The dynamics of the European water research network: a diversifying community with a stable core

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Abstract

Both in water management and in research policy there is a call for more integrative approaches to tackle large societal challenges. This requires collaboration in networks of actors with different institutional and geographical backgrounds. However, our understanding of the European water research network is limited. Applying social network analysis to data from projects in Framework Programmes 1 to 7, we identify central actors in the network and explore their institutional and geographical characteristics. Compared to the generic research network arising from all projects in the Framework Programmes, the water research network turns out to consist of organisations that are geographically more diverse and more equally distributed across different organisation types. Although the diversity of the network has increased over time, the traditional knowledge producers, higher education organisations and publicly-funded research organisations from the EU15, have kept their position in the network centre over time, resulting in a stable core since the 1980s.

Keywords: Europeanisation; Framework Programmes; Integrative participatory approaches; Research collaboration; Social network analysis

1. Introduction

Water research offers a strong potential to contribute to societal challenges. Two of the grand challenges addressed in Horizon 2020, the new European framework programme for research and innovation, are directly linked to water-related research: ‘Climate action, resource efficiency and raw materials’ and ‘Food security, sustainable agriculture, marine and maritime research and the bioeconomy’.

doi: 10.2166/wp.2015.185

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Researchers in both water management and research policy have called for an integral approach to tackle these societal challenges. Specifically in water management, the paradigm has shifted from the government as an exclusive authority managing resources to a multi-stakeholder approach in which stakeholders with various institutional backgrounds all contribute to the management of a resource. This implies the need for participatory research practices in which different actors collectively develop new knowledge (Pahl-Wostl et al., 2007; Frijns et al., 2013). Literature on knowledge production suggests that collaboration among different institutional partners drives innovation (Etzkowitz & Leydesdorff, 2000). Inspired by notions such as Triple Helix and Mode 2 knowledge production, both national and international research policies promote collaboration among organisations of different institutional backgrounds (Nieminen & Kaukonen, 2001; Potì & Reale, 2007). Collaboration in networks is hence essential to solve the water-related societal challenges.

Although knowledge about water is often specific to local (environmental) conditions, the challenges in water typically cut across administrative and cultural borders. Many countries struggle with similar issues, while the research actors are often still organised in national systems (Thomas & Ford, 2005; EIP, European Innovation Partnership, 2014). Given the importance of international collaboration in knowledge production there is a need for insight in the functioning of international research networks. Since the article by Granovetter (1973) on the strength of weak ties, a large body of literature has developed on the influence of the network structure on the performance of the network. The idea has developed that while strong ties between proximate partners may be easier for collaboration because its stability eases coordination and reduces uncertainty and transaction costs (Boschma, 2005), innovative performance will benefit from many weak and heterogeneous connections combining different knowledge bases (Nooteboom et al., 2007). In the water sector, however, our understanding of the structure of research networks is still limited. Existing literature (Breschi & Cusmano, 2004; Heller-Schuh et al., 2011) has provided insight into the features of the European research network at a generic level. Given the large differences between network dynamics across scientific fields and economic sectors, however, these generic analyses have limited value for understanding the composition of the network in a specific research field such as water research. The need for a better understanding of such collaboration networks is twofold. First, policy makers need deeper insights in the functioning and configuration of the networks to design effective funding instruments. Second, organisations in the water knowledge field can benefit from network analysis. Strategic insights in their positioning in the networks can support them in the transition to an adaptive and integral approach to water management.

The aim of this paper is to contribute to the understanding of the European water research network by an analysis of the participation of different actors in European Framework Programmes (FPs). What types of organisation are most central in the network, and what is their geographical distribution? We will enrich our analysis with a comparison between the water research network and the generic network constructed from all FP projects.

To enhance our understanding of the role of businesses, universities and governments, this paper specifically addresses the centrality of different types of organisation in research networks. Organisations become part of a research network by engaging in collaborative activities with others. Centrality refers to the position of individual organisations in a network, in terms of the number of partners they have, and the extent to which they are a crucial link in the network to connect other organisations (e.g. Newman, 2004). Network centrality hence indicates which organisations in the network have the best access to other organisations in the network.
Our three research questions are as follows:

- How has the composition of the European water research network developed, in terms of participation of different types of organisation and geographical distribution?
- What factors explain the structure of the network in terms of stability and heterogeneity?
- What factors explain the position of different organisation types in the network?

Access to different sets of data on the level of countries allows us to carry out more in-depth analyses of the geographical distribution of the network. This will hence also be our focal point in addressing the first question.

The article is organised as follows: in section two we give an overview of existing literature and present our conceptual framework. In section three we explain how we collected and processed our data and what methodology we used to analyse it. In section four we present our findings and results. In section five we present our conclusions and discuss implications for future research and policy.

2. Theoretical framework

In addressing the questions set out above, our study builds on several bodies of literature. Below, we briefly survey the literature on three issues central to our research question: the development of international research networks, the participation of different types of organisation in research networks, and the geographical development of research networks.

2.1. International research networks

Many studies have analysed characteristics of research collaboration networks, including the networks fuelled by FP funding. Some studies investigate changes in the knowledge flows at the level of regions (Foddi & Usai, 2013; Scherngell & Lata, 2013). Other studies analyse the network at the participant level. They suggest that collaboration is facilitated by prior acquaintance, thematic proximity and geographical proximity (Paier & Scherngell, 2011). Social distance seems to be more decisive than geographical distance (Autant-Bernard et al., 2007), but its influence is not evident in every study. A study on project proposals did not observe any significant tendency by organisations to preserve the same consortium across projects (Hazir & Autant-Bernard, 2012). R&D management literature suggests that the benefits of bilateral collaboration also stem from individual characteristics of the actors involved. Studies have shown that a company’s research potential, size and absorptive capacity increase the probability of collaboration (Autant-Bernard et al., 2007).

An important question at the network level is how well different types of actors are embedded in the network. A common notion to assess the position of an actor in the network is centrality. The concept can be operationalised in such a way that it accounts both for the access an actor has to other players, and for how often an actor forms an essential link between two other players. Earlier research has identified some relationships between the centrality of actors and their institutional characteristics. In general, organisations in higher education and public research tend to take the most central positions in a research network, while small and medium-sized enterprises (SMEs) have weaker positions (Protogerou et al., 2010). However, the specific roles and positions of different organisation types vary strongly...
across research domains. In aerospace, for example, companies occupy most central positions, while in the life sciences universities occupy very central positions (Heller-Schuh et al., 2011). It has also been shown that the geographical position of an actor can be of large influence to the centrality in the research network (Foddi & Usai, 2013).

2.2. Participation of different types of organisation

Science and innovation policy literature suggests that research networks have an increasingly heterogeneous composition. Gibbons and co-authors have claimed that the organisational diversity of research increases and that a larger variety of organisations cooperate in the production of knowledge (Gibbons et al., 1994). Studies using the ‘Triple Helix’ framework have also reported that the interactions among governments, universities and industry are intensifying (Etzkowitz & Leydesdorff, 2000). Both bodies of literature suggest that the intensifying interactions are important drivers of innovation and deserve to be stimulated and supported by public policies. Indeed, over the past few decades policies for research and innovation have provided incentives for universities to strengthen their collaboration with industry, the government and other organisations (Nieminen & Kaukonen, 2001; Potì & Reale, 2007).

Empirical evidence suggests that the interactions between different types of organisation collectively embarking on research activities are indeed intensifying (Hicks & Katz, 1996; Geiger & Sá, 2008). However, little is known about the precise position businesses and governmental organisations adopt in research networks. Institutional characteristics, such as the routines, aims and incentives of an organisation, are expected to influence centrality of an organisation in a network (Owen-Smith & Powell, 2004). Because knowledge production is not a primary task of non-academic organisations, one may wonder whether they will ever become central in research networks, as equally central partners with universities or public research organisations. The water sector involves actors from a broad range of institutional backgrounds (EIP, 2014), but it is unclear what that implies for the representation and centrality of actors in the research and knowledge production network.

2.3. Geographical distribution

The development of international research networks has been studied not only in terms of organisation types but – particularly in Europe – also in geographical terms. A central issue is the degree to which one can discern a trend of Europeanisation, the increasing integration of national research activities (Barré et al., 2013). Concerns about the fragmentation and compartmentalisation of national research efforts led in 2000 to a political desire for a European Research Area (ERA). The main instruments used to accomplish this are the funds of the Framework Programmes (Breschi & Cusmano, 2004), which promote the development of research networks across Europe. The Framework Programmes, especially from FP5 onwards, have included explicit incentives to integrate research in Europe and to transcend geographical borders (DeLanghe et al., 2009).

The empirical evidence about the effects of these policies on international research networks is ambivalent. Some studies have found evidence for the development of a European Research Area. Geographical factors (physical distance, territorial borders and language) have less impact on collaboration patterns in FP projects than on the collaboration patterns that emerge from co-patenting (Lata et al., 2012). Once the collaborative links are established through FP projects, they tend to continue after FP funding has ceased (Defazio et al., 2009; Hoekman et al., 2013). Recent decades have witnessed
a slight decrease in the influence of territorial borders within Europe on scientific collaboration (Schern-gell & Lata, 2013). Still, there is no evidence of large structural changes in the collaboration patterns between member states that would indicate further Europeanisation of research networks (Hockman et al., 2010; Chessa et al., 2013). For water research in particular, it has been claimed that the research is still largely organised in national systems (Thomas & Ford, 2005; EIP, 2014). What is more, the creation of a European Research Area is still incomplete in the sense that different member states of the European Union participate unequally in the European research network. The participation rate among the new member states in Framework Programme projects, for example, lags behind that of the older member states (Annerberg et al., 2010).

3. Data and methodology

3.1. Data selection

This paper is based on an analysis of data on participation in projects under the European Framework Programmes. Research networks are often analysed on the basis of research outputs, such as scientific papers, patents (Lata et al., 2012; Chessa et al., 2013) and/or survey data (Weterings & Ponds, 2009; Ferru, 2010). Data on the collaborative links in projects funded by the FPs are a promising alternative source of data for studying patterns in research networks (Heller-Schuh et al., 2011). Because the FPs explicitly aim both to promote Europeanisation and to involve actors with different organisational backgrounds, the research networks emerging from the FPs are well suited to answer questions about the relative impact of the country of origin and organisation type of an actor on its centrality in a research network in relation to the funding it receives. However, the policy-oriented nature of the FPs may promote a specific collaboration pattern, which should be kept in mind when interpreting the analysis of the networks emerging from their funding.

For our analysis we used the EUPRO database, which contains a cleaned and harmonised version of the publicly available data about FP projects through the information service CORDIS (Barber et al., 2008). EUPRO was produced by the Austrian Institute of Technology (AIT) and contains information about all funded projects in the FPs. Based on a set of selection keywords (see below) we extracted all water-related projects from the EUPRO database from FP1 to FP7 whose latest updates were in March 2010. Since FP7 has continued for several more years, our analysis did not allow us to draw conclusions about trends that might have occurred in the last few years of FP7, such as an increasing emphasis on innovation and a weaker emphasis on the inclusion of new member states.

In order to construct a database containing all FP projects on ‘the water sector’, we developed a set of keywords to filter out the relevant projects. This selection method is chosen because water cuts across many categorisations. We hence could not simply select several water-related calls in the FPs. This would have improved the precision of the selection, but at the expense of the recall: we would have missed out on substantial parts of the water network. In this paper we define the water sector as consisting of all human activities associated with the water cycle: production/purification and distribution of drinking water, collection, transport and treatment of wastewater, water storage, water use and water management, including flood protection. We excluded waterborne transport, maritime and off-shore activities, oceanography, coastal research and fisheries. Although the boundaries between these fields are sometimes blurred, they tend to function as separate communities with their own
organisations and scientific disciplines. Starting from this definition, we have formulated relevant keywords. In doing so, it is important to find a good balance between precision and recall, making sure most selected projects are relevant but also taking care not to exclude too many relevant projects. We took a three-stage-approach: we first used a very broad set of keywords to extract all potentially relevant projects, see Appendix A (available with the online version of this paper). Second, we employed a more refined set of keywords – building on Wen et al. (2011) – to filter out all false positives. To find additional terms related to trends and policy contexts, we consulted several policy documents, such as the Strategic Research Agenda of the Water Supply and Sanitation Technology Platform, the Strategic Implementation Plan of the European Innovation Partnership on Water, and EU Framework directives related to water. Third, we consulted several water experts from across Europe with experience of FP projects to add more keywords, with special attention to keywords typically used in the 1980s and 1990s. We have tested all potential keywords with random samples of projects to explore what kind of projects were extracted from the database. This final step of refinement has helped to reduce the number of false positives even further, without ignoring many relevant projects. It has resulted in a search algorithm that we have run on the entire EUPRO dataset. The final search algorithm is in Appendix A.

3.1.1. Data on scientific publications and R&D budgets. Beside the data on projects in the FPs, we used two other datasets to explore explanations on the distribution of projects over countries. We extracted data from the Web of Science (WoS) about publications in scientific journals in the period 2006–2008. This is a relevant timeframe for analysing projects in FP6 (2002–2006) given the conventional time lag in publications. Publications are often submitted at the end of a research project, and it takes a while before they are actually published; the exact timeframe was chosen because we had a cleaned and harmonised database available for that timeframe. We selected publications on water research with the help of keywords, similar to (though less extensive than) the set of keywords used for the main data in this article. We also extracted data on the R&D budget per country in the years 2002 to 2006 from the European statistics office, Eurostat.

3.2. Methodology

The network is based on participation in FP projects. Joint participation in a project is the basis for having a link in the network. The network is hence an affiliation network, with information of subsets of actors (the organisations) that participate in the same event (an FP project). We have constructed the network as a unipartite structure of organisations, linked by undirected edges. Our motivation is that we are essentially interested in the role of organisations, not of the projects (cf. Protogerou et al., 2010). All partners in a project are assumed to collaborate with each other. If an organisation participates in more than one project, the collaborators in one project become (indirectly) linked to the collaborators in the other project. To get more insight into the network and its constituents, we first generated a few basic statistics of the network, which are listed in Table 1 (see, for example, Newman (2004) for a broader discussion on these statistics). We then extended the results with both more elaborate statistical counts and comparisons with data on scientific publications and R&D budgets and more in-depth social network analysis using the concept of centrality. To enrich our interpretation of the results, we have consulted experts from state funding agency AgentschapNL (now RVO.nl), research council NWO, KWR Watercycle Research Institute, consultancy Evers + Manders, and European technology platform WSSTP.
3.2.1. Operationalising centrality. To assess the centrality of organisations in the network, we used two indicators from social network analysis. First, weighted degree centrality counts all the ties (edges) a participant has, taking into account how often two actors have collaborated (Newman, 2004). Second, we also measured eigenvector centrality, which accounts for the possibility that an organisation has only two direct collaborators but still functions as the only link between two otherwise separated parts of the network. This indicator assigns relative scores to all nodes in the network depending not only on their own edges but also the edges of collaborators; the scores are normalised values between zero and one, where a value of zero means that a node has no links to any other node, while the node with the highest centrality in a network per definition takes the value one – this is the node with the highest weighted sum of centralities in its neighbourhood. This measure can help assess what kind of nodes have most influence on the network (Bonacich, 2007).

3.2.2. Operationalising geographical and institutional diversity. To investigate the geographical diversity of the network and the degree of Europeanisation, we explored the differences between the centrality of organisations from traditional European member states, the newer entrants and non-European partner states.

In operationalising institutional diversity, we assume that a number of organisation types can be distinguished that each share a number of institutional characteristics, such as their resilience and the way they use and disseminate scientific findings. Following the classification in the EUPRO dataset (Barber et al., 2008), we distinguished seven different organisation types (see Table 2).

3.3. The organisation as a relevant aggregation level for network analysis

This study analyses a research network at the level of organisations and sub-organisations. Innovation increasingly depends on the ability of organisations to access the newest technological insights and to establish connections in order to bring products or services to new and existing markets. To acquire new knowledge, organisations strongly depend on their knowledge networks (Augier & Vendelø, 1999). The organisational level is also highly relevant for the networks that result from the European Union (EU)
FPs. Most of the projects are conducted by a consortium of organisations. Some instruments used in the FPs explicitly encouraged specific organisation types to participate, in particular firms (EC, 2007).

However, even within a sectoral network, large organisations sometimes operate in a variety of unrelated activity areas. The analysis of research networks becomes more informative if such organisations are split into sub-entities representing coherent activity areas; the decision to engage in collaboration with a specific partner is usually taken at the level of a sub-entity rather than at the highest aggregation level of an organisation. Moreover, in most cases the collaborations in a specific activity area will be unknown to the colleagues in other activity areas within the same organisation. In our analysis, therefore, we broke down universities into faculties or schools, and research institutes into research areas. Unfortunately, insufficient information was available on organisational structures in industry, consultancy and non-profit organisations, so only multinationals were broken down into national branches (see Barber et al., 2008). This does not imply that we have analysed incomparable units, because the organisations in the categories outside universities and research institutes generally participated in only a few projects in our database. The term ‘organisation’ as used below therefore also includes sub-organisations.

4. Analysis and results

4.1. Geographical and institutional development of the network

Let us first discuss how the European research network on water has developed over time and explore how its dynamics compare to the development of the network emerging from all FP projects. Table 3 presents the descriptive statistics of each FP as a separate network, and the network that is constituted by the grand total of all FPs. The network has grown enormously, in terms of projects per FP and in terms of participants. The number of participants per project and the average degree of organisations have increased strongly over time. These developments are similar to the developments in the generic network constituted by all FP projects (Heller-Schuh et al., 2011). They are mainly consequences of the strong increase of both the familiarity and the available funds in the FPs over time. Probably as a co-effect, the interconnections in the water network have become stronger over time. The giant component is much larger in relative terms in the latest FPs than it was in the first FPs, which is a common feature of networks with a growing number of nodes. The large difference in size between the generic network and the water network also implies that it is not very informative to compare
them on this aspect. The average distance has not changed much over time; the figures are comparable to the generic FP network (cf. Heller-Schuh et al., 2011). The density decreased over time until FP6, which was only to be expected, as the number of nodes and hence the number of potential links has grown strongly over time. The incidental increase of density in FP6 is associated with the strong increase in the number of partners per project at that time, especially in Integrated Project and Networks of Excellence. In FP7 there have been very few calls for Networks of Excellence; the number of partners per project has dropped again (Arnold et al., 2009). The largest distance is smaller in the water network (6–8) than in the general network (7–11). Combined with the relatively high clustering coefficients this implies that the water network is a ‘small world’-type network, in which knowledge can flow relatively easily and quickly through the network (Cowan, 2006; Heller-Schuh et al., 2011). To some extent this may be attributed to the fact that the generic network is simply much larger, but still the relatively high clustering is remarkable given the fact that the water sector is characterised in the literature as fragmented and bound in national systems (Thomas & Ford, 2005; EIP, 2014).

4.1.1. Explaining the geographical dynamics. We have examined the geographical patterns that we found in more depth. Using FP6 data we explored three different factors that may play a role the geographical dynamics observed: the R&D budget, projects in the entire FP, and the scientific output on water of each country.

The large disparities in absolute counts of projects among countries can be partially explained by a difference in overall R&D capacity (see Figure 1). The positive relationship between water projects and R&D budget corresponds with an earlier analysis of the generic research network, based on projects in FP2 and FP3 (Sharp, 1998). However, the ratio between the two is still quite skewed across countries, indicating that new member states and countries with a relatively small research budget, such as Portugal, have a relatively large number of projects on water.

To account for the possibility that some countries specialise more strongly in water-related knowledge production than others, we compared the relative share of water in FP6 projects with the relative share of

<table>
<thead>
<tr>
<th>Statistic</th>
<th>FP1</th>
<th>FP2</th>
<th>FP3</th>
<th>FP4</th>
<th>FP5</th>
<th>FP6</th>
<th>FP7*</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of network (nodes)</td>
<td>198</td>
<td>547</td>
<td>807</td>
<td>1,854</td>
<td>3,007</td>
<td>3,311</td>
<td>1,318</td>
<td>7,767</td>
</tr>
<tr>
<td>Number of projects</td>
<td>167</td>
<td>139</td>
<td>256</td>
<td>616</td>
<td>942</td>
<td>647</td>
<td>295</td>
<td>3,062</td>
</tr>
<tr>
<td>Average partners per project</td>
<td>2.1</td>
<td>6.1</td>
<td>5.4</td>
<td>5.1</td>
<td>5.5</td>
<td>8.7</td>
<td>6.9</td>
<td>6.1</td>
</tr>
<tr>
<td>Average countries per project</td>
<td>1.7</td>
<td>3.6</td>
<td>3.7</td>
<td>3.5</td>
<td>3.8</td>
<td>5.0</td>
<td>4.3</td>
<td>4.2</td>
</tr>
<tr>
<td>Average degree</td>
<td>4.3</td>
<td>15.3</td>
<td>10.8</td>
<td>10.2</td>
<td>15.9</td>
<td>34.5</td>
<td>20.5</td>
<td>18.9</td>
</tr>
<tr>
<td>Average weighted degree</td>
<td>5.7</td>
<td>16.5</td>
<td>11.7</td>
<td>11.2</td>
<td>16.7</td>
<td>37.3</td>
<td>21.4</td>
<td>21.0</td>
</tr>
<tr>
<td>Largest component (%)</td>
<td>47.0</td>
<td>89.6</td>
<td>87.4</td>
<td>83.0</td>
<td>85.0</td>
<td>96.6</td>
<td>96.1</td>
<td>93.7</td>
</tr>
<tr>
<td>Largest distance</td>
<td>8</td>
<td>6</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>7</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td>Average clustering coefficient</td>
<td>0.48</td>
<td>0.84</td>
<td>0.83</td>
<td>0.79</td>
<td>0.79</td>
<td>0.86</td>
<td>0.87</td>
<td>0.79</td>
</tr>
<tr>
<td>Density</td>
<td>0.086</td>
<td>0.028</td>
<td>0.013</td>
<td>0.005</td>
<td>0.005</td>
<td>0.010</td>
<td>0.016</td>
<td>0.004</td>
</tr>
<tr>
<td>Modularity</td>
<td>0.62</td>
<td>0.65</td>
<td>0.67</td>
<td>0.70</td>
<td>0.67</td>
<td>0.58</td>
<td>0.67</td>
<td>0.50</td>
</tr>
</tbody>
</table>

*Last updated until March 2010.
water in scientific publications, see Figure 2. Two groups of countries stand out, with a surprisingly large share of water projects in FP6. The first group of countries, comprising Malta, Romania, Latvia, Lithuania and the Czech Republic, have a small share in the scientific output compared to other countries, while they have a large share in the FP. A second group of countries (Cyprus, Estonia, Portugal) seem more genuinely specialised in water research: they are relatively prevalent both in the FPs and in terms of scientific output.

Altogether these three indicators show that small countries have a relatively large share in the European water research network: they have more projects per euro invested in R&D. This effect is stronger in the field of water than in the Framework Programme in general. For some small countries this may relate to a specialisation in water research, for other countries it seems that water is a relatively accessible field to start participation in the FPs.

4.1.2. Distribution of projects in groups of countries. The differences in participation also relate to the member status of a country: EU15, new member state (NMS), associated country, or other. Figure 3 shows the continuing large share of the EU15: in the first FPs there was at least one EU15 country in literally every project, and there is still at least one partner from the EU15 in about 90% of the
most recent projects. The share of projects with at least one NMS partner increased until FP6, but dropped slightly in FP7, to below 30%. The rise until FP6 can be partially attributed to explicit incentives in the calls to include organisations from the NMSs. The share of associated countries has...
increased strongly over time, and is now also around 30%. This is even more remarkable if one notes that the lion’s share comes from only three countries: Norway, Switzerland and Israel. This is not only the case in water projects; these three countries have a strong participation in FP6 in general.

4.1.3. Participation of different types of organisation. Universities and public research organisations have the largest representation in the water network, see Figure 4. They have increased over time in absolute numbers, but their relative share has decreased. This is mainly due to the rise of industrial partners (up to about 30% in FP7). Governmental organisations have a relatively small but stable share in the network. The ‘other’ group was marginal in the first FPs, yet nowadays this group is larger than the group of governmental organisations. Interestingly, the shares of industry and of other organisations have been larger in the network across all FPs than in any of the individual FPs. This suggests that participation by organisations in these categories often remains limited to one FP. Organisations in education and research tend to participate in more subsequent FPs than organisations in industry and in other organisations.

The water network differs from the generic network in terms of composition and dynamics. In the overall network, the share of higher education organisations increased from 32% in FP3 to 37% in FP6 (EC, 2004). In the water network, it decreased from 45% in FP3 to 31% in FP6. The share of industry (including consultancies) decreased in the general network, from 35% in FP3 to 30% in FP6 (EC, 2004), whereas it increased in the water network, from 22% in FP3 to 27% in FP6. For public research organisations it decreased both in the general network and in the water network: from 30% to 26% and from 28% to 24% respectively. All other categories together increased in the general network to 7% in FP6, but had a higher share in the water network: 20% in FP6. The differences in share may partly relate to differences in classifications, but these cannot completely account for the trends observed. Two clear developments can be identified: first, despite all the attention for the Triple Helix and participation of actors outside the traditional research system, the generic network is hardly diversifying, industry participation is even decreasing over time. Second, the composition of the water network is much more diverse than the generic network, and diversifies over time. This corroborates the characterisation of

![Figure 4. Share of each organisation type in the water network in participation by unique entities, per FP (count of total unique participating entities per FP in brackets).](https://iwaponline.com/wp/article-pdf/18/2/493/404463/018020493.pdf)
the water sector as consisting of many different organisation types, from utilities to water authorities, from consultancies to university departments (Thomas & Ford, 2005; EIP, 2014) and also shows that all these actors have found their way to EU funding.

To summarise, the FPs have witnessed strong growth over time in terms of projects, and even stronger growth in terms of participating organisations. Compared to the generic network, the water network can be characterised as a ‘small world’ network, where information flows easily. Although the ‘old’ countries still dominate the network in absolute terms, the water network stands out by the strong participation of small countries. The water network has also diversified over time in terms of institutional backgrounds. It is now institutionally more diverse than the generic network.

4.2. Centrality of organisations in the network

In this section we analyse how the centrality of actors in the network relates to institutional and geographical characteristics and the criteria of the available funding instruments. There are strong differences between the average centrality across organisation types (see Table 4). The distribution

<table>
<thead>
<tr>
<th>Orgtype</th>
<th>Measure</th>
<th>FP1</th>
<th>FP2</th>
<th>FP3</th>
<th>FP4</th>
<th>FP5</th>
<th>FP6</th>
<th>FP7</th>
<th>ALL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consultancy</td>
<td>Median weighted degree</td>
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*Measure cannot be computed because there are not enough organisations in the respective category.
of the centrality measures shows that all organisation types contain a large group with a low centrality, having few collaborations and positioned far from the core of the network. In some organisation types, in particular education and research, there also is a large group with a very high centrality; this is lacking in other types such as industry. This is recognised by the interviewed experts, who indicated that universities and public research institutes often benefit from dedicated resources such as project management offices for funding applications and project management. The administrative load for industrial actors is considered by many as rather large. The experts also indicate that many businesses have a relatively narrow focus and expertise, which explains why their centrality is lower: participation in FP-projects is only attractive for them if the scope of a call exactly matches their own expertise. The differences between the organisation types have increased strongly over time. For example, in FP1, the median of weighted degree ranged between 1 and 3 (with the exception of the ‘other’ category, yet there were only two entities in this group in FP1); in FP7, the medians ranged between 11 and 20.5, and the full ranges were even more diverse.

Organisations in education have the highest centrality in the network. They are immediately followed by research organisations. Governmental organisations have a much lower centrality than the first two. They lack a subgroup of entities with an extraordinarily high centrality. However, compared with all other categories they are relatively central. Industry has a relatively low centrality; the average organisation in industry has few links, and the ones it has are not important for the network. This seems to deviate from the generic network: there education and research have the highest centralities as well, but 15 out of the 100 most central organisations in FP6 are from industry (Heller-Schuh et al., 2011). This may relate to the fact that some multinational firms with a variety of activities have a strong position in the generic network; their activities in water alone (if any) are insufficient to make them a key player in this specific network.

4.2.1. Characteristics of organisations with a high centrality in the network. Given our finding that the largest differences in centrality are among the most central participants per type, let us now focus on the 50 organisations per organisation type with the highest scores on weighted degree and eigenvector centrality. We will explore these organisations in terms of country of origin, time since first participation in FPs, and number of projects. It turns out that the participants with the strongest positions participated in many more projects than the average participant. The difference amounted to a factor between two and eight, see Table 5. Their relevance to the network as measured by their eigenvector centrality differed even more from the average participant. The central organisations in higher education and public research have relatively long experience of FP participation, but organisations in the other categories do not. However, once they participate, they are less likely to leave: the actors with a high centrality have participated in many more FPs than the average. It follows from inspection of the groups of 50 organisations with highest centrality and degree that by far the most organisations with a high centrality are from the EU15.

All in all, we found that the skewed distribution of centrality across different organisation types has become even more skewed over time. The population of organisations with the highest centrality scores is dominated by research organisations and universities. Many actors from industry are involved, but almost all of them have a very low centrality.
5. Conclusions and discussion

In the concluding section of this paper, we present the answers to our research question, set out policy recommendations and present suggestions for future research.

5.1. Conclusions

Our analysis has shown that the network of research collaborators in water has grown strongly since the first FP in 1984 in terms of projects and in terms of participating organisations. Still, the largest distances in the water network are small and the clustering coefficients are relatively high. This implies that the water network functions as a ‘small world’ network, where information can flow relatively quickly. This characteristic is even stronger in the water network than in the generic European knowledge production network.

The dispersion over countries of the European water network follows the enlargement of the European Union over time. Remarkably, however, small countries in terms of R&D budget, including many new member states, have a relatively large number of projects. This effect is stronger in the water sector than in the generic FP network; the water network is geographically more diverse. It may be that the scarcity of funding in their own country prompts these organisations to look for funding from European programmes. In absolute terms, however, the larger and older members still dominate the projects. There have hardly been any projects so far without a participant from the EU15. In terms of organisation types the water network has also diversified over time. Especially in the later FPs the water network shows more institutional diversity than the generic network. This heterogeneity may be the result of the policy-oriented nature of the FPs which promotes collaboration with firms, governments and other knowledge users. We can conclude that the water network is still dominated by older and larger member states of the EU, yet geographically more diverse than the generic research network, and it is also institutionally more diverse than the generic network.

The stable core of the network primarily comprises organisations oriented towards knowledge production (higher education and public research organisations), mostly from ‘traditional’ countries. This effect would have been even stronger if we would have analysed universities and research institutes

Table 5. Comparison of characteristics of all entities versus the top 50 of each organisation type*.

<table>
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<tr>
<th></th>
<th>CON</th>
<th>EDU</th>
<th>GOV</th>
<th>IND</th>
<th>NFP</th>
<th>OTH</th>
<th>RES</th>
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<td>Average number of projects per entity, total</td>
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<td>1.3</td>
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<td>3.4</td>
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<td>Average number of projects per entity, top50</td>
<td>2.4</td>
<td>21.0</td>
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<td>1.8</td>
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<td>Median weighted degree, top50</td>
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<td>90</td>
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<td>Median eigenvector centrality, top50</td>
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<td>Average number of FPs per entity, total</td>
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<td>1.47</td>
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*CON = Consultancy, EDU = Education, GOV = Government, IND = Industry, NFP = Not-for-profit, OTH = Other, RES = Research.
at organisational rather than sub-organisational level. All organisation types include a large number of organisations with a low centrality in the network, but only some organisation types include a substantial group of organisations with a high centrality in the network as well. Interviewed experts state that universities and public research institutes often benefit from dedicated resources such as project management offices to write strong applications and carry out complex projects. Governmental organisations have a relatively small share of project participation, yet their centrality is relatively high. Businesses, on the other hand, have a relatively large numerical share, but their centrality is low. On this point the water network differs from the generic network, which contains a group of key players from industry. Our observation that the composition of the knowledge network is diversifying confirms claims made in the literature on the Triple Helix (Etzkowitz & Leydesdorff, 2000) and Mode 2 knowledge production (Gibbons et al., 1994). Still, our analysis indicates that universities and public research institutes remain the central hubs in the network. Although we have not formally tested this, it seems likely that the water network also has the property of preferential attachment: the actors that already have many direct collaborators are more likely to build up new collaborations than those who have few. This explains the stability of the network. Thanks to their acquired position, the central hubs in the network could strengthen their position and become an ever more prominent core of the network.

Organisations with a high centrality in general differ from the others first in that they started participating slightly earlier, and second in that they have participated over a longer period of time and in a larger number of projects. In contrast to findings on the overall network (Heller-Schuh et al., 2011), the strong organisations in the water network are not only large, broad-based research organisations, but also include smaller organisations with a thematic focus. Overall, our analysis shows that the centrality of an organisation in the research network is strongly associated with its institutional characteristics and national background: organisations from higher education and research and organisations from the oldest member states generally have higher centrality. This also implies that the core of the network is stable and homogeneous. The weak ties in the periphery of the network connect to organisations with a ‘weak’ position in several ways: the periphery is populated by organisations with more diverse organisational and geographical backgrounds, and with a lower centrality and hence fewer and weaker collaborations with other actors in the network. Probably they fuel the innovative capacity of the network by bringing in different knowledge bases and novel application areas from other networks beyond the water domain.

5.2. Policy implications

Before we close, let us elaborate on three policy implications.

First, the stable network core we have observed in the European water network can be helpful for its governance. The network diversifies: ‘new’ organisation types, especially not-for-profits and firms appear on the edges of the research network. This implies a form of network governance in water research that resembles the principle of integrated water resources management (Pahl-Wostl et al., 2007). The downside of such governance modes is that a clear division of tasks, responsibilities and accountabilities for addressing grand challenges is lacking (Biswas, 2004; Muro & Jeffrey, 2008). In the water research network under study, however, the fact that the core of the network is stable, still allows for a directed development of the network. It must be noted at the same time that the presence of these core actors can limit the introduction of new insights and approaches in the case where they all share a common dominant perspective. There are some promising developments in Horizon 2020 to
ensure long term commitment of industry. European Innovation Platforms (EIPs) have been launched to speed up the development of innovations and ensure their uptake by the market. Moreover, the European Council has announced a ‘Fast Track to Innovation’ pilot scheme that specifically aims to speed up the process from idea to market in projects. This track will probably follow a bottom-up logic, allowing participants to submit research and innovation projects at any time, making businesses less dependent on the specific themes of calls.

Second, funding instruments should be tailored to the needs and characteristics of specific research fields. Our analysis shows that the composition and dynamics of research networks vary across fields. In the field of water there are more small, specialised research organisations in the backbone of the network than in other fields. The network also includes many more organisations in the categories ‘non-profit’ and ‘other’ than the generic network. Both findings, which may relate to the relatively applied and challenge-oriented nature of the field, indicate that research policy should be tailored to the needs and characteristics of a field. The Responsible Research and Innovation approach which features prominently in Horizon 2020 demands active participation by non-governmental organisations (NGOs) and other stakeholders in the research process. This interactive and integrated approach to innovation will probably develop relatively easily in the water domain, but it will require more efforts to involve these organisations in other domains.

Third, the European Commission could consider strengthening the European Research Area by inducing collective knowledge needs. The distribution of projects over countries in general is very skewed. However, our analysis also shows that water projects are relatively accessible for new countries. This may be because most research is relatively applied and hence does not require large, well-established infrastructures for basic research, and requires less expensive equipment than other research fields. Moreover, EU legislation on water, such as the Drinking Water Directive and the Water Framework Directive, have given rise to a need to develop knowledge in this field to guarantee compliance. Apparently, regulation can act as a catalyst for participation by new countries and the development of the ERA.

5.3. Suggestions for future research

We close by discussing some recommendations for future research. First, it is an inherent feature of the type of data used that we are only able to analyse structural and quantitative properties of the network and its constituents. To gain further insights into the mechanisms behind network formation, such as the role of proximity and other factors in the selection of research partners, an analysis of data on both project proposals that received funding and those that were rejected would be promising. A second important research avenue deals with the performance of the research network, and in particular the synergy benefits for the research network that emerge from an ERA. Our study has aimed to add to our understanding of the dynamics required for such synergies. Using citation data the quality of the outputs of different water-related research projects could be investigated, which gives an indication of the value of the networks developed. Third, we recommend further research into the variation in participation of different countries in the water research network, which may relate to their respective levels

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of water security. Fourth, our understanding of the functioning of research networks could benefit from a number of case studies into smaller sub-networks to complement the macro-level analysis of the current paper with insights into the dynamics at the micro-level.

Acknowledgements

The authors would like to thank Barbara Heller-Schuh for her kind assistance in disclosing the EUPRO dataset, members of the ARC network for their assistance in delineating the field of water research, and Peter van den Besselaar, Edwin Horlings, Theo van den Hoven, Ben Kubbinga, Barend van der Meulen and Wim van Vierssen for their contribution to the research design and/or their feedback on earlier drafts of this article. The authors also thank two anonymous reviewers for their constructive comments.

References


Received 1 May 2014; accepted in revised form 21 August 2015. Available online 30 September 2015