

INTERDISCIPLINARITY IN PORTUGUESE WATER RESEARCH: THE ASYMMETRY BETWEEN THE SOCIAL AND THE PHYSICAL SCIENCES.

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ABSTRACT

Difficulties in the management of water have made clear that “technical fixes”, not taking into account social, political and cultural contexts, fail to address the root of problems and lead to unsustainability of the resource. This paper examines whether Portuguese water research is constructing interdisciplinary knowledge and how it integrates social science contributions. To explore the prevalence and nature of interdisciplinarity the co-authorships of a random selection of papers were assessed. The use of social network analysis reveals a divide between the social and the physical sciences as well as the asymmetric epistemological power between the fields.

INTRODUCTION: THE CHALLENGE OF INTERDISCIPLINARITY IN WATER RESEARCH

Anthropogenic and natural factors have led to unparalleled changes in the global water system, raising concerns for its unsustainability and a demand for better policies and management practices that are informed by solid scientific knowledge. With an aim to improve the social conditions of human kind, especially in developing countries, such matters started being discussed at least as far back as the 1977 United Nations Water Conference (Mar del Plata, Argentina). Fifteen years later the United Nations hosted an International Conference on Water and The Environment in Dublin, with the aim of addressing urgent problems related to water linked to environmental and socio-economical societal conditions. This conference proposed an Integrated Water Resources Management (IWRM) approach, for it recognised that exclusively top-down, supply-led, technically-based and sectoral approaches to water management were imposing unsustainable, high economic, social and ecological costs on human societies and the natural environment. The new approach requires the integration of different outlooks or frames of thinking about water and its management, as well as an important, not to be devalued, shift away from traditional knowledge construction circumscribed by the borders of disciplines.

Forty years later the planetary challenges linked to poor and unsustainable water management persist. They were translated into the Sustainable Development Goal 6: Ensure access to water and sanitation. As reported by the United Nations, 2.4 billion people still lack access to basic sanitation services, such as toilets or latrines; each day nearly 1,000 children still die due to preventable water and sanitation-related diarrhoeal diseases; more than 80 per cent of wastewater is discharged into rivers or seas without any pollution removal; and underground water sources in many places are threatened by the pollution produced in certain mining, farming and industrial activities, as stated by the United Nations (<http://www.un.org/sustainabledevelopment/water-and-sanitation/>). So many years after the Mar del Plata alert, one cannot but question the way science is addressing these challenges, particularly as most of the challenges denote problems which science has the scientific and technical knowledge to answer. The situation seems to be that current water research has largely ignored the underlying socio-economic forces (e.g. rapid urbanization, economic development, poverty, lack of education) and the conservation of species and ecosystem processes related to their sustainability (Braumoth & Craswell, 2008).

In other words, research does not seem to be addressing the ultimate end of water sustainability. Moreover, as people are increasingly placing a high value on maintaining the integrity of water resources and the flora, fauna and human societies that have developed around them, it has become harder to ignore sustainability issues (Gleick, 2000). Research agendas have responded by promoting interdisciplinary knowledge to a central role, for it was recognised as a precondition for sustainability (e.g. Porter & Rafols, 2009; Sterling 2004; van Rijnsoever & Hessels, 2011).

That “there is no question that research in water resources is an interdisciplinary endeavour” (p. 1865) was the conclusion reached by Freeze (1990) looking back at the interdisciplinary successes and failures of the *Water Resources Research Journal* on its 25th anniversary. Rajaram et al. (2015), reflecting on the first 50 years of the same journal, reached a similar conclusion. It is clear that the study of water includes a very wide number of disciplines such as hydrology, agronomy, civil engineering, mathematics, statistics, ecology, economy, hydrogeology, biology, chemistry, political science, history, business, sociology, and law, etc. Yet, it remains unclear for water studies what is actually meant by interdisciplinarity. Often this concept is used interchangeably with that of multidisciplinary, and even if they both pertain to the idea of linking disciplines for the purpose of researching complex problems, their purpose and reach are fundamentally different. Interdisciplinarity refers to the notion of something greater than the sum of the parts, “a synthesis of knowledge, in which understandings change in response to the perspectives of others” (Petts et al., 2008, p. 596). According to Raffols (2014) knowledge constructed this way constitutes a means of reaching new answers to new problems. By contrast, multidisciplinary refers to the addition of parts from multiple disciplines without conscious, organic integration among them (Hansson, 2012).

Multidisciplinary studies, rather than interdisciplinary studies, are still abundant in environmental studies, and this practice in itself may be at the root of the environmental problems. For Bina (2013) a significant part of the problem has arisen from the highly fragmented and reductionist manner of knowing and interpreting reality. This idea is eloquently stated by Pope Francis in the encyclical *Laudato Si*, (2015): “the fragmentation of knowledge and the isolation of bits of information can actually become a form of ignorance, unless they are integrated into a broader vision of reality” (p. 104). He also says, “If we are truly concerned to develop an ecology capable

of remedying the damage we have done, no branch of the sciences and no form of wisdom can be left out, and that includes religion and the language particular to it” (p. 45). The implications of this knowledge fragmentation for sustainability are increasingly a matter of concern and have raised demands for change (sometimes even for radical change) in the way of doing science and constructing knowledge for the 21st century (UNESCO 2016).

However, despite frequent calls to foster interdisciplinary research, active collaboration, including knowledge exchange, remains rare to date (e.g. SCSS, 2012). The difficulties of collaboration among disciplines have been widely reported. Both the formal and informal structures of university and research centres have created negative incentives for interdisciplinary teaching and research. The whole institutional organisation of university and research centres is conceived in a way that motivates and compensates narrow disciplinary orientation. At the formal level the division into disciplinary based departments, practices such as promotions and recruitment following the logic of disciplines, and teaching with a strong discipline bias, just to name a few examples, all obstruct interdisciplinary knowledge construction.

Informally there are also built-in negative incentives, such as the stigma of interdisciplinary researchers being worse than disciplinary researchers, or the accusation of superficiality in interdisciplinarity research, on top of researchers’ psychological discomfort of doing research in areas the researchers do not control epistemologically. Doing interdisciplinary research involves overcoming resistance from disciplinary logics and incumbencies that are anchored in their scientific practices (Cortner, 2000). Some of these disincentives and informal sanctions reflect the ethos of science today: science is a short term enterprise that values above all the quantity of published materials in the top journals of each discipline (Fischer et al., 2012). Because disciplinary integration is a long-term effort and implies great investment of time and energy, incentives are needed to motivate researchers to pay this price (Lyll et al., 2013).

All these obstacles are amplified if the collaboration crosses the social – natural/physical sciences divide. In its 2009 position paper, the Standing Committee for the Social Sciences of the European Science Foundation identified the collaboration between social sciences and life sciences as a key cross-cutting challenge for the 21st century (SCSS, 2012). Despite the increasingly prominent support for research engaging both the natural and social sciences (though rarely the humanities) in a truly collaborative endeavour, practice beyond statements of good intentions remains rare. One example of an obstacle is simply that researchers from both fields “do not know each other” (Varanda & Bento, 2012). In the case of interdisciplinary research on water, water conferences are usually at least twice as expensive as typical social science and humanities conferences, so social scientists working with much lower budgets cannot afford to spend their limited funds there. But even when they do get to know each other, misunderstandings are still common. Skills like empathy, positive relationships and humility are not valued and trained in the academic environment, but are preconditions for understanding one another’s position and for the effective translation of multiple knowledges into a coherent whole (Podesta et al., 2013). For instance social scientists working in natural sciences-led research projects may become frustrated by their reduced involvement in the research problem, and by the invitation to intervene only in communication and dissemination tasks (Varanda & Bento, 2013). The resistance of some social scientists to be limited to communication and dissemination tasks may be perceived by natural scientists perceive as lack of interested in collaboration (Heberlein, 1988), hence a “chicken and egg” problem.

The history of science illustrates how difficult the process of integration of knowledge from these paradigms of thinking is. Since the 19th century science has been characterised by a process of disciplinarianisation and professionalisation of knowledge (Gulbenkian Commission, 1996). A consequence of this process is that the social sciences and humanities have become marginalised. In the 19th century the context was that of the triumph of Science (Newtonian knowledge) over philosophy (speculative knowledge). At this time natural sciences (or simply “science”) had already conquered internal cohesion and an autonomous institutional life, unlike the social sciences and the humanities, which at the time had not even agreed on a common designation. The social sciences and humanities were called: arts, humanities, philosophy... By contrast, the standing of “science” was already the result of the social, political and financial support, received in return for the production of practical outputs which could be translated into immediate utility (Gulbenkian Commission, 1996).

A more recent history of the science of water depicts a not so different picture. The hydraulic-engineering and the scientific paradigms, which are closely linked to the economic-financial paradigm, have dominated water research and have guided its management in advanced industrial states and global financial systems of the 20th and 21st centuries (Hassan, 2011). Furthermore, these have subjugated the spiritual religious and aesthetic – recreational paradigms of previous epochs and have led to a deficient understanding of water systems (Hassan, 2011). Notwithstanding, the social sciences have been perceived as taking on the role of brokers between the technical disciplines (e.g. hydrological fluid mechanics, geochemistry, geomorphology, etc.) with policy making. The idea that “...the social sciences provide sound principles as guides to the public decisions about the development of water” is well established (Rajaram et al., 2015, p. 7830). But again, practice is different.

A meta-analysis of water science projects shows that persistence of disciplinary perspectives impedes the much desired integration of water science with water policy (Braithwaite & Craswell, 2008). Similarly, Freeze, again on the 25th anniversary of the *Water Resources Research* journal, recognises the lack of truly interdisciplinary policy articles: “one can count on one hand the papers that have been co-authored by physical and social scientists together” (1990, p. 1866). He adds that “the one interdisciplinary interaction that was most explicitly desired by the founders of the journal, and which has been actively promoted by every editorial board since, has in many ways been the least successful”. It is not surprising that a reliance on physical solutions continues to dominate traditional planning approaches even in the face of increasing opposition (Gleick, 2000). For Heberlein (1988) “the public is ill served as we present pieces of the puzzle but seldom the whole picture” (p. 5). This can only be overcome when all those dealing with water - both academics and practitioners - develop common frameworks, concepts and methods for knowledge construction.

Freeze’s (1990) last message was that there is great value in physical scientists and social societies sharing the same journal, but he is clear that “this is not a marriage, it is a limited partnership. We should not expect more from their relationship than it can deliver” (p.1867). Has the limited partnership moved on to a marriage 17 years later? Is water research still framed by the visions of disciplinary knowledge or is it integrated to address the water challenges of our time? Dwelling into these questions, we concentrated on water research in Portugal. Therefore, this paper aims to inform how recent water research in Portugal embeds interdisciplinarity in knowledge

construction, through the empirical analysis of the networks of co-authorships. We will focus on which disciplines cooperate in the study of water, how prevalent they are, what network patterns are to be found between them, and what they can reveal about the power relations among disciplinary fields, with a specific concern for the collaboration between the social sciences and the physical sciences.

METHODOLOGY: DATA COLLECTION AND ANALYSIS

The initial step of data collection was a web-based search (complemented by the authors and their colleagues' previous knowledge of the field) to identify all the research centres studying water in Portugal. A total of 29 research centres were found. In order to assure each research centre's specialisation in water and its level of expertise in the matter, complementary information was collected:

- description of the mission of the research centre or just the water subgroup + board members (and their disciplines);
- FCT (Portuguese Foundation of Science and Technology) field area;
- FCT evaluation.

Secondly, based on the websites of each research centre, 3 articles (year 2015 or the most recent available) were randomly chosen. These were chosen using a key word search of all the research related to water. Key words and or prefixes used were: *water, hydr, hidr, aqu, água, ocean, sea, mar, river, rio, estuar, lake, lago, rain, chuva, pluv, precip, wave, onda, bent, dam, barrage*. Tricky issues were dealt with on a case by case basis. For example, articles on some freshwater species were not regarded as water research as such in spite of having “water” in the title of the article. By contrast, research about humans or other species linked with water were accepted (e.g. a hydro-gymnastics study or a study of the effects of different water conditions on crabs). This second step resulted in 67 articles selected. Thirdly, for each article the PhD disciplines of the first 3 authors were identified. The disciplines of authors were coded based on:

- Web of Science (WoS) subject area; and
- OECD's 2007 revised field of science and technology.

The final step, related to data management, was to build a two mode (rectangular) matrix “article x discipline of author”, which was transformed into 1 mode (square) matrix “discipline of author x discipline of author” (Borgatti et al., 2012). This last matrix is the database used to identify the prevalence and nature of interdisciplinarity. Using social network metrics the integration of disciplines of co-authors of randomly selected papers can be visualised and measured. Social network analysis (for a classic reference see Wasserman & Faust, 1994) is a useful tool to identify relations (or patterns of interdependencies or networks) through the measurement of the flows and

exchanges of resources of all kinds (material, informational, emotional, etc.). It can also be used to identify commitment vis-à-vis the exchange partners (Lazega, forthcoming). The assumption is that there are no social processes without a relational dimension, and scientific research in general and co-authorships in particular are social processes, like any other, and as a result are constrained by social relations (Moody, 2004). The relationship of co-authorship implies great commitment among the parts, especially with regard to interdisciplinary collaboration, as it implies an interaction beyond the comfort zone of each researcher, which entails greater risk (e.g. Ledford, 2015). Viewed from the perspective of the individual, interdisciplinarity can be counterproductive because it is much easier (less demanding) to work with others from the same discipline, who employ the same theoretical framework and methodologies and use the same terminology. As a consequence, an interdisciplinary career, driven by scientific curiosity and creativity, is often a more strenuous trajectory (Pfirman & Begg, 2012; Klein, 2010).

RESULTS

The results section will start by presenting a simple analysis of frequencies of the disciplines and disciplinarily fields of water researchers followed by the social network analysis mapping and metrics.

Sample Description per OECD disciplinary fields, disciplines and number of researchers

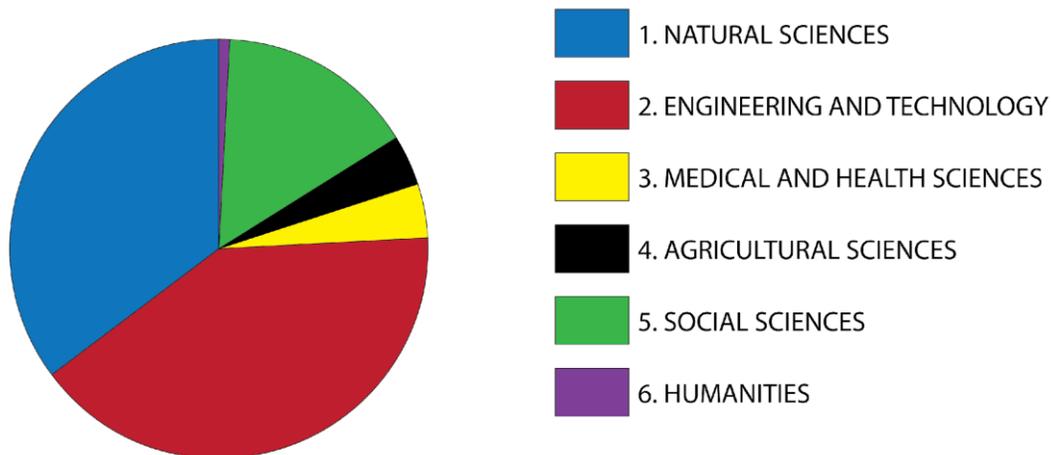


FIGURE 1. ILLUSTRATES THE WEIGHT OF EACH OECD DISCIPLINARY FIELD IN THE STUDY OF WATER IN PORTUGAL FOR 2015

TABLE 1. SAMPLE DESCRIPTION

OECD disciplinary fields	# of researchers	# of disciplines
1. Natural Sciences	67	20
2. Engineering & Technology	77	13
3. Medical & Health Sciences	8	5
4. Agricultural Sciences	7	4
5. Social Sciences	29	10
6. Humanities	2	2
Total	190	54

The visual mapping of the network of co-authorships

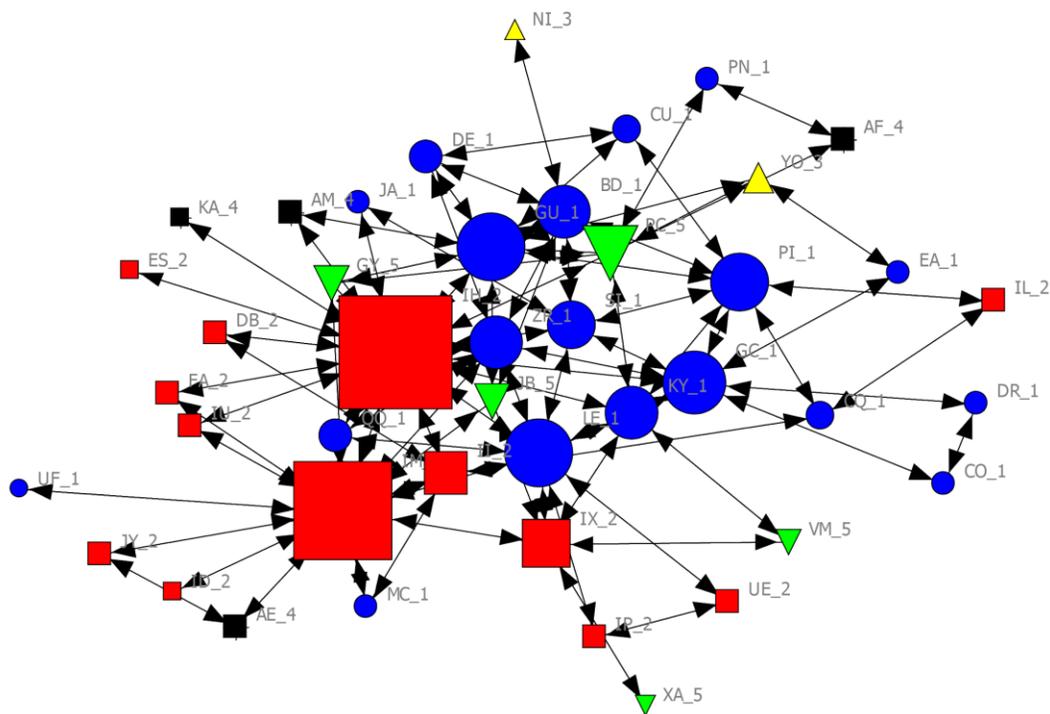


FIGURE 2. THE MAIN COMPONENT OF THE NETWORK OF DISCIPLINARY CO-AUTHORSHIPS

Colour/shape codes: Natural Sciences: Blue /circle; Engineering & Technology: red/square; Medical sciences: yellow/up triangle; Agricultural Sciences: black/square; Social Sciences: green/down triangle; Humanities: purple/box. The nodes represent disciplines and their size is linked to their centrality degree (i.e. the number of links per discipline)

The network graph expresses well the divide between the Engineering & Technology (red/square) and the Natural Sciences (Blue /circle) and the positioning of other scientific areas in the periphery. (Below we will present social network analysis metrics corroborating this visualisation of the network.) As previously noted, this divide has long characterised science. These two areas of knowledge with two different epistemologies have been separate since the 19th century under the concepts of nature vs. humans, matter vs. mind, physical world vs. social/spiritual world, and they refer to two ways of knowing, or in the expression of C.P. Snow “two cultures” (Gulbenkian Commission, 1996).

The prominence of the engineering & technology and natural sciences disciplinary field: top centrality results

The centrality measures in social network analysis give a measure of the importance of nodes in the network. In this case nodes are disciplines. The centrality measures used here are degree and betweenness (Freeman, 1979). The degree centrality calculates the number of adjacent relations of a node. In this case a discipline with a high centrality score is a discipline that is present in a high number of articles with other disciplines. On the other hand, when a discipline has low or zero centrality (an isolated node), it signifies that it is not present in articles with other disciplines. Having a high centrality degree reveals the prominence of a discipline in the field. As shown in Table 2, the disciplinary fields with the highest presence in co-authorships are Engineering & Technology and the Natural Sciences. The Social Sciences are represented in the top seven of the most active disciplines through the discipline of Management.

TABLE 2. DISCIPLINES AND INTERDISCIPLINARY FIELD – LIST OF THE TOP SEVEN IN-DEGREE CENTRALITY

Discipline and its OECD field	Degree Centrality
IH_2 Environmental engineering	18
IM_2 Civil engineering	15
Gu_1 Ecology	10
LE_1 Geosciences	10
GC_1 Geochemistry & geophysics	9
PI_1 Aquatic biology	8
PC-5 Management	7

Betweenness centrality (Freeman, 1979) is a measure of how often a given node falls along the shortest path between two other nodes. Betweenness reaches its highest value when the node lies along every shortest path between every pair of other nodes, measuring the bridging capacity of a node, in this case a discipline. A discipline with high betweenness centrality is a kind of broker that provides links among diverse disciplines. In this case Environmental Engineering is the discipline that bridges the most with other disciplines in water research. Again the disciplines with the highest centrality are those of the Natural Sciences and Engineering & Technology. Among the Social Sciences only Management and Economics are represented in this top list of degree betweenness.

TABLE 3. DISCIPLINES AND INTERDISCIPLINARY FIELD – LIST OF THE TOP 7 IN BETWEENNESS CENTRALITY

Discipline and its OECD field	Betweenness Centrality
21 IM_2 Civil engineering	22.000
IH_2 Environmental engineering	18.000
Gu_1 Ecology	17.000
GY_5 Economics	10.000
PC_5 Management	6.000
BD_1 Biodiv_conservation	6.000
IX_2 Geological Engineering	3.000

It has been argued that the centrality of nodes (here disciplines) is related to their power (Lazega, 1998; Brass & Burkhardt, 1992), meaning that those with higher centrality have greater control of the resources (knowledge, information) circulating in the network. In other words, nodes/disciplines with higher centrality are less dependent on others' resources, which is in itself a measure of power. The results show that the Natural Sciences and Engineering & Technology occupy the most central places in the network and have easier access to all the resources flowing through it. Thus, these disciplines are the ones most engaged in knowledge production, most active and most capable of making bridges among disciplines. Furthermore, as the number of authors is restricted here to the first three authors, it is possible that underlying such co-authorships other resources are expected to be exchanged such as information on access to funding, job or contracting opportunities. The authors belonging to disciplines in the periphery of the network, or those who are isolated, must make much a greater effort to access such resources.

The core vs peripheral disciplines in water research: the “elite vs the masses”

The core periphery metrics in social network analysis allows for the identification of the nodes (i.e. disciplines) within the core vs the periphery of a network. According to Borgatti & Everett (1999, p. 377), “the core periphery model consists of two classes of nodes, namely a cohesive subgraph (the core) in which actors are connected to each other in some maximal sense and a class of actors that are more loosely connected to the cohesive subgraph but lack any maximal cohesion with the core”. Table 4 indicates the disciplines at the core of the network.

TABLE 4. THE CORE OF THE NETWORK OF CO-AUTHORSHIPS

OECD Disciplinary field	Disciplines
Natural sciences	GC_1;KY_1;LE_1;SI_1;ZR_1;BD_1; GU_1;PI_1
Engineering	IM_2;IH_2;
Social Sciences	GY_5 ; PC_5

The core includes seven disciplines from the Natural Sciences, two disciplines from Engineering & Technology, and two disciplines from the Social Sciences. The Social Science disciplines are Economics and Management. These disciplines can be looked upon as the “elite” of water studies. This subgroup of disciplines has a much greater cohesion. This is measured though the density, which is simply the number of ties in the network, expressed as a proportion of the number of potential ties (Borgatti et al., 2012). In this case the core has a density of 0.47, meaning that they co-author papers much more frequently than the disciplines of the periphery, which have a density of just 0.028 (*i.e.* the core is almost 17 x denser than the periphery). These values can be read as a measure of the power of each group in the water research field. Such cohesion implies some trade-offs in the process of knowledge building. If, on the one hand, the core has a solid epistemological approach that favours internal coordination (e.g. making it easier to create and manage large research teams that are more able to access funding and conduct large research projects), on the other hand it is potentially less open to innovation, less creative, less able to introduce new ideas in its milieu and to re-think its approaches. The core becomes a victim of path dependency; they continue to do the same as they have always done, as long as they keep on being rewarded for it.

The social sciences literature - especially that using the social network analysis approach - has shown how the cohesion (Coleman, 1990) (or closure (Burt, 2005) or bonding social capital (Putnam, 2001)) of a social system is related to high levels of trust, reciprocity and the capacity to coordinate efforts. The same literature has pointed to the relation between the network’s sparseness, translated by concepts such as brokerage capacity (Burt, 2005) or bridging social capital (Putnam, 2001), with the innovation potential and creativity of that collective. These references can be found in Kadushin (2012, p. 63), together with a summary of the argument. The strong cohesion of the core raises doubts as to its capacity to come up with a completely new approach to water planning and management that successfully meets human demands in the next century (Gleick, 2000).

“Homo vs hetero” collaboration in water studies

The homophily tendency, i.e. the attractiveness between equals, has been repeatedly detected in its multiple dimensions (age, race, religion...) in social science studies (e.g. Mcpherson et. al., 2001). Naturally, the choice of discipline with which one chooses to collaborate will follow the same tendency. In interdisciplinary collaboration researchers rapidly fall into a discomfort zone as “our educated capacity in one discipline (or more realistically in one subdiscipline) tends to be associated with trained incapacity in other fields of relevant knowledge” (Freeman 2000, p. 484). Hence interdisciplinarity has to face human beings’ “natural” impetus to relate to equals and strengthen the relations among them (e.g. Homans, 1950) in addition to the institutional barriers referred to previously (e.g. disciplinary career track, division into departments, etc.).

Through the measure of E-I index, it is possible to verify which disciplines choose to collaborate with each other more frequently. In our case, we seek to confirm whether in water studies there is also a tendency for homophily and which disciplines show a greater tendency to collaborate in the write-up of scientific articles. The E-I index measure, developed by Krackhardt & Stern (1988), is a very simple and useful measure to compare the numbers of ties within groups and between groups. The E-I (external - internal) index takes the number of ties of group members to outsiders, subtracts the number of ties to other group members (in this case disciplines belonging to a disciplinary field), and divides by the total number of ties. The resulting index ranges from -1 (all ties are internal to the group) to +1 (all ties are external to the group). (For more details see for instance Hanneman & Riddle, 2005.)

The following E-I index results were obtained:

- **Natural Sciences:** with an E-I index value of - 0.275, the natural sciences show the highest homophily, i.e. it is the group of disciplines that has the greatest tendency to co-author with those of the same group. Note that - 1 is the value of maximum homophily and 1 is the value of minimum homophily.
- **Engineering & Technology:** this field has an E-I index close to zero - 0.067, which indicates a similar number of co-authorships both inside and outside the disciplinary area.
- **Medical Sciences and Agricultural Sciences:** both have an E-I index of 1 (minimum homophily), meaning that all co-authorships are with colleagues from different disciplinary fields.
- **Social Sciences:** the value of 0.778 represents a very low homophily, which indicates a great tendency to collaborate with colleagues from other disciplinary fields.

One can reflect on these results with reference to epistemic power issues, an idea that has emerged before in the context of centrality and core-periphery metrics. Engineering & Technology and the Natural Sciences co-author with their disciplinary peers in greater proportion than other scientific areas. The Social, Medical and Agricultural Sciences, which both have low centrality values and

are at the periphery of the network, have the lowest homophily values. That is, they rarely or never co-author within their disciplinary fields. They do not have autonomy; on the contrary, they depend on other disciplines to participate in a significant manner in the world of water research. For instance, they may lack access to funding for water research, which is consistently and disproportionately higher in the Natural Sciences and Engineering & Technology). The Directorate General Research & Innovation of the European Union report, *Integration SSH in Horizon 2020: Participants, Budget and Disciplines*, edited by Hetel, Møller, & Stamm in 2015 reveals that only 5.9% of the whole funding goes to Social Sciences and Humanities partners.

All the social network metrics analysed indicate that the Social Sciences are in a position of dependence towards other disciplinary fields in water studies. Paraphrasing George Orwell in *Animal Farm* (1944), one can say “all are equal but some are more equal than others”. It is as if they do not have a life of their own, such as when they are called upon to tick the box of communication and dissemination and societal impact but without the real commitment of incorporating social science theory and methods in the research. The so-called character of interdisciplinarity, such as mutuality and reciprocity, is based on the assumption that power differentials do not exist. According to Callard & Fitzgerald (2015), those in the social sciences and humanities who have experienced collaboration with the natural sciences feel the asymmetry of power. They go on to say, “You can have all the frank conversations in the world with collaborators about the conditions under which your exchanges are taking place; you can agree on clear distribution of resources and labour throughout the collaboration; you can put in agreed strategies to ensure, as far as possible, that this will work; you can reason as open, and transparent and clear, as dialogic as possible; but the reality is that financial and epistemic power is not distributed equally within the collaboration” (Callard & Fitzgerald, 2015, p. 103). In such a setting social scientists’ reactions may range from feelings of frustration to feelings of being insulted (Ledford, 2015). These feelings of frustration are not only shared among social sciences and humanities. Interdisciplinary collaboration is often entangled in less than obvious and much thicker structures of power than those involved in it are able or willing to recognise, creating huge obstacles to both natural and social scientists who want to collaborate. Furthermore, one should not ignore that “scientists” who collaborate with social scientists lose value in the process (Callard, Fitzgerald, 2015).

CONCLUSIONS AND DISCUSSION

“When we speak of the “environment”, what we really mean is a relationship existing between nature and the society which lives in it. (...) Recognising the reasons why a given area is polluted requires a study of the workings of society, its economy, its behaviour patterns, and the ways it grasps reality (...).” (Pope Francis, 2015, p. 147). Similarly, to understand the workings of water systems and to manage them implies knowledge about nature, people, technology, and political and organisational structure. However, despite the critical situation of the resources and the severity of its social and political impact (e.g. see the Liquidity Crisis, 2016), the paradigm currently leading water research, public policies and the management of water resources is techno-scientific and economic-financial, and it marginalises social, spiritual and aesthetic structures of

thinking. To frame issues in this way, which in fact, extends to all the environmental fields, inevitably leads to a narrowing of the possible range of solutions (e.g. Bina, 2013).

This paper aimed to determine how recent water research in Portugal fit the current paradigms by empirically analysing the networks of co-authorships of water researchers, and specifying the patterns of collaboration, with a special concern for the collaboration between the social sciences and the physical sciences. The findings corroborate the hegemony of the techno-scientific and economic paradigm. The scientific production in the field of water is based mostly on a collaboration within the physical sciences (mainly earth and environmental sciences and biological sciences and engineering) with some collaboration with social sciences (humanities excluded), represented by business and economics. That business and economics are the most active social sciences in water studies is revealing. Despite the short time span of the data analysed, and the circumscription to Portugal, it is consistent with the recent EU report, on the role of social sciences and humanities in the Horizon 2020 (Hetel et al., 2015).

All three network analysis measures, as well as the visualisation of the network map, clearly reveal the dominance of the Natural Sciences and Engineering & Technology fields on water research and the divide among these and the Social Sciences. The centrality measures give us such information on the most prominent disciplines in this field, and the a core–periphery measure clearly identifies a core composed of Natural Sciences and Engineering & Technology, while the Social Sciences are in the periphery, revealing a hierarchical division of work within water research. Moreover, there is a tendency for homophily in the Natural Sciences and very high heterophily in the Social Sciences, which, linked to their peripheral position, suggests a position of dependence. Today it is clear that whenever social problems have the slightest technical dimension, politicians call technical experts – the natural scientists – to help solve them (Lélé & Noorgaard, 2005). This can also be a form of “protection” for politicians, as the belief in the superiority of the natural scientists is so deeply rooted that it would be too risky to call for social scientists, who continue to be perceived as “second class” scientists, i.e. those that were not good enough to get into the “science stream”. This should be a matter of concern for science funders and water policy makers because the epistemic division and power imbalances impede the creation of innovative knowledge. In a case study of geo-engineering, Szeerszynski & Galarraga show that the task of social science is to “expose assumptions, bring out the multiplicity and incommensurability of different views and ontologies and keep problem definitions open”, thus producing “greater diversity and reflexivity in how different disciplines and approaches are brought together” (2013, pp. 2818-2822). Old thinking is still prevalent among water planners and managers. The direct consequence of this knowledge construction paradigm leads us to continue policies that do not preserve the sustainability of resources. It is because fundamental changes on how water is thought about and acted upon are required that the goal of sustainability is coming about slowly (Gleick, 2000).

A change of paradigm in research and teaching of water seems urgent. One that moves beyond positivist, empiricist and technocratic ways of knowing. Other ways of knowing related to the social, spiritual and aesthetic dimensions of water have been relegated to marginality, with the justification that it is difficult and complex to collect data (McDonnell, 2008). Yet at the same time, higher education institutions worldwide have invested millions in the production, dissemination and application of scientific and technical knowledge and information. According to Peters & Wals

(2014), a body of systematic ignorance is produced due to the priorities, methods and dynamics of our educational and political systems and by the workings of power. Investments in the social production of wisdom are far smaller and weaker (Maxwell, 2007).

If the inevitable links within the different domains of the social and the natural sciences, as well as links across these scientific worlds, are not taken into account in forming scientific inquiries, then our ability to gain knowledge and understanding of how we can sustain societal developments will be inherently limited. By failing to take into account the social, political, economic and cultural context, water studies fail to address the root of the problems and, in not doing so, endanger the sustainability of the resource. This has been repeatedly stated in the context of the rhetoric on development models for sustainability and the use of resources (Bina, 2013).

One of the follow-up aims of this research will be to understand why at the level of policy-making (planning and the ensuing implementation) social scientists' epistemologies are marginalised and what can be done to naturalise them. *Homophilisation* among social and physical sciences could do the trick. Whether the steps to get there are a matter of equalising funding, creating more interdisciplinary higher education programs, organisational participatory methodologies or other is a focus of future research for the authors.

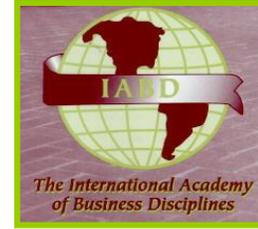
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