International R&D networks in renewable technologies – Evidence from the Portuguese participation in European Framework Programmes

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International R&D networks in renewable technologies – Evidence from the Portuguese participation in European Framework Programmes[1]

ABSTRACT

The aim of the current paper is to analyse international research collaborations in order to define patterns of international knowledge sharing. Research collaborations have become the norm in scientific and technological research. These collaborations often materialise in formal research projects. In this paper we will focus on research projects funded by the European Commission with Portuguese participation, mainly within the context of the Framework Programmes (FPs).

We adopt the Triple Helix framework to investigate the way Portuguese universities, companies and other organisations are inserted in these collaborations and the role they play within them, in a dynamic form. This framework stresses the complex dynamics between academia, industry and government in the processes of knowledge production and innovation.

We use Social Network Analysis to capture the composition and configuration of these international collaborations, considering them as knowledge networks. The empirical analysis of this research draws on data from the CORDIS database. We consider only projects that involve at least one Portuguese partner and address the "Renewable Sources of Energy" subject. We have identified 427 different projects, involving 2530 organisations from 83 countries. The analysis covers the period between 1985 and 2014.

The results uncover an evolution consistent with the propositions of the Triple Helix framework. First, we witness the importance of universities, which are becoming more and more central in the knowledge network. Second, we observe the increasing participation of companies in the research, raising their share in the network composition to values similar to those of universities. Finally, the results reveal the strengthening of the interaction between the three agents: projects that bring together academia, industry and universities are now the most frequent type, unlike what occurred at the beginning of the period under review. This study contributes to further the understanding of cross-border knowledge sharing and creation, considering several types of actor and interaction and their dynamics.

KEYWORDS: international knowledge networks, international research collaborations, European Framework Programmes, social network analysis, sustainable energy technologies.

[1] This paper draws on research carried out within Project TESS - Transition to an environmentally sustainable energy system - The role of technology-intensive firms in the commercialization of emerging energy technologies, funded by FCT – Fundação para a Ciência e a Tecnologia (PTDC/CS-ECS/113568/2009), DINÂMIA'CET-IUL, Lisbon, Portugal.

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1. INTRODUCTION

Since the modern era, new scientific ideas have crossed national boundaries but their diffusion was slow and difficult. This has changed dramatically in current times when new ideas circulate worldwide almost instantaneously. Therefore the making of science – far more than its diffusion process and the circulation of scholars - has changed profoundly. In recent decades, the creation of knowledge has become a highly internationalised, shared and connected activity. The information and communication technologies, first, and later the Internet, provide the technical infrastructure of this new stage, characterised by the constitution of international knowledge networks assembling scholars of different countries and continents. These networks have been defined as knowledge networks.

Increasing knowledge complexity, sharp scientific specialisation, the frequent need for multidisciplinary and interdisciplinary approaches, the large scale equipments and financial resources required, the huge uncertainty regarding the outcomes are driving this transformation (Powell and Grodal, 2005). Even top universities and laboratories, and big companies are no longer able to conduct large cutting-edge scientific projects at a single and domestic level. Research in biotechnology became a striking exemplar of this new tendency, giving rise to a substantial number of studies (Powell, Koput and Smith-Doerr, 1996). Soon, this became the standard in basic science and in fast changing technological domains such as computers, semiconductors, pharmaceuticals, software and more recently renewable energy technologies (Powell and Grodal, 2005; Cloodt, Hagedoorn and Roijakkers, 2010). Few relevant actors were left out this surge. The exceptions include defence related fields and some large companies, which, for commercial reasons, develop in-house parallel research, while collaborating within external projects (Luukkonen, 2002).

A second reason for building large scale cross-border networks is policy related. The formation of a European Research Area is a case in point. Aiming to exploit synergies and create critical mass to boost scientific excellence in Europe - and eventually improving the European technological competiveness -, this goal gave rise to policies which support research collaboration at European level. The RTD Framework Programmes, launched in the early 1980s, are a major instrument of these policies, due to the huge and increasing budgets allocated to them. These multi-annual Programmes enable research institutions, government agencies and industrial partners to cooperate in R&D projects and generate knowledge that spans across national borders. They are seen as pivotal for transforming informal nation-based research networks into formal collaboration arrangements between organisations at European level (Heller-Schuh et al, 2011).

The collaborative research carried out under these programmes has been studied by authors such as Protogerou, Caloghirou and Siokas (2010). They focused on the networks created across European countries in the Information Society area, over the FP4 to FP6 period.

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In this paper, we focus on the Portuguese participation from the starting programme till the present, that is, since FP1 to FP7, in the "Renewable Sources of Energy" subject, including also projects funded by the European Commission through specific support schemes. We have identified 427 different projects, involving 2530 organisations from 83 countries. Using social network analysis, we study the configuration of the networks built and their evolution. Resorting to the triple helix approach (Etzkowitz and Leydesdorff, 2000), we classified those projects according to the several types of entity involved.

In short, this paper shows how international knowledge networks have evolved over the last decades within the context of European funding, and how the different actors (universities, companies and government) have influenced the networks deployment and dynamics.

2. INTERNATIONAL KNOWLEDGE NETWORKS AND COLLABORATIVE RESEARCH

Knowledge networks are conceptualised as "consisting of *nodes* that serve as repositories of knowledge and agents that search for, adopt, transmit, and create knowledge. Nodes are simultaneously sources and recipients of information and knowledge" (Phelps, Heidl and Wadhwua, 2012: 1236). These nodes may be individuals or collectives. In our research, the nodes are either countries or organisations involved in research projects. In the case of Framework Programme projects or Networks of Excellence, the networks usually gather entities from different states, mostly, but not exclusively, from the EU.

These networks have evolved over time along various dimensions: the dominant kind of actor; the dominant origin of the actors; the purpose of the collaboration; and the type and form of the links established. Many of these characteristics are captured through social network analysis.

Network composition analysis allows quantifying the absolute and relative number of each kind of entity, as well as the country´s origin of the entities. Since we are addressing R&D collaborations, universities are expected to play the central role. However, we also find other types of organisation, namely firms, which are very active in some areas. When analysing the countries, we are enabled to identify the patterns of international knowledge sharing. When analysing the organisations, we are enabled to characterise the types of actor which are more active in this process of knowledge creation and sharing.

Networks also differ by the positioning of their actors. Usually centrality is the most studied characteristic. A more central position in the network gives the actor an advantage as it offers more opportunities to access the most relevant knowledge sources (Powell, Koput and Smith-Doerr, 1996). Centrality can be analysed from different perspectives resorting to different measures.

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In this paper we analyse the centrality of the actors, both in terms of countries and organisations. We use both the degree centrality and the betweenness centrality. The former indicates the actors' activity level, a central agent being one who has a large number of connections or ties. The latter indicates the potential for control a central actor has over the others, due to the position it occupies between various pairs of actors (Freeman, 1979).

A central position is supposed to provide several advantages to the actors benefiting from that positioning. In fact, a greater centrality provides central actors with timelier access to a broader and more diverse array of knowledge and information and other resources (Phelps, Heidl and Wadhwua, 2012). The access to better information gives rise to better opportunities (Gulati, Nohria and Zaheer, 2000) and to higher reputation and credibility, therefore improving the organisations' attractiveness to others (Powell, Koput and Smith-Doerr, 1996).

As above mentioned, the relevance of universities is expected to be confirmed by the empirical analysis. In fact, in increasingly knowledge-based economies, universities have risen to a central and prominent position in the innovative process, as stated by the Triple Helix approach (Etzkowitz and Leydesdorff, 2000). Triple Helix authors propose a conceptual framework where academia, industry, and government are interconnected by a network of relationships. They are the three institutions, or retention mechanisms, of this model. Three functions, or selection mechanisms, are addressed: wealth generation, novelty production and normative control. These functions do not correspond on a one-to-one relation with institutions. Novelty, or variation creation, for instance, can emerge either within the academia or the firm (Leydesdorff and Meyer, 2006).

This evolutionary model proposes a heuristics for studying the complex dynamics between the three types of organisation within the networks (Leydesdorff and Meyer, 2006). They evolve through interaction processes, whereby institutions are themselves transformed, although preserving their distinctive identity and clear-cut boundaries. In these 'endless transition' systems, knowledge and networks are two fundamental elements.

The model presented above corresponds to the Triple Helix policy model III. Here, the state interacts dynamically with the other two institutions, and overlapping domains emerge across the three institutional spheres. During this process, hybrid organisations are created at the interfaces. The degree of interconnectedness and integration in Triple Helix III is far higher than in Triple Helix model II, where institutions are kept apart and establish non-transformational links only. In addition, the role of the government is deeply modified in relation to the 'etatistic' Triple Helix model I, where the nation state directs the whole system, the other institutions being deprived of any autonomy (Etzkowitz and Leydesdorff, 2000).

Empirical studies have confirmed that universities and research organisations have become more and more important with the course of time within European projects, namely within Framework

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Programmes (Protogerou, Caloghirou and Siokas, 2010). This is namely due to the fact that recent programmes are less technology mission oriented and more devoted to reinforce the science basis.

The conceptual change in European programmes, combined with the global trends in the making of science, is also captured in our study. In fact, it deals with the networks' evolution over time, in an exercise of comparative static analysis. We expected that in an emerging technological field such as renewable energy technologies, research would be dominated by academic organisations in the first periods and that companies would exhibit a relatively more modest profile. As a consequence, we expect that the configuration of the networks change over time in terms of composition and positioning of the different actors. Thereof, we hope to contribute to draw interesting conclusions on the Portuguese participation in this area within the context of European projects, enabling us to provide useful policy suggestions.

3. METHOD

The empirical analysis of this research draws on data from the CORDIS database, which contains information on all research projects funded by the European Commission. We consider only projects that involve at least one Portuguese partner and cover the "Renewable Sources of Energy" subject. We have identified 502 different projects. We have then excluded from our analyses those projects that involved only one organisation or only Portuguese partners, since they do not represent international collaborations. Our analysis resorts to data from 427 projects, involving 2530 organisations from 83 countries, dating from 1985.

The data retrieved from the database in November 2014 was treated in order to correct errors in the spelling of organisations' names and to reconcile them (e.g. the same organisation appeared named by its acronym and by its full name). This procedure was also performed for the countries of origin of each organisation.

As above mentioned, the Triple Helix model considers the existence of different types of actor. Based on this framework, we have classified the organisations in four different categories: universities and research centres (universities hereafter), companies, governmental agencies and other organisations (namely industry and professional associations). This was a lengthy undertaking, involving the analysis of the organisations' websites and/or other information available on the Internet.

In order to trace the evolution of the collaborations, we have considered six 5-year intervals: 1985-1989, 1990-1994, 1995-1999, 2000-2004, 2005-2009 and 2010-2014. The evolution of the number of projects in each period is represented in Figure 1.

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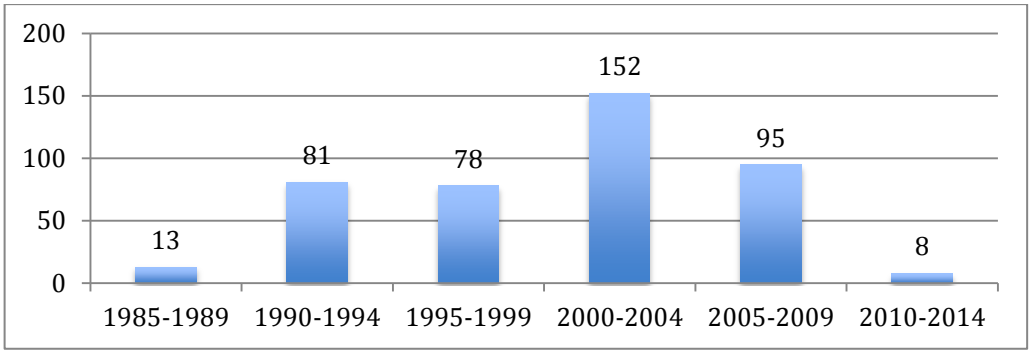
Figure 1: Number of projects by starting period (Total= 427)



Source: Own elaboration.

Research collaborative projects constitute two-mode networks that link the organisations to the projects. From these we have drawn two types of one-mode network: one considering inter-organisational relations, where two organisations are joined by a tie if they collaborate in the same project; the other one considering inter-country relations, where two countries are joined by a tie if organisations from them collaborate in the same project. Then, symmetric adjacency matrices, valued by the number of common projects, were built, analysed (using UCINET software) and represented in diagrams (using NetDraw software). Three specific features of the knowledge networks are examined: network composition, the predominant types of relation and the centrality of actors, using degree and betweenness measures alike.

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4. RESULTS

4.1 Network composition

In order to capture the diversity of the actors present in these international knowledge networks, the analysis is centred on the networks' composition. Two levels of analysis are considered: country and organisation.

The analysis of composition in terms of countries enables to capture the patterns of international knowledge sharing. It enables to detect the countries that are more relevant in the co-production of knowledge in the area of renewable energy technologies for the Portuguese organisations. Table 1 presents the results of the analysis. Until the 2005-2009 period, there was a surge in the number of countries interacting with Portugal in the production of knowledge in this technological area, complemented with a rise in the number of ties, which has resulted in a decrease in the network density compared with the former periods. The evolution in the last period (2010-2014) suggests a consolidation of the network, with a decrease in the number of country partners more pronounced than the decrease in the number of ties and the consequent rise in the network density. In this period there was a sharp reduction in the number of projects (Figure 2).

Table 1: Country-level analysis of international knowledge networks

	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014
Countries	17	25	42	64	75	57
Ties	85	150	253	783	1340	1037
Density	0.625	0.500	0.294	0.388	0.483	0.650
% Strong ties	67	63	61	66	61	60

Source: Own elaboration.

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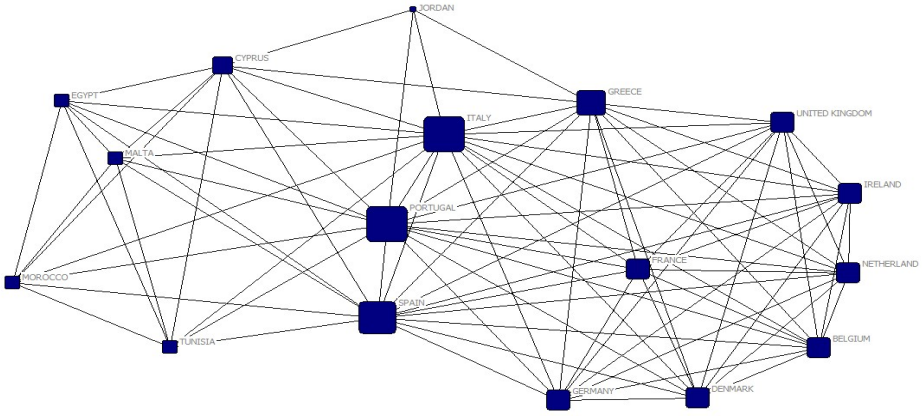
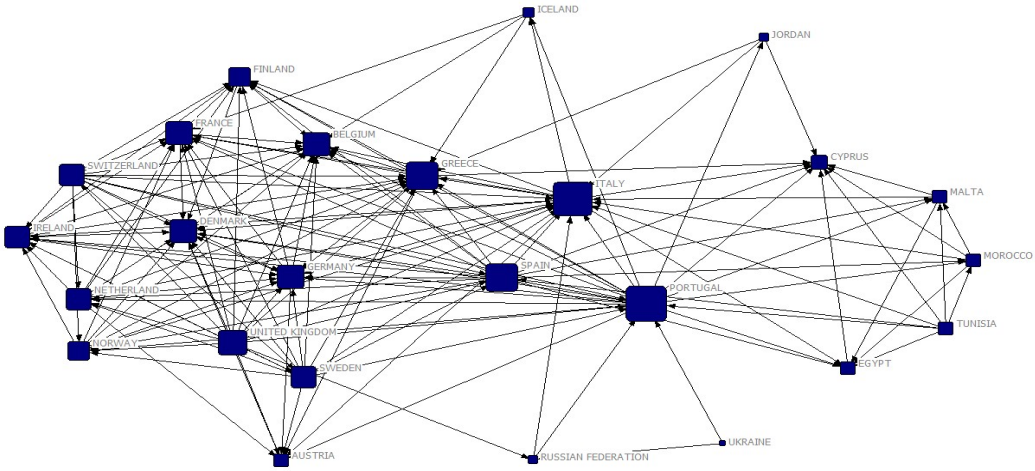
Figure 2: Inter-country network diagrams

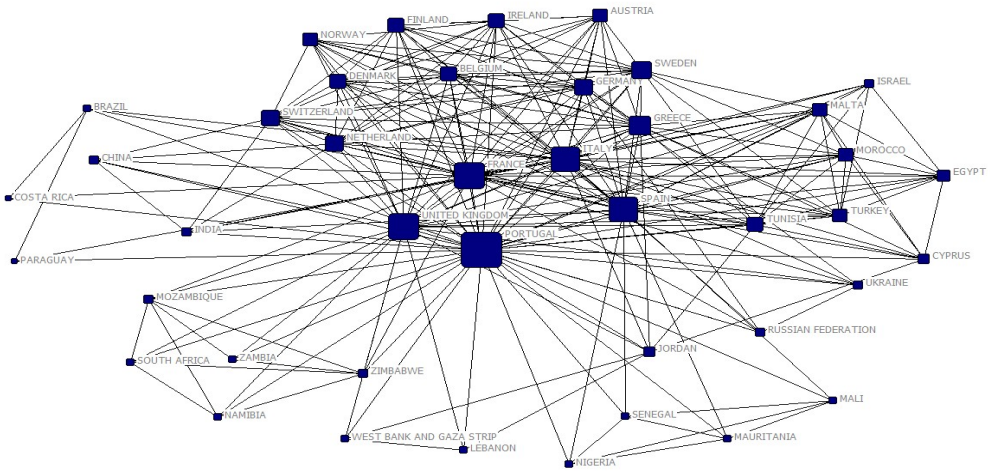
1985-1989



1990-1994



1995-1999



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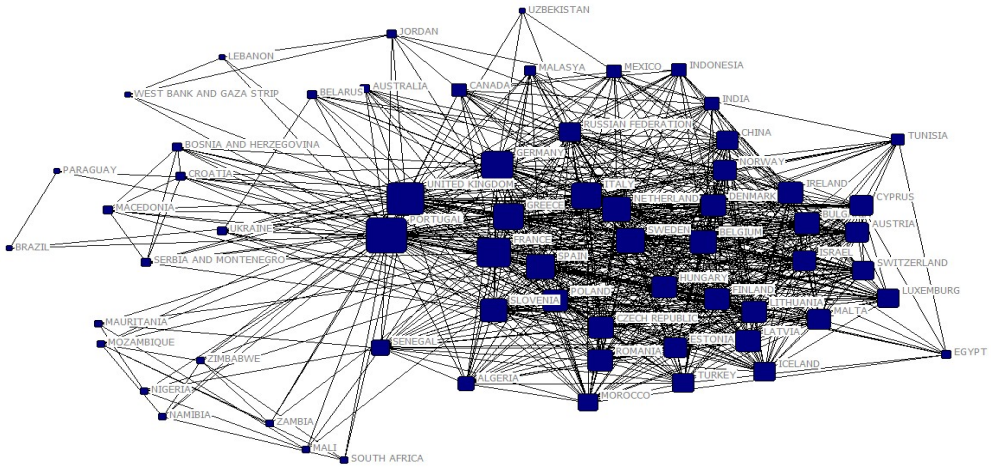
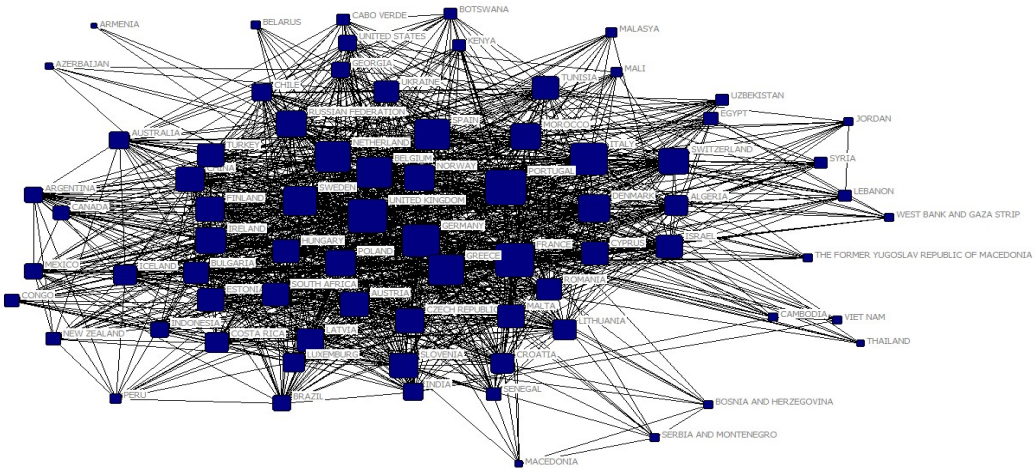
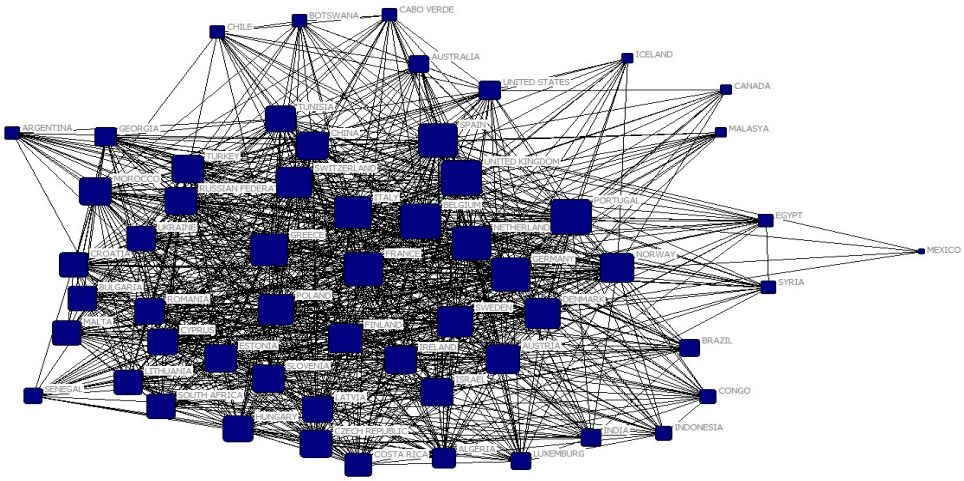
2000-2004



2005-2009



2010-2014



Source: Own elaboration.

Legend: The size of a square is proportional to the degree centrality of the country represented.

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The evolution of inter-organisational networks is depicted in Table 2 and in Figure 3. We can observe the growth both in the number of organisations involved in these collaborations, and in the number of links between them. Therefore, the knowledge network becomes more populated. As noted in the country-based analysis, there is, in the last period, a sharp reduction in the size of the network, both regarding the number of partners and the number of ties. However, contrary to what we have found for countries, we do not find a densification in the inter-organisational network.

The analysis of the composition of the inter-organisational networks enables us to characterise the types of actors which are active in this knowledge sharing process. As mentioned before, four different organisation types are considered: universities and research centres, companies, government agencies and other organisations. As expected, universities have a high participation in these networks. However, the results show a significant increase in the participation of companies, which in the penultimate period have reached the same percentage as universities. This result contrasts with those of other empirical studies using the CORDIS dataset, namely the one by Protogerou, Caloghirou and Siokas (2010) on information society technologies.

Table 2: Organisational-level analysis of international knowledge networks

	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014
Organisations	81	297	465	1399	1871	987
Ties	440	2124	2741	24543	40699	20449
Density	0.136	0.048	0.025	0.025	0.023	0.021
% universities	59	57	49	42	44	47
% companies	25	28	34	41	44	38
% government	11	10	12	9	6	9
% other	5	5	5	8	6	6

Source: Own elaboration.

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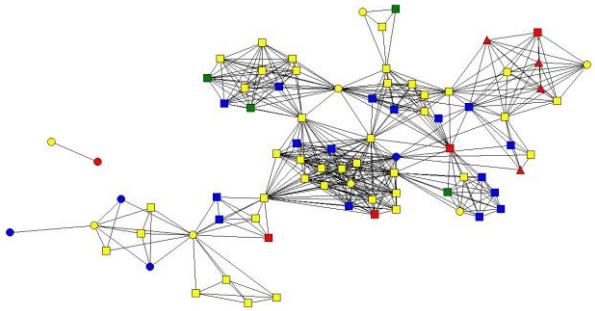
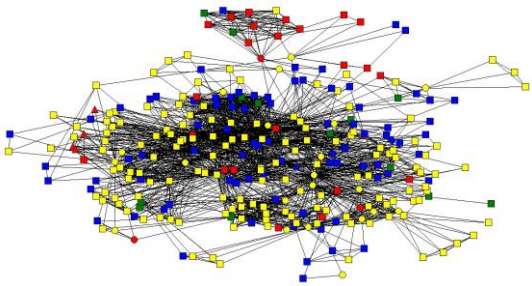
Figure 3: Inter-organisational network diagrams

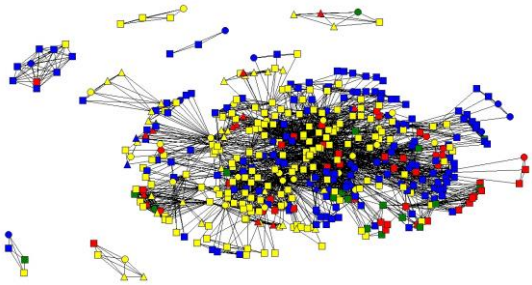
1985-1989



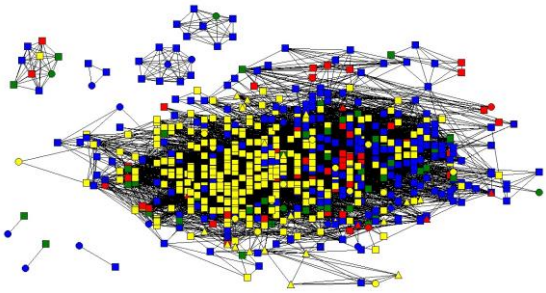
1990-1994



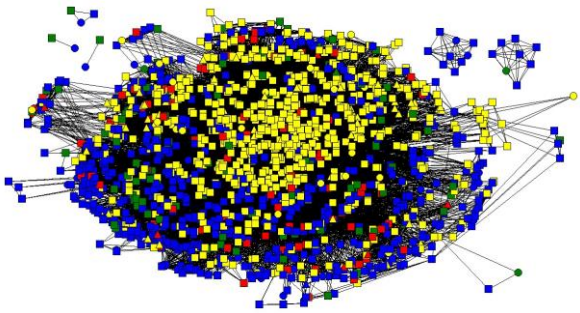
1995-1999



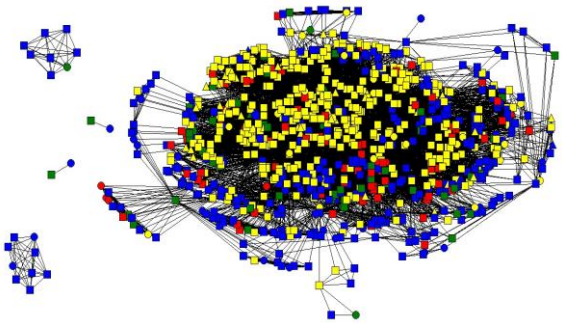
2000-2004



2005-2009



2010-2014



Source: Own elaboration.

Legend: Colours represent the organisation's type: yellow – universities; blue – companies; red – government; green – other. Shapes represent the organisation's country: circle – Portugal; square – other EU country; up triangle – non-EU country.

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4.2 Types of relation

In order to apply the Triple Helix framework we have classified each project according to the type of partners involved. For instance, projects only involving research organisations were classified as U-U projects, projects involving partners from the academia and the industry were classified as U-I and projects involving academic, industry and government partners were classified as U-I-G.

Results in Table 3 show, as suggested by the Triple Helix model, an intensification of research involving simultaneously academic, industry and government partners: in the last period, almost half of the projects are U-I-G. In the first periods, the projects involved only two types of organisation, with the dominance of university-industry collaborations. In addition, universities were always present in the research collaborations.

As we move forward in time, we can observe a sharp decline of "purely academic" projects, which are completely absent in the last period, suggesting the relinquishment of the "ivory tower model" of knowledge production (Etzkowitz et al, 2000) in these collaborations. Moreover, projects involving industrial partners only are slowly increasing in importance.

Table 3: Evolution of types of projects (%)

	1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014
U-U	25.0	27.7	18.3	9.8	8.6	0
I-I	0	0	2.4	6.7	5.4	7.5
G-G	0	0	0	0.5	0	0
U-I	66.7	32.5	42.9	45.6	42.5	42.5
U-G	8.3	16.9	15.1	6.2	2.2	2.5
I-G	0	0	1.6	1.6	0	0
U-I-G	0	22.9	19.8	29.5	41.4	47.5

Source: Own elaboration.

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4.3 Network position

Regarding the country-based networks, we find that the Portuguese organisations collaborate mostly with other EU countries, which is revealed by the countries' values of degree centrality (Table 4). Among those partners, we find large countries with strong S&T systems, but also smaller countries where renewable energy technologies have a strong presence, both at academic and industry level, as are the cases of Denmark and the Netherlands. The exceptions to this pattern are mostly Greece and Belgium. In terms of betweenness centrality, it is also possible to observe the presence of large EU countries, but in some periods non-EU countries emerge in the top 10.

Table 4: Most central countries in the knowledge networks – top 10

		1985-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014
Degree	1	Portugal	Portugal	Portugal	Portugal	Portugal	Portugal
	2	Italy	Greece	UK	Germany	Germany	Germany
	3	Spain	France	Spain	UK	France	Italy
	4	Greece	Italy	France	Italy	Italy	Spain
	5	France	UK	Italy	Spain	UK	UK
	6	Germany	Germany	Greece	France	Spain	Belgium
	7	UK	Spain	Germany	Greece	Belgium	France
	8	Netherlands	Netherlands	Denmark	Netherlands	Greece	Netherlands
	9	Denmark	Denmark	Belgium	Belgium	Netherlands	Greece
	10	Belgium	Belgium	Netherlands	Sweden	Sweden	Denmark
Betweenness	1	Italy	Portugal	Portugal	Portugal	Portugal	Portugal
	2	Portugal	Italy	UK	UK	UK	Spain
	3	Spain	Spain	France	France	France	Germany
	4	Greece	Greece	Spain	Italy	Germany	Belgium
	5	Cyprus	UK	Italy	Spain	Greece	UK
	6	-	Cyprus	Greece	Germany	Italy	Netherlands
	7	-	France	Sweden	Greece	Spain	France
	8	-	Germany	Germany	Sweden	Russian Federation	Italy
	9	-	Denmark	Switzerland	Slovenia	Belgium	Greece
	10	-	Russian Federation	Netherlands	Senegal	Netherlands	Sweden

Source: Own elaboration.

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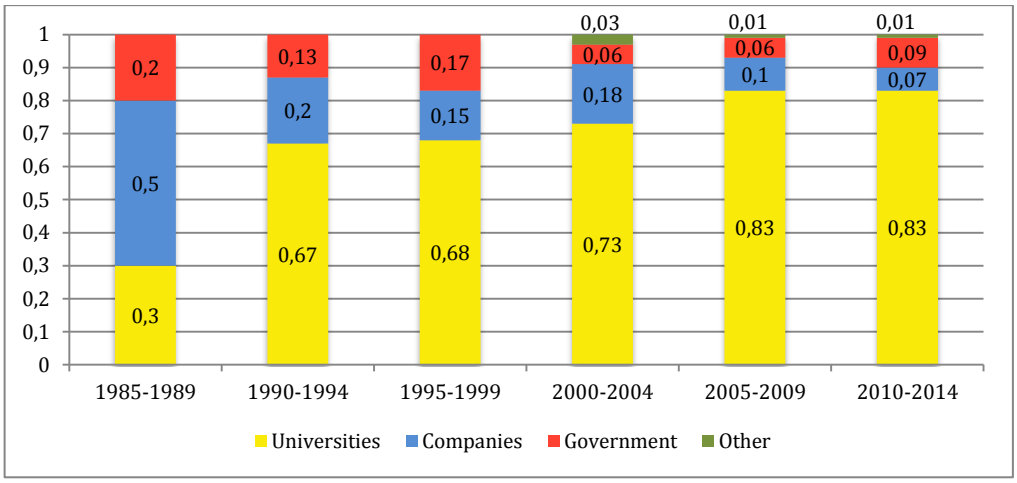
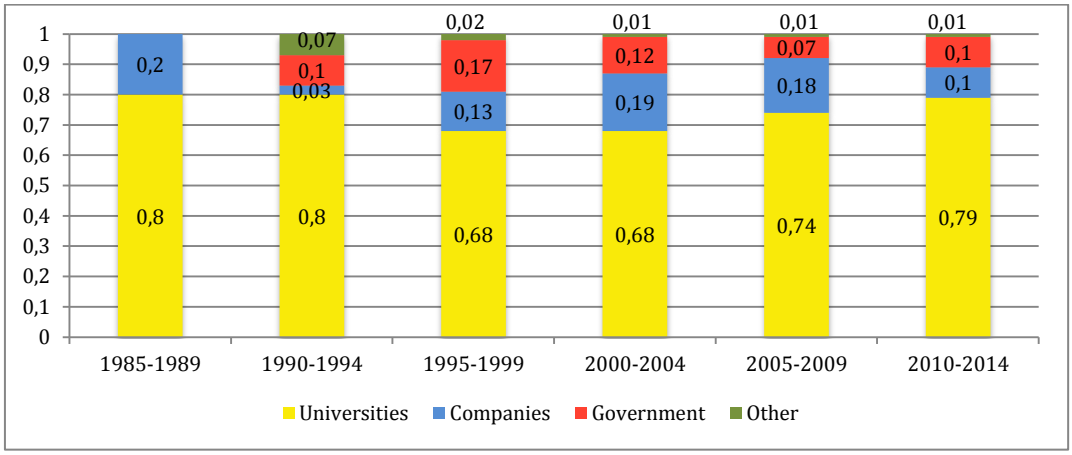
Regarding inter-organisational relations, the results show that universities are the most central actors in these knowledge networks, either if we consider degree or betweenness. This outcome is shown in Figures 4 and 5, where we present the share of each type of actor in the first decile of the centrality measure distribution. In terms of degree, we found that universities are becoming increasingly central throughout the period under analysis, whilst companies reduce their weight.

Figure 4: Share of each type of partner in the top 10% of the most central organisations in terms of degree



Source: Own elaboration.

Figure 5: Share of each type of partner in the top 10% of the most central organisations in terms of betweenness



Source: Own elaboration.

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5. CONCLUSION

In this paper, we focus on the Portuguese participation on collaborative research projects, in the area of renewable energy technologies. The main aim of the paper is to capture patterns of international knowledge sharing and to assess, in a dynamic way, the role played by the different partners involved in these knowledge networks. The paper attempts to further the understanding of the international scientific production in sustainable energy technologies.

For that purpose, we draw on the Triple Helix framework, which highlights the interaction between different types of organisation and the hybridisation of knowledge from academia, industry and government. Triple Helix scholars highlight the changes that have been taking place in the mode of knowledge production, dissemination and usage, and the actors, relations and institutional arrangements underlying these processes. We consider that knowledge networks, built from collaborative research, provide a good setting for the analysis of the change that has occurred in the mode of knowledge production and sharing.

We are analysing knowledge networks in a very relevant technological area, both at European and Portuguese level. The results of this study show the growth of the knowledge networks associated with collaborative research involving Portuguese organisations and funded by the European Commission, through general and specific support schemes, at least until the latest period of our analysis. This has resulted in the growth of the number of countries and the number of organisations involved in the collaborative research, but also in the number of partnerships established between them.

Our results confirm the important role of universities in these networks, either Portuguese or from other countries. They are the most frequent actor and, despite losing some expression in the total number of actors, they are consolidating their position in terms of degree centrality. In addition, they remain dominant in terms of betweenness centrality. This is in accordance with the fundamental thesis of the Triple Helix approach (Etzkowitz and Leydesdorff, 2000), whereby in an increasingly knowledge-based economy universities are rising in importance in the innovative process.

Our analysis uncovers an evolution consistent with other propositions of the Triple Helix framework. We observe the relinquishment of the "ivory tower model" of knowledge production, where universities produce knowledge in isolation from industry and society. The results clearly show that projects increasingly involve partners from academia, industry and government, in co-production processes. Therefore, the role of government in the area of new renewable technologies is not limited to research funding, taking also an active role in the production of knowledge.

In future research, it would be interesting to compare the analysis presented here with that of the

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Portuguese participation on collaborative research projects in other areas, such as for instance IT or biotechnology. The case of renewable energy technologies projects centred on other countries should also be addressed, in order to find out whether there are national specificities in research carried out within this technological area. Another line to be explored should be the study of the actors involved in the knowledge networks, namely the universities, which play a central role, but also of the companies involved, which have gained importance over the period under analysis.

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