiştir. H2020 programında, bölgesel işbirliği ağları daha yoğun ve kapsayıcı hale gelmiştir.
- **Merkeziyet ve Arabuluculuk:** H2020 programında, belirli bölgeler daha merkezi ve kritik arabuluculuk rollerine sahip olmuştur. Bu, bölgeler arası bilgi akışını ve inovasyonu artırmıştır.

Bu analizler, FP7 ve H2020 programları kapsamında enerji projelerindeki ağ yapılarının evrimini ve bu yapıların inovasyon sonuçlarına olan etkilerini anlamak için kritik öneme sahiptir. Bu bulgular, Avrupa Birliği'nin enerji politikası hedeflerine ulaşmak için inovasyon politikalarının nasıl tasarlanması ve uygulanması gerektiğine dair önemli içgörüler sağlamaktadır. Ayrıca, bu çalışmalar, gelecekteki politika müdahaleleri için önerilerde bulunmak açısından da değerli katkılar sunmaktadır .

NUTS2 Bölgeleri üzerine detaylı sosyal ağ analizi ve istatiksel analiz sonuçları özetlenmiştir. Öncelikle, FP7 ve H2020 programlarında, NUTS2 bölgeleri düzeyinde bölgesel ağ yapıları incelenmiştir. Bu analiz, projelerde yer alan katılımcıların coğrafi dağılımını ve bölgesel işbirliklerinin nasıl yapılandığını anlamak için kullanılmıştır. NUTS2 bölgeleri, projelerin koordinatörleri ve katılımcıları olarak belirli rollerde yer almakta ve bu rollerin projelerin başarısı üzerindeki etkisi incelenmektedir.

Analiz sonuçları, FP7 ve H2020 programları kapsamında enerji projelerinin ağ

yapılarında önemli farklılıklar olduğunu göstermektedir. H2020 programında daha fazla proje ve katılımcı bulunmasına rağmen, patent sayılarında beklenen artış gerçekleşmemiştir. Bu durum, projelerin sayısının artmasının her zaman yenilikçi çıktılara doğrudan yansımadığını göstermektedir. Ayrıca, üniversiteler ve kamu kuruluşlarının ağ yapısında merkezi bir rol oynadığı, bu aktörlerin genellikle ağın merkezinde yer aldığı tespit edilmiştir.

Sosyal ağ analizinin sonuçlarına göre, FP7 ve H2020 programlarında bölgesel ağ yapıları incelenmiştir. Yenilikçi bölgeler ağın merkezinde yer alırken, yüksek enerji talebi veya vulnerabiliteye sahip bölgeler ağın kenarlarında kalmaktadır. Ayrıca, üniversiteler ve kamu kuruluşlarının ağ yapısında önemli bir rol oynadığı ve genellikle ağın merkezinde konumlandıkları tespit edilmiştir.

Bu bölümde, FP7 ve H2020 programlarında yer alan enerji projelerinin NUTS2 bölgeleri düzeyinde performansı incelenmiştir. İki modlu ağ, NUTS2 bölgeleri ile projeler arasında kurulmuş ve bu ağlar, her iki program için analiz edilmiştir. Daha sonra, iki modlu ağ, NUTS2 bölgelerinin bir modlu ağına dönüştürülmüştür; bu, iki bölgenin aynı projede en az bir katılımcıya sahip olması durumunda bir bağa sahip olduğu anlamına gelir.

FP7 ağının daha fazla yapısal boşluklara sahip olduğu, H2020 ağında ise bağların uzunluğunun daha kısa olduğu ve düğümlerin daha düşük toplu kısıtlamalara sahip olduğu gözlemlenmiştir. H2020 programında, düğümler daha merkezi pozisyonlarda yer almakta ve bilgi akışını daha etkili bir şekilde sağlamaktadır. Ayrıca, H2020 programında yeni katılımcıların farklı çekirdek bileşenlere bağlandığı, yol uzunluğunun azaldığı ve kümelenme katsayısının arttığı tespit edilmiştir. Bu, NUTS2 bölgelerinin ağının küçük dünya özellikleri sergilediğini ve bilgi yaratma ve yayılımında yüksek verimlilik sağladığını göstermektedir.

Bu araştırmanın bulguları doğrultusunda, Avrupa Komisyonu'nun enerji projelerinde yenilikçiliği artırmak ve bölgesel eşitsizlikleri azaltmak için çeşitli politika önerileri sunulmuştur. Özellikle, küçük ve orta ölçekli işletmelerin (KOBİ) projelere daha aktif katılımının teşvik edilmesi, yenilikçi bölgelerin desteklenmesi ve enerji talebi yüksek olan bölgelerin daha fazla fon almasının sağlanması önerilmektedir.

Politika önerileri, enerji projelerinin daha etkili ve yenilikçi olmasını sağlamayı amaçlamaktadır. KOBİ'lerin projelere daha aktif katılımı, yenilikçi çözümlerin geliştirilmesine katkıda bulunabilir. Ayrıca, yenilikçi bölgelerin desteklenmesi ve enerji talebi yüksek olan bölgelerin daha fazla fon alması, projelerin başarısını artırabilir. Bu öneriler, enerji projelerinin daha verimli ve yenilikçi olmasını sağlamayı amaçlamaktadır.

Sonuç olarak, bu araştırma, AB'nin FP7 ve H2020 programları kapsamında enerji projelerinde oluşturulan işbirliği ağlarının yapısını ve bu yapıların yenilikçilik üzerindeki etkilerini anlamak için kapsamlı bir analiz sunmaktadır. Gelecek araştırmalar için, diğer araştırma alanlarıyla karşılaştırmalı analizler yapılması ve daha uzun dönemli verilerin incelenmesi önerilmektedir. Bu tür çalışmalar, enerji projelerinin daha etkili bir şekilde yönetilmesine ve yenilikçi çıktılar elde edilmesine katkı sağlayacaktır.

Dokümanın 4. bölümünde patent sayılarına yönelik yapılan analiz, FP7 ve H2020 programları kapsamında enerji projelerinden elde edilen patentlerin belirleyicilerini incelemektedir. Bu analiz, proje bazlı özelliklerin patent sayılarını nasıl etkilediğini anlamayı amaçlar.

Regresyon Modeli: Analiz, aşağıdaki bağımlı ve bağımsız değişkenlerle gerçekleştirilmiştir:

- **Bağımlı Değişken:**
  - Patent Sayısı: Projeden elde edilen toplam patent sayısı.
- **Bağımsız Değişkenler:**
  - Yayın Sayısı: Projeden çıkan toplam yayın sayısı.
  - Katılımcı Sayısı: Projeye dahil olan toplam katılımcı sayısı.
  - Betweenness Merkeziyet: Ağ içindeki düğümün genel bağlantısındaki önemi.
  - EU Maksimum Katkı: Projeye AB tarafından sağlanan finansman miktarı.
  - Hub Değeri: Ağda merkezi düğüm olup olmadığı (dummy değişken).
  - Çekirdek Kümeye Dahil Olma: Projenin ana kümeye dahil olup

olmadığı (dummy değişken).

Sonuç olarak FP7 projelerinde yayın sayısı ile patent sayısı arasında pozitif ve anlamlı bir ilişki bulunmuştur. Ancak, H2020 projelerinde bu ilişki anlamlı bulunmamıştır. FP7 projelerinde betweenness merkeziyet değeri yüksek olan projelerin daha fazla patent ürettiği gözlenmiştir H2020 projelerinde ise bu ilişki negatif ve anlamlıdır. FP7 projelerinde hub değeri negatif ve anlamlıdır , H2020 projelerinde ise anlamlı bir ilişki bulunmamıştır .Her iki programda da EU katkısı ile patent sayısı arasında anlamlı pozitif bir ilişki bulunmuştur. FP7 projelerinde çekirdek kümeye dahil olma negatif ve anlamlıdır, H2020 projelerinde ise anlamlı bir ilişki bulunmamıştır.

NUTS2 bölgeleri üzerine yapılan regresyon analizi, bu bölgelerin ağ içindeki performanslarını ve etkileyen faktörleri değerlendirmektedir. Analiz, aşağıdaki bağımlı ve bağımsız değişkenlerle gerçekleştirilmiştir:

- **Bağımlı Değişken:**
  - Eigenvector Merkeziyet: Bir bölgenin ağ içindeki etkisini ve bağlantılarını gösteren merkeziyet ölçütü.
- **Bağımsız Değişkenler:**
  - Bölgesel İnovasyon Puanı (RIS): Bölgelerin inovasyon performansına göre kategorize edilmesi.
  - Gayri Safi Yurtiçi Hasıla (GDP): Bölgenin ekonomik aktivitesini ölçen veri.
  - Isıtma ve Soğutma Derece Günleri (HDD ve CDD): Bölgenin enerji tüketimini ölçen metrikler.
  - EU Maksimum Katkı: Bölgedeki projelere sağlanan maksimum AB fon miktarı.
  - Bilim ve Teknolojide İnsan Kaynakları (HRST): Bölgede bilim ve teknoloji alanında çalışan insan sayısı.

Sonuç olarak yüksek inovasyon puanına sahip bölgeler, yüksek eigenvector merkeziyet değerlerine sahip olmuş ve bu bölgeler ağ içinde daha etkili ve bağlantılı olmuştur. Ekonomik olarak güçlü bölgeler, daha merkezi bir konumda bulunmuş ve ağ içindeki etkileri daha yüksek olmuştur. Enerji talebi ve kırılganlığı yüksek olan

bölgeler, daha düşük merkeziyet değerlerine sahip olmuştur. AB fonlarından daha fazla yararlanan bölgeler, daha yüksek merkeziyet değerlerine sahip olmuştur.Bilim ve teknoloji alanında insan kaynağı yüksek olan bölgeler, ağ içinde daha merkezi ve etkili bir konumda bulunmuştur.

En son bölümde, tezin genel bulguları, araştırmanın Bilim, Teknoloji ve İnovasyon (BTİ) politikaları üzerindeki etkileri, araştırmanın sınırlamaları ve gelecekteki araştırmalara yönelik politika önerileri sunulmaktadır. Bu bölüm genel bulgular, politika önerileri ve araştırmanın Sınırlamaları ve Gelecek Çalışmalar başlıkları altında incelenmiştir.

Bu çalışmanın ana amacı, Avrupa Komisyonu Çerçeve Programları (FP) kapsamında enerji projeleri ağlarının yapısını ve etkinliğini değerlendirmek için metodolojik bir çerçeve geliştirmek ve uygulamaktır. FP7 (2007-2013) ve H2020 (2014-2020) programlarında finanse edilen enerji projelerinin karakteristiklerini ve performanslarını incelemek için Sosyal Ağ Analizi (SNA) araçları kullanılmıştır.

Veriler, Avrupa Komisyonu CORDIS veritabanından toplanmış ve NUTS2 Avrupa bölgeleri düzeyinde bölgesel bir analiz gerçekleştirilmiştir. Tezdeki genel bulgular ve analizler aşağıda belirtilen üç tür analiz çerçevesinde gerçekleştirmiştir:

1. Projeler çeşitli istatistiksel göstergeler açısından incelenmiştir:
    - Katılımcı sayısı ve Avrupa Komisyonu'ndan alınan mali katkı.
    - Katılımcıların ve projelerin katılım ve koordinasyon sıklıkları.
    - Patente ve yayınlara yönelik katılım ve çıktı dinamikleri.
2. SNA teknikleri ve yöntemleri kullanılarak ağların yapısal özellikleri sistematik bir şekilde analiz edilmiştir:
    - Katılımcılar, projeler ve NUTS2 bölgelerinin ağdaki konumları.
    - Önemli organizasyonların (merkezler) belirlenmesi ve bilgi yayılımındaki etkinlikleri.
    - Katılımcıların projeler ve bölgeler arasındaki bağlayıcı rollerinin belirlenmesi.
    - Çeşitli merkeziyet ölçütlerinin dağılımı ve fon toplama pozisyonlarındaki yerleri.

- Merkez ve çevre bölgeler arasındaki işbirliği desenleri.

3. İki farklı regresyon analizi gerçekleştirilmiştir:
    - İlk regresyon modeli, projelerle ilişkili toplam patent sayısı ile merkeziyet ölçütleri arasındaki ilişkiyi vurgulamaktadır.
    - İkinci regresyon modeli, yenilikçilik (inovasyon odaklı katılım) veya enerji talebi/güvenlik açığı (zorluk odaklı katılım) değişkenlerinin enerji programlarındaki katılım düzeylerini nasıl etkilediğini araştırmaktadır.

Bulgular, FP7 ve H2020 programları arasında patentleme davranışında belirgin bir fark olduğunu göstermektedir. H2020'de proje ve katılımcı sayısında artış olmasına rağmen, patent sayıları orantılı olarak artmamıştır. H2020'deki patentli projelerin oranında dört kat düşüş, yenilikçilik verimliliğinde azalma olduğunu göstermektedir.

Bu çalışmanın ana amacı, Avrupa Komisyonu Çerçeve Programları (FP) kapsamında enerji projeleri ağlarının yapısını ve etkinliğini değerlendirmek için metodolojik bir çerçeve geliştirmek ve uygulamaktır. FP7 (2007-2013) ve H2020 (2014-2020) programlarında finanse edilen enerji projelerinin karakteristiklerini ve performanslarını incelemek için Sosyal Ağ Analizi (SNA) araçları kullanılmıştır.

Veriler, Avrupa Komisyonu CORDIS veritabanından toplanmış ve NUTS2 Avrupa bölgeleri düzeyinde bölgesel bir analiz gerçekleştirilmiştir. Bu bilgiler ışığında çalışma üç tür analiz gerçekleştirmiştir:

1. **Projelerin İstatistiksel İncelemesi:**
    - Katılımcı sayısı ve Avrupa Komisyonu'ndan alınan mali katkı.
    - Katılımcıların ve projelerin katılım ve koordinasyon sıklıkları.
    - Patente ve yayınlara yönelik katılım ve çıktı dinamikleri.
2. **Sosyal Ağ Analizi:**
    - Katılımcılar, projeler ve NUTS2 bölgelerinin ağdaki konumları.
    - Önemli organizasyonların (merkezler) belirlenmesi ve bilgi yayılımındaki etkinlikleri.
    - Katılımcıların projeler ve bölgeler arasındaki bağlayıcı rollerinin belirlenmesi.

- Çeşitli merkeziyet ölçütlerinin dağılımı ve fon toplama pozisyonlarındaki yerleri.
- Merkez ve çevre bölgeler arasındaki işbirliği desenleri.

3. **Regresyon Analizleri:**
   - İlk regresyon modeli, projelerle ilişkili toplam patent sayısı ile merkeziyet ölçütleri arasındaki ilişkiyi vurgulamaktadır.
   - İkinci regresyon modeli, yenilikçilik (inovasyon odaklı katılım) veya enerji talebi/güvenlik açığı (zorluk odaklı katılım) değişkenlerinin enerji programlarındaki katılım düzeylerini nasıl etkilediğini araştırmaktadır.

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Politika önerileri, politika problemlerini çözmek için önerilen politika tasarım modeli kullanılarak belirlenmiştir. Bu modelde, politika problemlerini ele almak için üç farklı düzeyde politika önerileri belirtilmiştir: makro, mezo ve mikro düzeyde.

Öncelikle, politika hedefi, FP7 ve H2020 programlarındaki yapısal ağ değişiklikleri ile destek mekanizmalarının verimliliğini artırmak olarak belirlenmiştir. Bu hedefe ulaşmak için, proje katılımcı çeşitliliğini artırmak ve bölgeler için uygun bir ortam yaratmak amacıyla politika önerileri geliştirilmiştir.

Mikro Düzeyde Politika Önerileri:

- **FP7 ve H2020'nin sağladığı yapısal değişikliklerle katılımcı çeşitliliğini artırmak:** Bu öneri, katılımcı çeşitliliğini artırmak için FP7 ve H2020'de yapısal değişiklikler yapılmasını içermektedir. Bu değişiklikler:
  - Özel sektör katılımını teşvik etmek
  - Aracı rolleri güçlendirmek
  - Proje konsorsiyumlarında kapsayıcılığı teşvik etmek
  - Kapasite geliştirme faaliyetleri sağlamak

- **Sorumlu BTİ Aktörü:** Katılımcı Ağları

Mezo Düzeyde Politika Önerileri:

- **İşbirlikçi ağlar oluşturmak:** Farklı projeler ve bölgeler arasında işbirliğini teşvik etmek için uluslararası işbirlikleri için ek fon ve destek sağlamak. Öneri ayrıca:
    - Özel sektör katılımını teşvik etmek
    - İletişim ve işbirliğini kolaylaştıracak işbirlikçi platformlar oluşturmak
- **FP yöntemleri aracılığıyla bölgesel farklılıkları ortadan kaldırmak:** FP yöntemlerini kullanarak bölgesel farklılıkları azaltmak. Bu öneri:
    - Bölgesel Yenilik Merkezleri geliştirmek
    - Sınır ötesi işbirliğini artırmak
- **Sorumlu BTİ Aktörü:** Proje ve Bölgesel Ağlar

Makro Düzeyde Politika Önerileri:

- **Farklı destek mekanizmalarının yenilikçiliğini artırmak:** Katılımcıları daha iyi hizmet vermek için destek mekanizmalarını geliştirmek ve yenilikçi hale getirmek. Bu mekanizmalar:
    - Yenilik Merkezleri ve Tematik Yenilik Merkezleri geliştirmek
    - İşbirlikçi platformları geliştirmek
    - Kapasite geliştirme ve eğitim programları sağlamak
- **Kapsayıcı sürdürülebilir çerçeveler aracılığıyla Avrupa enerji sektörünün rekabetçiliğini artırmak:** Avrupa enerji sektörünün rekabetçiliğini ve sürdürülebilirliğini artırmak için çerçeveler geliştirmek. Bu çerçeveler:
    - Kapsayıcı politika çerçeveleri oluşturmak: Çeşitli paydaş katılımı ve bölgesel ihtiyaçlara göre fon dağılımı
    - Sürdürülebilir yatırım teşvikleri ve sertifikasyon sağlamak
    - Kamu-özel ortaklıklarını teşvik etmek
- **Sorumlu BTİ Aktörü:** AB Komisyonu

Bu politika önerileri, tanımlar, araçlar ve politika hedefleriyle birlikte üç düzeyde özetlenmiştir.

Bu çalışmanın sınırlamaları, veri setlerinin istatistiksel güvenilirliği veya bazı araştırma yönetimi örgütsel sorunlarıyla doğrudan ilgili değildir. Bu çalışma enerji ile ilgili FP programlarına odaklanmıştır. Bu, projelerin yapısını ve ağlarını bu alt alanda ayrıntılı olarak anlamamızı sağlamıştır. Ancak, ERA içindeki bu RDI alt alanının genelliğini veya özelliklerini tam olarak değerlendirmek için diğer alt alanlarla karşılaştırmalar yapmak gereklidir. Ancak, bu tür karşılaştırmaların yapılabilmesi için benzer çalışmaların eksikliği nedeniyle bu egzersiz gerçekleştirilememiştir. Bu nedenle, Avrupa Komisyonu'nun FP yaklaşımının diğer alt alanlarıyla karşılaştırılmaması, politika önerilerimizin genel karakterini sınırlamıştır.

Son olarak, bu çalışmanın sınırlamaları arasında enerji alanında FP projeleri konusunda deneyim sahibi uzmanlara erişimin sınırlı olması yer almaktadır. Bu araştırma programının devamında, bulgularımızı çeşitli üye ülkelerden gelen yüksek merkeziyet projelerinin koordinatörleri ile karşılaştırarak daha geniş bir anlayış elde etmeyi planlamaktayız.

Sonuç olarak, bu tez, enerji alanındaki FP türü proje ağlarının nasıl oluşturulduğunu anlamaya yönelik çeşitli yöntemler ve yaklaşımlar sunmuştur. Ayrıca, işbirliği ağlarını incelemek için SNA çerçevesini kullanmıştır. Bu nedenle, bu tezin enerji alanındaki FP'ler ile ilgili bilim ve teknoloji politikası araştırmalarına önemli bir katkı sağladığını ve bu programlardaki işbirliği ağları hakkında yeni perspektifler açtığını düşünüyoruz.

Bu çalışmanın sınırlamaları, veri setlerinin istatistiksel güvenilirliği veya bazı araştırma yönetimi örgütsel sorunlarıyla doğrudan ilgili değildir. Bu çalışma enerji ile ilgili FP programlarına odaklanmıştır. Bu, projelerin yapısını ve ağlarını bu alt alanda ayrıntılı olarak anlamamızı sağlamıştır. Ancak, ERA içindeki bu RDI alt alanının genelliğini veya özelliklerini tam olarak değerlendirmek için diğer alt alanlarla karşılaştırmalar yapmak gereklidir. Ancak, bu tür karşılaştırmaların yapılabilmesi için benzer çalışmaların eksikliği nedeniyle bu egzersiz gerçekleştirilememiştir. Bu nedenle, Avrupa Komisyonu'nun FP yaklaşımının diğer alt alanlarıyla karşılaştırılmaması, politika önerilerimizin genel karakterini sınırlamıştır.

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Bölümü / Department : Bilim ve Teknoloji Politikası Çalışmaları / Science and Technology Policy Studies

TEZİN ADI / TITLE OF THE THESIS (**İngilizce** / English): Social Network Analysis of Energy Projects in the EU 7th Framework And Horizon 2020 Programmes

TEZİN TÜRÜ / DEGREE**:** **Yüksek Lisans** / Master ☐ **Doktora** / PhD ☒

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