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Research article

How do information flows affect impact from environmental research? - An analysis of a science-policy network

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ABSTRACT

Evidence of the impact arising from environmental research is increasingly demanded. Exchanges between science providers and actors that use scientific knowledge to address environmental problems are recognized as a key component of the mechanisms through which impact occurs. Yet, the role of interactions between science and policy actors in delivering and shaping research impact is not well established. We aim to better understand how transfer of science in a science-policy network generates impact. Our approach relies on an exploratory social network analysis (SNA), applied to a network of organisations working on land and water management in a catchment in the UK. We analyse flows of scientific information across these organisations and how those contribute to impact, which we conceptualized as change in organisations at three levels: increased awareness, operational change and strategic change. We find that organisations occupying central positions in the network facilitate the transfer of science and influence the level of change achieved. We also find that the effectiveness of the flows of information and impact delivery depends on boundary organisations, in particular public regulatory bodies, that connect agents with others. Moreover, intended change reported by science providers does not often transform directly into change as reported by the receivers of the information. We conclude that both exchanges between researchers and research users and the role of boundary organisations are key to impact delivery and making change possible. This is valuable for understanding where improvements to information flows between organisations might enhance impact.

1. Introduction

Research funders and governments are increasingly interested in demonstrating the value of their investment to society (Tsey et al., 2016). This has intensified discussions about how to evaluate research and its societal value, and increased the demand for evidence of research impact (Bornmann, 2013). Research can lead to a wide range of impacts, understood in this context as the “perceived and demonstrable benefits to individuals, groups, organisations and society that could not have been possible without new knowledge arising from research” (Reed et al., 2020 p7). Academic work in this area has mainly focused on capturing, assessing, and demonstrating research impact (Richards and Panfil, 2011; Martin 2011; Reed et al., 2020). Most studies focus on methods and tools to account for, monitor, and claim research impacts (Reed et al., 2018; Greenhalgh et al., 2016), or to evaluate impacts from specific research (Reed et al., 2020). Some have focused on understanding how to measure the significance (the magnitude of the impact on individuals or groups) and reach (number, extent or diversity of individuals or groups that benefit from the research) of research impacts (Reed et al., 2020; Alvarez et al., 2010; Douthwaite et al., 2003). Others have discussed issues such as attribution (defining how much impact is the result of the research) (Dickson et al., 2017), additionality (whether the research generates benefits that could not have been generated otherwise), and timing caused by the variation of the delivery of impact over time (Klautzer et al., 2011; Bornmann, 2013).

What transpires from these studies is the critical importance of the exchanges between researchers and research users as a key component of the mechanisms through which impact materializes. There is an increasing number of studies that look at the potential and added value of inter- and trans-disciplinarity networks across science and policy for tackling complex environmental questions (Bixler et al., 2019). However, the role of interactions between science and policy actors in delivering and shaping impacts from research has not been well established (Broström and McKelvey, 2017; Sarkki et al., 2020). This hampers

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further significant progress in this area, as having this knowledge would allow to invest in activating suitable and efficient mechanisms to deliver impact. Accordingly, this study aims at filling this knowledge gap by placing the focus on understanding flows of scientific information between potential users of the research and researchers, the nature of the interaction between the two, and the role of "knowledge brokers" (Bornbaum et al., 2015) that act as mediators and connect different parts of the network.[1] The underlying purpose and direction of information flows between actors in a science-policy network can be a useful indicator of how meaningful and impactful the research is to others and how far the research benefits others. It can help capture whether research is affecting new communities and sectors (Hoppe and Reinelt, 2010). Moreover, an in-depth understanding of what facilitates or hampers these flows, and the exchange and use of science can help guide recommendations on how research impact can be enhanced. Thus, this is another key contribution of this study. For example, identifying organisations that play an important role in transferring scientific information can help to more effectively direct research findings to relevant policy actors. Indeed, researchers might be able to extend the reach of their work to otherwise inaccessible actors by working closely with organisations with more widespread, and strong links.

This is the first study that contributes to our understanding of how the flow of scientific information and resulting levels of interconnectivity between science actors and policy actors (encompassing any organisation engaged in policy decision-making) foster the extent and type of impact from environmental research. This is highly valuable as improving our understanding of interactions between actors could be a useful way to enhance impact. Thus, using social network analysis (SNA), we investigate how information network structures and specific roles and characteristics of participating organisations affect their capacity to generate and facilitate impact from research. While impact from research can be understood in a broad sense and encompasses multiple dimensions (Reed et al., 2020), our study focuses on a one dimension, i.e. change at organisational level following exchange of scientific information. In particular, we distinguish three levels of changes derived from the use of scientific information: increased awareness, operational change, and strategic change in an organisation. These changes will ultimately translate in wider changes, such as economic, societal, or environmental impacts (Faure et al., 2020).

As a case study, we use the Yorkshire Integrated Catchment Solutions Programme (iCASP) in the United Kingdom. This programme, funded by the UK's Natural Environment Research Council (NERC), is explicitly aimed at translating environmental science into concrete solutions for land and water management generating environmental, social, and economic benefits to the Yorkshire region (Richardson et al., 2020). iCASP's aim is to fulfil such a mandate through the establishment of a multi-stakeholder process connecting researchers and potential research users, and the promotion of an integrated catchment management (ibid). Our case study can be conceptualized as a local science-policy network, featuring the exchanges of scientific information among various policy actors, including research institutes and government agencies, civil society organisations and private sector actors engaged in regional water management. Thus, the case offers insights on the effect of these interactions on impact from research. The way we operationalize impact from research fits directly with iCASP's aims and its ambition to improve networking, allowing us to explore the role of scientific information flows in delivering impact across a network.

In the face of the current proliferation of such multi-stakeholder processes for environmental research and practice (Research to Action, 2018; Wyborn et al., 2019), and the broader interest in knowledge co-production and establishment of transdisciplinary partnerships (Ekboir et al., 2017), this study serves as an exemplar for how impact emerges through such contemporary approaches for environmental management. While our analysis does not enable us to capture co-production mechanisms as such, this study helps us to better understand the role of knowledge brokers in mediating science across the science-policy network and facilitating impact delivery. This is important as those are often featured in multi-stakeholder co-production approaches that are believed to be more effective in producing solutions for end-users, and thereby generating change (Reed, 2008).

The remainder of this paper is organized as follows. In section 2, we lay down the conceptual grounds for focusing on the role information flows and network relations on research impact. In section 3, we describe the case study and the SNA methodological application. In section 4, we present the results of the SNA investigating the patterns of information flows between science and policy actors. We assess the impact of the information on the organisations through examining how the information is being used. We then discuss our findings in section 5 and the implications of existing information and knowledge flows for research impact.

2. Research impact and information flows

The delivery of impact from research (hereafter referred to as research impact) relies on a transformational process of science into something explicitly useful for and beneficial to someone (Reed, 2018a; Matt et al., 2017). This mainly occurs through developing ways of making the research work accessible and understandable to the potential users and beneficiaries, and through fostering a learning process (Reed et al., 2014). The various mechanisms put forward to enable that process such as, early engagement of beneficiaries, collaboration with partners in industry, rely on the notion of working on awareness, attitude, behaviour, and policy, which are referred to as "intermediary domains" (Reed et al., 2018). The idea is that producing change in these intermediary domains (for example by increasing awareness, inducing changes in attitudes, or influencing a policy) is what leads to impact (ibid). Some of these changes are tightly linked to each other. For instance, an increased awareness or a better understanding of individuals in regard to a specific issue stimulates a change of their views or perceptions that may itself encourage a change of behaviour or practice (Reed, 2018b).

The basis of this process is effective sharing of both information and knowledge between science, policy, and practice interfaces. For instance, passing on new evidence from researchers to relevant management stakeholders will help optimize the implementation of on-the-ground interventions. Similarly, facilitating the transmission of expert opinion to policy makers can drive policy change (Kowalski and Jenkins, 2015). Thus, the direction of scientific information flows contributes to our understanding of the pathways that lead to change, and consequently of how impact from research occurs. For example, a communicative exchange (from researchers to stakeholders) can result in knowledge transfer that can then influence on-the ground interventions. A consultative exchange (from stakeholders to researchers) can generate capacity influencing the research itself and make it more useful in practice (Partidario and Sheate, 2010: Fazey et al., 2014). Deliberative (two-way flow between researchers and stakeholders) exchange is conducive to co-production of knowledge, and despite its cost (Lemos et al., 2018) is regarded as an effective way to shape research aimed at addressing complex problems (Norström et al., 2020). It relies on "productive interactions" between researchers and stakeholders (Spaapen and Van Drooge, 2011; De Jong et al., 2014; Bornmann, 2013; Reed, 2018a; Muhonen et al., 2020) whereby exchanges focus on the interaction process and aim to discuss how a research can be adopted, diffused, and applied (Gaunand et al., 2015). These information flows, which can be analysed as a network, are therefore key in shaping impact

[1] A 'knowledge broker' can be defined as a "stakeholder that facilitates the transfer and exchange of information in a given context" (Bornbaum et al., 2015: 1). In this paper, we use the term as defined here in the impact literature, and we are not referring to the use of broker or brokerage roles as used in SNA terminology.

from research (Fritsch and Kauffeld-Monz, 2010).

In whichever direction they flow, information exchanges alone do not determine whether change occurs. Factors such as institutional arrangements, willingness to take risks, capacity to implement change, organisational learning, and competition also need to be considered to facilitate change and its durability within an organisation (Montalvo, 2006; Lundvall and Kristensen, 1997). It is within this context that the role of information networks that policy actors form, in particular how scientific information is exchanged, contributes to shape impact from research (Fritsch and Kauffeld-Monz, 2010). In addition to understanding how the nature and direction of information flows shape impact from research, it is also useful to examine actors' characteristics or attributes (McPherson et al., 2001). Attributes influence relations, including the extent to which actors seek or provide information to one another (ibid). Moreover, some actors are more open to embrace change than others; others perform well in initiating change in other actors (Erwin and Garman, 2010). Some actors occupy "central" positions in the network and therefore exert higher level of influence on others. Some, having the position of intermediaries in information exchanges are referred to as "knowledge brokers" (Bornbaum et al., 2015) or, since our actors are in fact organisations, "boundary organisations" (Gustaffon, 2018). These knowledge brokers have a distinct role in connecting a high number of different actors, which is essential in most domains to facilitate and drive change in individual and organisational behaviour (Chauhan et al., 2017; McSherry et al., 2006; Ingold, 2011; Posner and Cvitanovicc, 2019; Ward et al., 2009). Boundary organisations make substantial contributions to information-sharing networks as they facilitate information flows across various scales, knowledge domains and types of actors (Victor et al., 2016). In fact, they are often perceived as useful informants in an evaluation process because of their connection to larger parts of a network (Hoppe and Reinelt, 2010), thus helping to reach otherwise uncontactable actors. They contribute by improving mutual understanding Morin et al., (2016); Gray (2016); Drimie and Quinlan (2011); Victor et al., 2016; Crona et al., (2011) and facilitate capacity building among stakeholders they help connect (Bornbaum et al., 2015). Boundary organisations are therefore key to the transfer of knowledge and interactions between researchers and research users, including decision makers (Morin et al., 2016; Ward et al., 2009; Cvitanovic, 2017) and may be essential to the process of translation of research into impact (Gustafsson and Lidskog, 2018; Gustafsson and Lidskog, 2018; Morin et al., 2016; Conklin et al., 2013).

The above section highlights two key elements to the process of impact generation from research: 1) the flow of knowledge between researchers and potential users of the research, and 2) the nature of the interaction between the two in the network that they conform (Gaunand et al., 2015). These aspects are particularly important in the domain of environmental management, which is characterized by complexity and uncertainty (Polaski et al. 2011). Information sharing mechanisms are particularly relevant since they enable regular updates of knowledge to address changing conditions and uncertainties, helping to promote common perception and understanding of the problem, and the capacity to design suitable responses (Vignola et al., 2013; Weiss et al., 2012). Interactions within the network facilitate the access to and the integration of different sources of knowledge and skills, and thus foster individual and collective learning (Newig et al., 2010).

In this study, we use social network analysis (SNA) to analyse these two elements in the environment research context. In the area of research impact, SNA has mainly been used to assess researchers' performance and the effect of interactions within the research community on impact (Bellotti, 2016; Shiffrin and Bo, 2004; Newman, 2001; Worrell et al., 2013; Barabasi et al., 2002; Ebadi and Schiffauerova, 2015, Bertsimas et al. 2014; Lightowler and Knight, 2013). Others have used SNA to map research collaborations and partnerships to identify emerging research areas and links between network configurations and research activities (Ekboir et al., 2017). Only a few studies used SNA to evaluate impact from research on society. For example, Reed et al. (2018) analyse the impact of peatland conservation research on policy in Scotland and explore relative influence of interpersonal interactions between researchers and policy actors and pathways of specific research findings on the awareness and understanding of research. Cvitanovic et al. (2017) use SNA to evaluate the effectiveness of knowledge brokers in connecting researchers and decision-makers. In a study of transition to organic farming in the Camargue territory in France, Quiédeville et al. (2018) examine the relevance of SNA in understanding the role of networking on research impact. These studies show that SNA is a valuable tool to evaluate research impact. It can help to identify "facilitating bonds" in a network and to examine their role in connecting researchers and decision-makers (Cvitanovic, 2017). By applying SNA on a local science-policy network, this study makes a unique contribution to understanding how flows of information foster impact from environmental research, and influence the nature (type of change induced by the use of science), reach (number and range of organisations reached by science) and significance (magnitude of the organisational change) of this impact.

3. Materials and method

3.1. Case study

The Yorkshire River Ouse catchment is located in the north east of England in the UK and encompasses the cities of Leeds, York, and Sheffield. It is home to 6.7% of the UK population and several global companies and regulatory agencies have their headquarters or environmental offices in the region. Moreover, the catchment is one of the largest UK manufacturing areas and many of the large businesses are engaged with catchment responsibilities. Further, there are around 54,000 rural businesses in the basin. Thus, the region is characterized by the presence of important players involved in the management of environmental resources and landscape, which ranges from large urban areas to lowland agriculture and sparsely populated uplands (sources for about 70% of Yorkshire's potable water). These features are associated with several environmental concerns, including risk of flooding, vulnerability to drought in lowland agricultural zones, water pollution, as well as resilience and sustainability planning as the region's economy expands (Richardson et al., 2020). These issues call for the need of an integrated and collaborative catchment management and the development of suitable solutions (Stewardson et al., 2017; Wang et al., 2016; Richardson et al., 2020).

The Yorkshire Integrated Catchment Solutions Programme (iCASP) works on stimulating science-user engagement and on translating environmental science into concrete tools and solutions useful to catchment actors. This programme relies on the creation of a regional network of catchment experts, the creation of a dialogue between researchers and stakeholders, and the exchange of scientific information among organisations to increase impact from research and create regional benefits (Richardson et al., 2020). This exchange materializes in the development of project ideas, and the co-design and co-running of projects involving both researchers and practitioners of the region, following the identification of specific land and water management issues, and the desire to translate relevant environmental science that can help solving those. The iCASP programme operates along the following workstreams: flooding risk regulation, climate change mitigation, sustainable agriculture, carbon sequestration, and water quality. An example of such projects that rely on the use and translation of science, includes the design of a "User Guide" on environmental valuation methods. This user guide was co-designed with peatland restoration practitioners in order for them to select adequate valuation methods for valuing the ecosystem services provided by peatlands and their restoration, and therefore better make the case for their restoration. The programme and its co-funded projects aim to produce changes at both individual and organisational levels, including increasing awareness, changing perceptions and attitudes, policy changes, and adoption of new practices, all combined leading to a long-term cultural change. These changes aim to foster numerous benefits, including the preservation of natural capital, increased uptake of sustainable agriculture, cost savings, new products and jobs, as well as have an influence on regional investments.

Thus, iCASP follows the trend of partnership approaches that promotes stakeholder participation and transdisciplinarity for catchment management in recognition of the importance of adopting more holistic approaches to address environmental issues (Richardson et al., 2020). Since this programme places the emphasis on the partnership dimension and on the use of scientific evidence and research outputs to design catchment solutions, it is an ideal candidate for our research question. Addressing the latter in this context will provide useful insights on the role of information flows in shaping research impact, and on understanding how regional networks such as iCASP can foster integrated catchment management.

The science-policy interface includes organisations working on water and land management within the Ouse catchment in Yorkshire, comprising of both scientific and non-scientific actors. This group of actors forms what in the SNA terminology is referred to as the 'network boundary' of our study, i.e. the actors that are part of the science-policy interface we are studying (Laumann et al., 1983). Because of its catchment focus, the network boundary includes actors that are active within the physical (natural) boundaries of the catchment, making the research question place-based. At an initial screening, about 140 organisations were considered as potential participants in the study. Out of these 140 organisations, 65 explicitly engage with the iCASP programme and are therefore formally considered part of the network. Out of those 65, we obtained 35 responses to the SNA survey. Four respondents stated that they were not affiliated with organisations working on land and water management. Six organisations were represented by more than one respondent. For these, we only kept the entry of the respondent that showed more connections to other organisations as these are assumed to represent a more comprehensive view of the organisation's connections. We therefore obtained complete network responses for 25 organisations (38% response rate), yielding 99 responding and nominee organisations.[2] The analysis is conducted on the network of information exchanges among the 25 participant organisations. We classified organisations by type distinguishing public and private organisations leading to four categories: public, business, nongovernmental organisations (NGOs) and hybrid actors (multi-stakeholder forums including public and private actors); and by sector. See Table 1 below for an overview of the participants and descriptions of their function and the main activities they are responsible for. While this study is based on a case study, our approach is such that the findings will be valuable to the understanding of science-policy networks in other contexts and regions. Hereafter, we use the acronyms of organisations.

3.2. Social network analysis

Social network analysis (SNA) is an analytical approach that is used to investigate interactions between actors within specific domains (Scott, 2013), including how information flows and network configurations influence the spread and adoption of behavioural change (De Lange et al., 2019; Welles and González-Bailón, 2020; Angst and Hirschi, 2017). In our case, it allows us to investigate a science-policy network in order to assess its capacity to foster the effective use of scientific knowledge in decision-making processes. SNA can help identify ways to strengthen research impact, and achieve organisational change (Cvitanovic, 2017; Ward et al., 2009; Lightowler and Knight, 2013; Quiédeville et al., 2018). Further, the approach can be used to detect different roles of organisations in a network, such as particularly well-connected organisations (i.e. central organisations) and organisations that act as important conduits of scientific information (i.e. knowledge brokers) (Segarra et al., 2017; Borgatti et al., 2018). This paper uses exploratory SNA, meaning that it mainly uses simple network measure, and does not rely on inference analysis on network structures (Nooy et al., 2011).

We designed a survey to capture flows of both scientific information and general information among science and policy actors within our network (Brockhaus et al., 2014: appendix 1). We asked respondents separately to which organisations their organisation provided scientific information, and from which organisations they received scientific information. We also asked about the purpose of information provision by those providing it, as well as how it was used by those receiving it (see survey in Appendix 1). The various uses of scientific information, and the intention behind provision (Table 2), were described in three categories of change within organisations incremental in the level of change that they represent, namely: increased awareness, operational change, and strategic change. These changes conceptualize the notion of impact, and are 'ranked' to signify the level of impact, with increased awareness the lowest and strategic change the highest (Table 2). This conceptualization aligns with impact evaluation frameworks such as theory of change or logic models, which support the articulation of the pathway to impact including the understanding of different levels of change occurring along that path, i.e. from outputs to the use of these outputs, first levels of change in people (awareness, knowledge, attitude), secondary levels of change (behaviour, capacity), and higher levels of change like policy (Blundo Canto et al., 2020; Reed et al., 2020).[3]

In order to contextualize the broader exchanges of information within which the exchange of scientific information happens, we also asked respondents to indicate with which organisations their organisation regularly exchanged general information. Flows of general information among actors tend to be correlated with the flows of more specific information such as scientific information, since the use of the same channel for multiple reasons reduces transaction costs (Leifeld and Schneider, 2012). Hence, analysing non-scientific flows will provide insights on the broader communication among organisations that can facilitate scientific information flows. We asked respondents to specify whether general information exchanges were either informal exchanges or linked to formal agreements, or both. Informal exchanges refer mainly to the sharing of information, documents and reports by email or phone, at workshops or meetings, while formal exchanges refer to exchanges occurring in the frame of consultancies, commissioned work, secondments or joint research projects. Note that while we distinguish provision of scientific information from the providers' versus from the receivers' perspective (or point of view) and investigate them separately as directed networks, in the case of general information, we consider the notion of exchange of information as undirected (Gallemore et al., 2015).

The survey was distributed online through requests to targeted organisations and was promoted at dedicated events gathering organisations working on land and water management-related topics in Yorkshire. Special attention was given to the participation of organisations that were deemed well connected by key informants, as those have an important weight in explaining the structure of information networks. To ensure robustness and avoid bias in the network's representation, we took care that we had not missed organisations that had been nominated several times by respondents, but for which no representative completed the survey, following the methods approach developed

[2] Nominee organisations are organisations that were mentioned by participants as actors they network with but who did not take part to the survey.

[3] We acknowledge that this hierarchy among these levels of change is not necessarily evident. Different kinds of change may be appropriate at different points in an issue cycle. For example, if an issue is novel, awareness raising may be the most important contribution research can make. Yet, for the type of change considered here, we think that this ranking is relevant.

Table 1
Participant organisations.

Type	Sector (n)	Acronym	Function	Main activities
Public organisation	Research (6)	*Public_Res*	Education, research	Producing and sharing knowledge
	Regulator (5)	*Public_Reg*	Law enforcement	Enforcing measures for protecting and enhancing the environment
	Park (1)	*Public_Park*	Nature management	Protecting and managing places of natural beauty
	Council (1)	*Public_Coun*	Administration	Providing regional services to society, e.g. education, transport, waste management, social care
Businesses	Utility (1)	*Bus_Util*	Distribution	Distributing water and treating wastewater for clients in the Yorkshire region
	Consultancy (3)	*Bus_Consul*	Advise offer	Offering advice and expertise to client organisations to help them improve their performance or solve a particular issue
Non- Governmental Organisations (NGO)	Environment/conservation (6)	*NGO_Env*	Lobbying for improved environmental management	Promoting environmental conservation to improve landscape and raise environmental benefits
Hybrid organisation/ Partnerships	Multi-stakeholder-forum, incl. Businesses, public organisations, NGOs (2)	*Multi. BusPublicNGO*	Exchange and networking	Realising improvements on local environment

Table 2
Purpose and use of scientific information and level of organisational change.

Purpose and use of scientific information	Organisational change/impact	Impact level
To increase awareness and understanding	Increased awareness	low
As the basis of follow on activities (e.g. consultancy, commissioned work, joint research projects)	Operational change	medium
To change day-to day-activities		
For practical adoption of new models' methods or tools		
To change policies or strategies	Strategic change	high
For cultural change within the organisation (e.g. change attitudes)		

by Brockhaus and Di Gregorio (2014).[4] Lastly, we selected participants very carefully by identifying the most knowledgeable people about the activities of their organisation in link with land and water catchment management (e.g. worked on the issue and represented their organisation in the actual consortium). While it is always possible that some information might have been missed, because our survey respondents have very good knowledge of their organisation, we are confident that the network representation is robust. Besides, the study being conducted on a relatively bounded network and small area, this also facilitated the recalling of information from participants.

3.3. Analyses and network measures

In our science-policy network, nodes represent organisations (Victor et al. 2016; Ofem et al., 2013). Organisations are connected through distinct relations (also referred to as ties): the provision and the reception of scientific information, and the exchange of general information (Leifeld and Schneider, 2012; Brockhaus et al., 2014). Scientific information flows are investigated as directed relations and separately for provision of information and for reception of information. This allows us to distinguish between an organisation stating that it provides scientific information to another and an organisation acknowledging that it receives scientific information from another. This concept is different from reciprocity, which instead refers to mutuality of exchanges (e.g. both actors provide scientific information to each other) (Borgatti et al., 2018). The former distinction between provision and reception is of particular interest in this paper, as explained next.

We first analysed the flow of scientific information by distinguishing the perspective of the providers of science from the perspective of the receivers. The perspective of the providers captures the intended purpose with which they provide the scientific information and, in consequence, the change that they intend to induce in other organisations. The perspective of the receivers reflects the reported use of the scientific information, referred to as "information absorption" by Fritsch and Kauffeld-Monz (2010). Thus, we can identify the organisations that generate and those that experience change from using science. Secondly, through an understanding of the type of use of the scientific information, we examined the level of change induced in the organisation, and we compared it with the intended change (considering the perspective of the providers). Third, we analysed the exchange of general level information among organisations as an undirected network. See a synthesis of the network relations that we investigated in Table 3 below.

We also assessed whether organisational characteristics such as presence of regulatory power and operational scale affect network position. For this, we conducted a linear regression first on centrality and then on betweenness measures whereby we considered, for each regression test, the nature of the organisation (regulatory or not) and its operational scale (regional, national) as explanatory variables. This simple analysis allowed us to assess how organisational characteristics mapped against central network roles of the organisations in the science-policy network.

Table 3
Network relations investigated.

Relations	Description
Relation: Provision of scientific information (directed)	An organisation has provided scientific information to another organisation
Relation: Reception of scientific information (directed)	An organisation has received scientific information from another organisation
Relation: Exchange of general information (undirected)	An organisation has exchanged general information with another organisation
Strength of scientific information exchange	Number of intended or reported organisational changes
Type of general information exchange: formal and/or informal	An organisation has exchanged informal information (sharing of information, documents and reports by email or phone at workshops or meetings) and or formal information (through consultancies, commissioned work, secondments or joint research projects) with another organisations

Note: The structure of the table is inspired by Fritsch and Kauffeld-Monz (2010).

[4] Indegree centrality varies from 0 to 21, and all organisations for which the indegree is greater than 5 participated to the survey. This ensures that we have not missed any organisation among the most central actors in the network, that might have indegree close to the top of the mentions. Moreover, the average indegree differs significantly between respondents and non-respondents (equal to 3.6 (std. 5.9) and 1.1 (std. 0.8), respectively, p-value = 0.006), indicating that the most well-connected organisations are included in the analysis.

We investigated actor-level network measures as follows. We considered indegree and outdegree 'centrality' of the organisations, which are indicators of popularity and reach respectively and are associated with different types of influence in a network (Golbeck, 2015). Indegree centrality refers to the number of incoming relations and outdegree is the number of outgoing relations. We also considered betweenness centrality, which measures the number of times an actor lies on the shortest path between other actors (Wasserman and Faust, 1994). This "actor in the middle" exercises some control over these paths, has the ability to absorb information flowing along these paths and transfers it to other actors (Owen-Smith and Powell, 2004). In our case, it can be seen as a proxy for the extent to which an organisation plays the role of mediator of information or knowledge broker.

These measures help identify on the one hand 'central' organisations in the network that are either sought after as direct sources of scientific information or are actively disseminating it, and on the other hand, 'boundary' organisations, which maintain control on broader information flows throughout the network. These organisations occupy advantageous network positions and are well placed to induce innovation and shape processes of change (Abrahamsen et al., 2012; Rogers, 2010; Borgatti et al., 2018).

4. Results

4.1. Actors' positions in the scientific information network

We first analyse the exchange of scientific information among organisations from the perspective of the providers (Fig. 1). Among the 25 organisations, 14 (56%) reported that they provide scientific information to others. Five of these are public research institutes, which are also the most important providers, with three of them displaying the highest outdegrees in the network (see individual scores in Fig. 1). One regulator (Public_Reg2) and one business utility (*Bus_Util*) are the major targets for scientific information provision (highest indegree) and a variety of organisations provide them with scientific information, including public research institutes, consulting companies, NGOs, and local councils. We also observe that the type of organisational change intended by providers of science is higher for the flows targeting the regulatory body (Public_Reg2) than for the others (see the thickness of the flows in the figure).

Organisations providing scientific information to *Public_Reg2* target, for the majority of the flows, changes at all three levels (such as increased awareness as well as operational and strategic changes), while flows directed to other organisations carry lower levels of expectations with respect to the impact they intended to generate in others. This is notable but also logical in the sense that policy changes are mainly to be expected from regulatory bodies. Next, we find that three major knowledge brokers (highest betweenness scores) transferring scientific information to others - two public research institutes (*Public_Res2* and *Public_Res4*) and the business utility company (*Bus_Util*) -, emerge from the perspective of providers of scientific information. Note that this betweenness score corresponds to a partial view of the flows of scientific information, and the complete picture emerges when incorporating the point of perspective of the receivers as well.

From the perspective of receivers (Fig. 2), we find that 22 organisations (88%) indicated to receive scientific information from others. We illustrate the relations in the same way as in the network of provision of information, but this time, the data derive from the perspective of receivers (Fig. 2). We find a very different picture compared to the providers' perspective. In this case, *Public_Reg2* is recognized by the others as a major provider of scientific information (highest outdegree centrality score). According to receivers, *Public_Reg2* is also recognized as a major mediator transferring scientific information to others, and in fact the main knowledge broker in the network (highest betweenness centrality score). Yet, this same organisation does not appear as a self-reported key provider (in Fig. 1), i.e. *Public_Reg2* does not see itself as a provider of scientific information but it is perceived as such by others. This might be explained by the fact that *Public_Reg2* mainly receives scientific information from others and then passes it on, so it identifies itself mostly with its role as a boundary organisation within the network. Similarly, an NGO (*NGO_Env5*), *Public_Res2* and the business utility (*Bus_Util*) are also recognized as important providers of science,

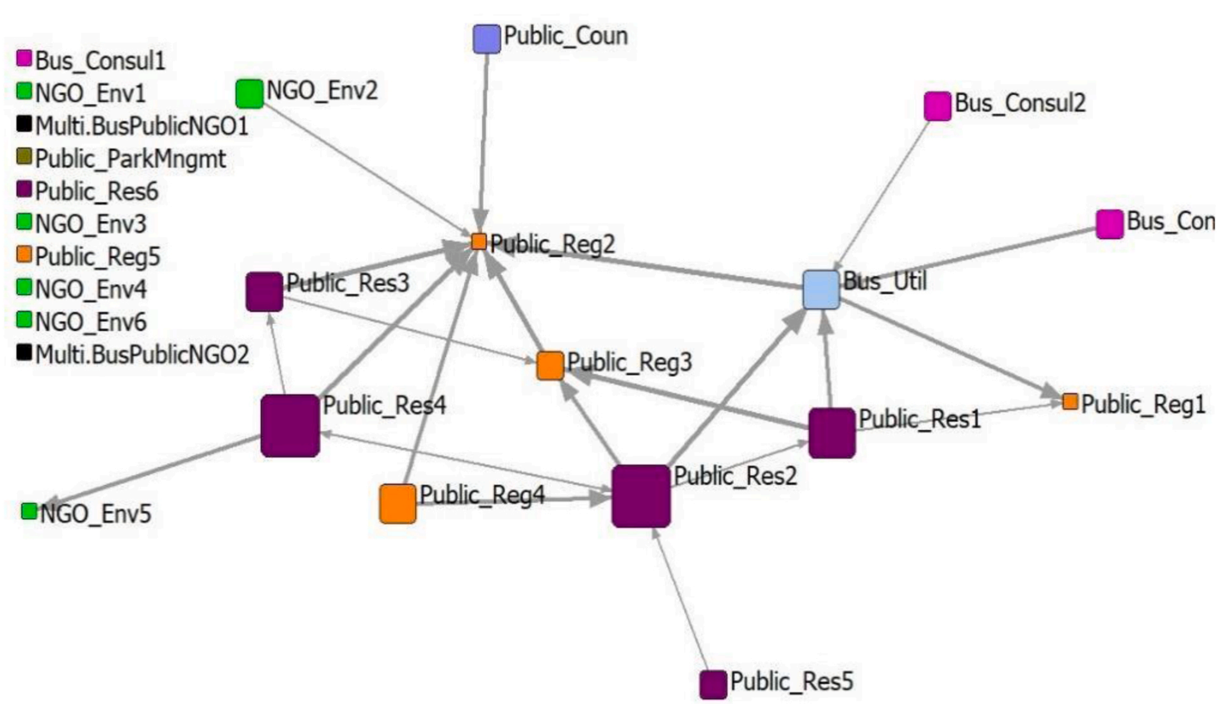

Fig. 1. Provision of scientific information - Providers' perspective (node sizes proportional to outdegree), and individual scores. Note: The thickness of the arrows corresponds to the significance of the intended impact on another organisation, represented by the number of types of change (out of the three types of levels) an organisation intends on another.

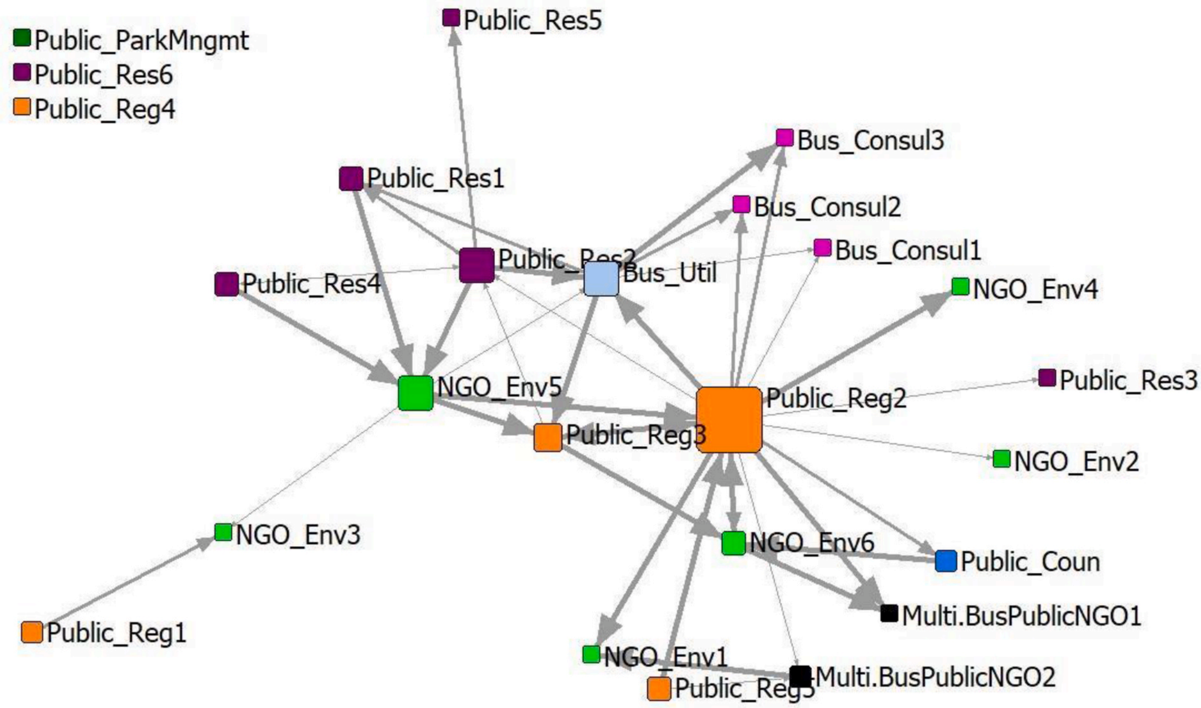

Fig. 2. Provision of scientific information – Receivers' perspective (nodes size proportional to outdegree), and individual scores. Note: The thickness of the arrows corresponds to the significance of the intended impact on another organisation, represented by the number of types of change (out of the three types of levels) an organisation reported following reception of scientific information.

contributing to bridging science between the different organisations.

Furthermore, the change that these knowledge brokers report following provision of science, and the change that they produce on other organisation is substantial (as demonstrated by the number and thickness of the flows, Fig. 2). More specifically, *NGO_Env5, Bus_Util, and Public_Reg2* report organisational change across all three types of change (increased awareness, operational change, and strategic change), hence reporting impact following reception of science up to the highest level. They also impact others across all three levels. This is again not reflected in the network of the perspective of providers.

Thus, the configurations of networks with respect to the position and centrality of the organisations differ between the perspectives of the providers and those of the receivers. There is a significant difference in the perceptions of the organisations in terms of where they get scientific information from versus to whom they provide it to. We suggest one potential preliminary explanation to this: scientific information does not go directly from providers to recipients, but is mediated by other actors that serve as boundary organisations, who perform a crucial role in diffusion of research in the network.

Next, we merge the two networks from Figs. 1 and 2 into one, illustrating the provision of information from both perspectives combined (Fig. 3). Acknowledged relations (represented by the pink flows in Fig. 3) are one-way flows of scientific information that are acknowledged by both providers and receivers. This network represents the complete scientific information network, which we use to further establish the role of boundary organisations in how scientific information is shared. Cases whereby an organisation provides scientific information to another and the latter (the receiver) acknowledges reception, concern very few links. It concerns the following pairs: *Public_Res2* providing to *Bus_Util*, *Public_Res2* providing to *Public_Res1*, *Public_Res2* providing to *Public_Res4* and the other way around, *Public_Res4* providing to *NGO_Env5*, and *Public_Reg3* providing to *Public_Reg2*. In these cases, scientific information travels directly from the providers to final receiver of information. But what is much more common is that knowledge brokers play the main role in ensuring the transfer of scientific information in the network, and scientific information is transferred in multiple steps, from the initial provider through intermediaries to final receivers. This also explains why there are only a limited number of acknowledged exchanges of received scientific information from key providers (e.g. universities). We find that regulator *Public_Reg2* is by far the major boundary organisation and knowledge broker of scientific information in our science-policy network. This organisation does not recognise itself as a provider of scientific information, but is widely recognized as such by others. With a highest betweenness centrality score (173.7), this organisation is the major conduit of scientific information. It mediates scientific information flows between universities and other policy actors. Yet, it is not the only knowledge broker as a few smaller mediating roles are played by the main utility *Bus_Util* and a public research institute (*Public_Res2*).

4.2. Intended and reported organisational changes

We compare the use of science intended by providers with the reported use that is acknowledged by the receivers. This is used as a way of inferring impact, i.e. does intended organisational change translate into reported change? We compare the perspectives of both providers and receivers of scientific information for each of the three levels of changes: awareness raising, operational change, and strategic change. This way, we can assess the role of the major providers or knowledge brokers of scientific information in achieving intended change. We can investigate, for example, whether they trigger the highest level of change in organisations, and hence the most extensive impact. See Appendix 2 for visualising the networks representing the flows of scientific information at the three levels of change. Notably and along the three levels of change examined (increased awareness, operational change, and strategic change), the one regulator (*Public_Reg2*) that was found to be the major knowledge broker, is also recognized by the others as the most important actor for inducing change in others.

Looking at each of the levels of change and starting with increased awareness, we analyse the flows of scientific information that contribute

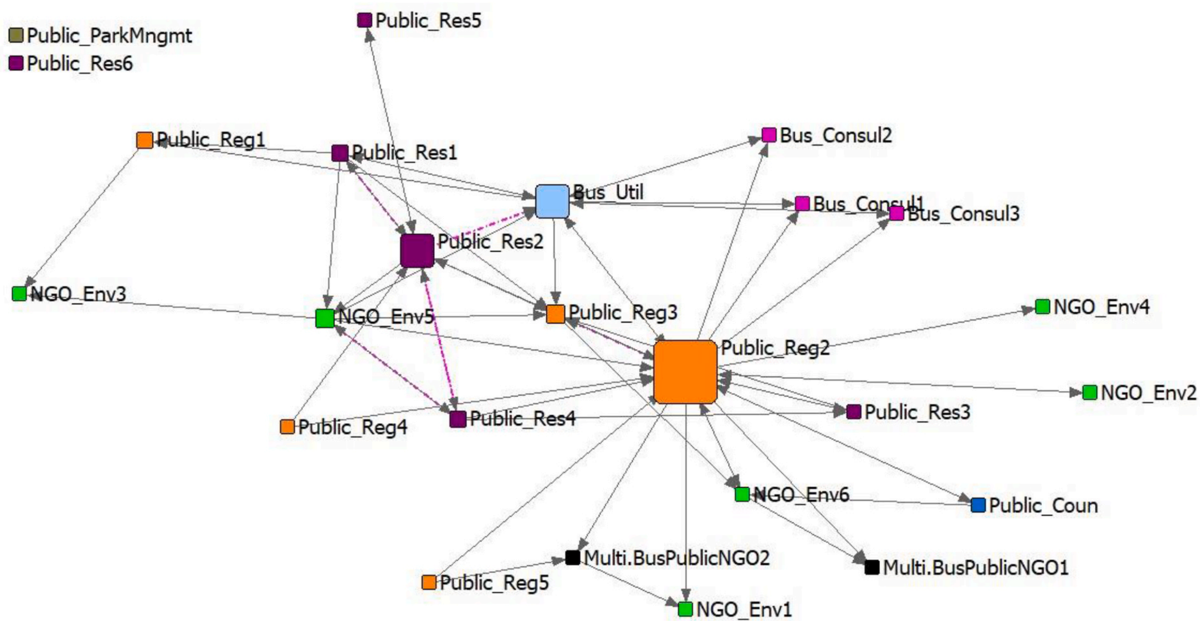

Fig. 3. Provision of scientific information based on the merger of provision and reception of scientific information relations) (nodes size proportional to betweenness) – dashed pink lines correspond to acknowledged exchanges. Note: This network is built by adding the providing network matrix to the transpose of the receiving scientific information matrix. Therefore, the relations mean provision of scientific information. . (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

to raising awareness in organisations, which is the lowest level of impact in our categorisation (see network in Appendix 2.1). We observe that research institutes as well as *Public_Reg4,* and *Bus_Util* make major efforts to increase awareness of new science in others (highest outdegree scores), and especially towards regulatory organisations (see indegree scores in Table 4). In some cases, the intention of producing a change is reflected in a reported change by the recipient organisation. For example, *Public_Res2*, through providing scientific information, is recognized by *Bus_Util* for contributing to increase awareness in the organisation. This is also the case between *Public_Reg3* impacting on *Public_Reg2* and *Public_Res4* on *NGO_Env5*. Another interesting finding is that *NGO_Env5* scores second in betweenness (equal to 28.2) behind *Public_Reg2* (70.8). This NGO appears as an important agent in mediating information received from universities in particular, and forwarding this information to regulators, resulting in an impact on awareness. As part of providers of science, *Bus_Util* and *Pub_Reg3* play the role of bridges in collecting information from universities, consulting companies, and transferring it then to the main regulatory body (*Env_Reg2*), which has the ability to elicit change in others. We observe that a number of organisations, including research institutes, NGOs, and *Public_Reg4* have a common desire to increase awareness within the regulatory body *Public_Reg2*. Interestingly, *Public_Reg2* impacts them as well as other peripheral organisations such as NGOs.

Then, we analyse the flows of scientific information that result in operational change (network in Appendix 2.2 and scores in Table 4). The findings are similar to the network representing the flows inducing increase of awareness in organisations, including the two same acknowledged relations (intention for operational change that transform into reported operational change, for *Public_Reg3* on *Public_Reg2*, and for *Public_Res2* on *Bus_Util*). The difference resides in the presence of

Table 4
Individual scores – intended versus reported organisational changes.

Intended change	Reported change	Intended change	Reported change	Intended change	Reported change
Indegree	*Indegree*	*Outdegree*	*Outdegree*	*Betweenness*	*Betweenness*
Increased awareness					
Public_Reg2: 7	Public_Reg2: 4	Public_Res1: 2	Public_Reg2: 9	**Bus_Util: 6**	Public_Reg2: 70.8
Bus_Util: 3	Public_Reg3: 3	Public_Res2: 2	**Public_Res2: 4**	Public_Res2: 3	NGO_Env5: 28.2
Public_Reg3: 2	NGO_Env5: 3	Public_Res4: 2	**Bus_Util: 3**	**Public_Reg3: 1**	**Bus_Util: 13.8**
	NGO_Env6: 3	Public_Reg4: 2	Public_Reg3: 2		**Public_Reg3: 9.2**
		Bus_Util: 2	NGO_Env5: 2		
Operational change					
Public_Reg2: 6	Public_Reg2: 4	Public_Res4: 4	Public_Reg2: 13	**Public_Res2: 18**	Public_Reg2: 88.7
Bus_Util: 4	Public_Res2: 4	Public_Res1: 3	NGO_Env5: 5	**Bus_Util: 7.5**	NGO_Env5: 41
Public_Res2: 3	Public_Reg3: 3	Public_Res2: 3	Bus_Util: 5	Public_Res4: 7	**Public_Res2: 23.7**
Public_Reg3: 2	NGO_Env5: 3	Public_Res3: 2	**Public_Res2: 4**	Public_Res1: 5	NGO_Env6: 17
Public_Reg1: 2	Bus_Util: 3	Public_Reg4: 2	Public_Reg3: 3		**Bus_Util: 12**
		Bus_Util: 2			Public_Reg3: 11.3
Strategic change					
Public_Reg2: 4	Public_Reg2: 4	Public_Res2: 2	Public_Reg2: 6	**Public_Reg3: 1.5**	Public_Reg2: 49
Public_Reg3: 3	NGO_Env5: 3	Public_Res4: 1	**Public_Res2: 3**	**Bus_Util: 0.5**	NGO_Env5: 23
Bus_Util: 1	Public_Reg3: 3	Public_Res1: 1	Bus_Util: 3		**Bus_Util: 11**
		Public_Reg3: 1			**Public_Reg3: 11**

Note: bold indicates congruence between intended and reported change.

Public_Res1 that does recognise operational change following information provision from *Public_Res2*, and the mutually recognized operational change that *Public_Res2* has on *Public_Res4* and the other way around. An interesting finding is that in contrast with awareness increase, operational change is reported by a much larger number of organisations as compared to the number of organisations intending to achieve that type of change (see networks and scores in Appendix 2.2 and 2.4 respectively). This means that actual operational change occurs even in cases where it is not intended by the organisations providing the scientific information.

In comparison with the awareness and operational changes, strategic change (that is, influence on organisational policy and culture) involves a lower number of organisations (Appendix 2.3). This indicates that the highest level of impact is present in fewer pairs of interactions between organisations. As previously with organisational change, we observe that *Public_Reg3*'s intention to induce policy change on *Public_Reg2* is accomplished. This is also the case for *Public_Res2* on *Bus_Util*. We also find that *NGO_Env5* plays a role of a boundary organisation in the network by enabling research institutes (*Public_Res1*, *Public_Res2*, and *Public_Res4*) to have an impact on *Public_Reg2*. Furthermore, we again find that reported strategic change concerns a much larger number of organisations than intended strategic change, that is, that the impact generated is more significant than intended by the providers of scientific information.

In sum, intended impact does not often translate directly into reported impact. However, impact also occurs unintentionally across all three levels of change within the organisations. The regulator (*Public_Reg2*) that is a central knowledge broker is both targeted and enables impact on other organisations along the three types of change considered. *NGO_Env5*, *Bus_Util* and *Public_Res2* are important actors in connecting science and facilitating indirect change between other organisations. Merging "intended" and "reported" impact networks allows to capture the flow process in the generation of impact. It becomes clear that research institutes (mainly) target (smaller) regulatory bodies, business, and NGOs with scientific information that is then transferred to the main regulatory body *Public_Reg2*. *Public_Reg2* then impacts on a number of other organisations.

4.3. Effect of general information exchanges on organisational change

We then examine how the flow of general information among organisations in our science-policy network may influence the change(s) organisations trigger in others. Fig. 4 presents exchanges of general information as undirected ties and their nature: whether interactions between two organisations occur through formal or through informal exchanges, or both. First, as expected we find that the amount of general information flows occurring among organisations is more extensive than the amount of scientific information flows. Secondly, most of the organisations maintain either informal information exchanges among each other (58.2%), while many maintain both informal and formal exchanges (35.0%). We find that regulators (Public_Reg2 and Public_Reg3 especially), an NGO (NGO_En5), and the business utility (Bus_Util) are at the centre of general information exchanges, having the highest degree centrality. Based on the scores of betweenness,[5] *Public_Reg2* and *NGO_Env5* hold the position of knowledge brokers facilitating general flows of information in the network. Besides *Public_Reg3*, *Public_Res2*, and *Bus_Util*, we also note the role of more peripheral multi-actor organisations like *Multi. BusPublicNGO1* in mediating exchanges. Furthermore, we find that all organisations that reported an actual change (as per previous findings) entertain formal exchanges with others (in addition to informal exchanges), apart from one pair (*Public_Res4* on *Public_Res2)* that is linked through informal exchanges only.

In sum, for general information flows, the same regulator (*Public_Reg2*) acts both as the main knowledge broker and central agent in the network, which mirrors the knowledge brokerage results from the scientific information flows. But in contrast to the findings on scientific information, there are a number of other and diverse organisations (for example, *Multi. BusPublicNGOs*) that also mediate general information exchange. Finally, change resulting from the use of science is more evident among organisations that are linked through formal agreements.

4.4. Effect of organisational characteristics on exchange of scientific information

The change that science drives in an organisation may also depend on the characteristics of the organisation (McPherson et al., 2001). Thus, using a simple linear regression model, we test the effect of two organisations' characteristics on their level of centrality. Through differentiating the organisations that play the role of regulatory bodies from the others, we test the link between having regulatory power and relational power. We are also interested in understanding whether there is a link between the reach beyond the network and the nature and the impact of the flow of information that the organisation is having with others. Along similar lines, Quiédeville et al. (2018) consider organisation size, expressed as number of employees and turnover, to understand their network and the determinants of research impact. To assess the reach beyond the local network, we categorize organisations according to whether they operate primarily in the Yorkshire region or on a wider scale as well. We test the effect of these two variables (regulatory power and operational scale, both treated as a 0/1 dummy explanatory variables) as follows (i.e. translating into three regression tests):

- on indegree score (treated as continuous dependant variables) for the provision
- on outdegree score (treated as continuous dependant variables) for the reception of scientific information networks
- on betweenness centrality score for the merged provision/reception network (represented in Fig. 3).

From the perspective of those providing scientific information, first we find that the presence of regulatory power has a significant effect on both indegree and outdegree centrality levels of organisations (at 90% confidence level: p-values equal to 0.082 and to 0.056 respectively). Organisations with regulatory power should display higher number of relations associated with reception of scientific information and lower number of relations associated with provision of scientific information compared to other organisations. Second, we find a significant effect of the scale of operation (p-value = 0.009) on outdegree centrality: organisations having a wider operational scale than Yorkshire are more likely to have a higher outdegree in provision of scientific information, and therefore a broader reach within the regional network. Thus, those active at national and international level (i.e. beyond Yorkshire), also provide most scientific information within the Yorkshire River Ouse catchment. From the perspective of the receivers of scientific information, we find no significant effect of regulatory power or scale of operation on the outdegree. Notably, we find no significant effect of regulatory power (or operational scale) on betweenness centrality score. While networks in the previous sections show that regulatory bodies are key knowledge brokers in our science-policy network, this result confirms that other (smaller) organisations are not to be underestimated in their role of facilitating transfer of research findings to other organisations.

5. Discussion

Through the analysis of the flows of scientific and general

[5] While betweenness scores in directed and undirected networks are not directly comparable, they identify actors that play key roles in mediating interactions across the whole network structure in both cases (White and Borgatti, 1994).

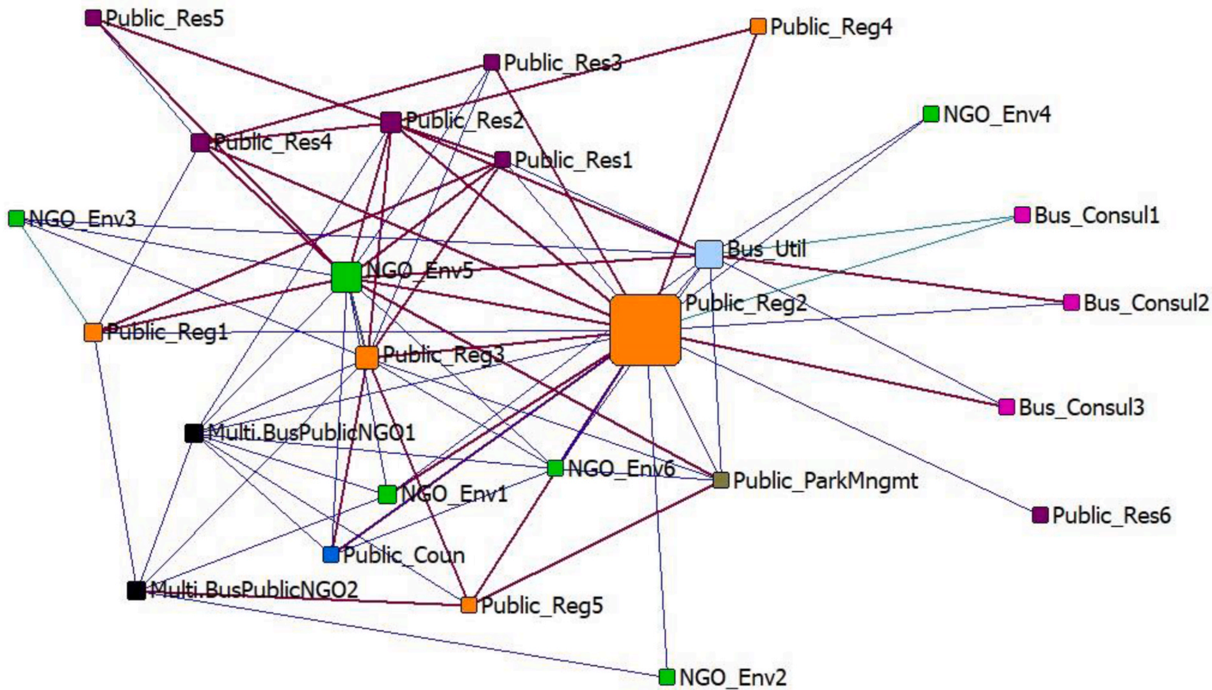

Fig. 4. Exchanges of general level information (nodes sizes proportional to betweenness), and individual scores. Note: Nature of the relations: informal exchange = blue; formal exchange = green; multiplex: both informal and formal exchange = dark red lines.. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

information in a place-based science-policy network comprising actors working on land and water management, we addressed the following questions: Which mechanisms and paths does the transfer of science follow in the network? How does it lead to and shape change in organisations? Which factors co-determine central and mediating roles of organisations in the network?

Our results clearly show how the reach of scientific information and the change it might trigger in an organisation is reported differently by information providers and receivers. We identified organisations that are central in providing scientific information directly to policy actors. However, we also found that key boundary organisations play a crucial role in mediating flows of scientific information between science providers and users (receivers) and therefore are major players in the impact delivery process. Investigating provision and reception of scientific information as separate networks revealed an interesting finding: public research institutes, who state that they provide most scientific information within the network, are often not mentioned as direct sources of scientific information by recipient science users. This reveals that intermediaries are important in the transfer of scientific information. Thus, we found that the impact delivery mechanism is mediated in two main steps: 1) from public research institutes, through public regulators, and to a lesser extent the business utility and one environmental NGO, which in turn, 2) impacts numerous other policy actors in the network. In other words, the mechanism that generates organisational change is such that “producers” of science pass scientific information on to knowledge brokers, especially to regulatory bodies, which then transfer it to other policy actors, inducing change.

The nature of the impact of scientific information flows is more complex than expected. Knowledge brokers have a major role not just in passing on information, but also in contributing to change in other organisations (as shown by Cvitanovic et al., 2016; Maag et al., 2018; Koster and Van Leynseele, 2018). We found that public research institutes and some policy actors target regulatory bodies for change. However, the latter mainly act as conduits of scientific knowledge and might repackage it and eventually trigger change in others. Thus, the major regulatory body in the network is a major receiver of scientific information and is further able to further transfer and transform this information into impact in other organisations. This might in part be explained by its role as a major regulatory body and its legal authority, which facilitates its role in transmitting scientific information in a way that is impactful due to its statutory and relational powers (Jessop, 2008). This brokerage role and the resulting organisational change may also be operationalized via regulatory guidance and different levels of influence of the regulatory bodies on other organisations. Yet, this is more likely to be the case for the general information network than for scientific information network for which the question is specifically about scientific information flows suggesting an acknowledgement of the science content of the information.

This result aligns with the findings from the literature on the importance of boundary organisations for connecting researchers and decision-makers, and converting research into impact (Reed et al., 2018; Tsey et al., 2016; Cvitanovic et al., 2017; Quiédeville et al., 2018). Notably in our study, we find two types of knowledge brokers: 1) regulatory bodies (which are the most prominent brokers) and, 2) an array of other organisations (including NGOs and some of the public research institutes and businesses) that act as additional agents pooling information and circulating it to key influencers, and thus also contributing to induce more diffused impact. The presence of boundary organisations also explains why intended impacts of scientific information flows on target organisations by providers are rarely matched by reported impacts on the part of receiving organisations. Our findings show that most of the changes are generated indirectly and occur along multiple steps, but also that impacts occur sometimes beyond providers intentions and might remain un-accounted for, as suggested by the higher number of reported impacts as compared to the intended ones across the highest levels of strategic change. A more systematic recording of impact, drawing on science users’ reporting, could help reveal the actual reach and significance of impact from science (Rau et al., 2018).

The presence of knowledge brokers in science-policy networks is a performance indicator of knowledge diffusion of such networks (Qiao et al., 2019). However, this also means that the performance relies on these mediators’ capacity to maintain connections and the credibility acquired on both sides of the knowledge broker (Drimie and Quinlan, 2011). This highlights the importance of considering other factors, at the level of the organisations or the information flows, which can strengthen the network configuration and reinforce the process of impact delivery. Thus, and in line with answering our third research question, we first found that with regard to general information flows, organisations beyond regulatory agencies, such as NGOs, public research institute and multi-actor hybrid partnerships gathering representatives of different types of institutions/authorities also play an important role in transferring information. This contributes to organisations knowing about each other's activities and getting regular updates, thus creating social capital and trust, which is known to smooth interactions between agents, facilitating resource mobilization and promotion of knowledge sharing and learning (Leifeld and Schneider, 2012). We also found a possible influence of the nature of general information flows, whether they are formalised, on the realisation of organisational change following provision of science. Information exchanges based on formal agreements could lead to stronger relations than informal exchanges as they allow for more effective collaboration and involve sharing of resources, which stimulate trust and acquaintance between agents. Furthermore, we found that organisations that operate beyond the physical boundaries of the network at national and international scale play a major role in increasing the reach of science within the regional network, and that public regulators are indicated as major sources of scientific information by science users. However, neither of these significantly influence the connecting capacity of an organisation. This suggests that any type of organisations in our policy network could play a significant role in mediating knowledge.

This study shows that SNA can help better understand the specific paths that scientific information flows take between producers, disseminators, and users of science, and assess how impact from research is achieved. Yet, some limitations need to be noted. First, this type of organisational level analysis relies on the ability of an organisation's representative to provide a comprehensive picture of the type of exchanges the organisation has with others, which also entail specific ethical aspects to be considered (Borgatti and Molina, 2005). For large organisations that are split in various sectors/branches, it might not be possible to trace a high number of network partners. This limitation, however, is usually mitigated by purposefully selecting respondents that have best knowledge of the network under investigation (Laumann and Knoke, 1987) and in our case because its place-based focus makes it more likely for representatives of the local/regional branches to be aware of the most relevant information exchanges at such a level. Second and inherent to the SNA methodology, when used in isolation or without additional qualitative evidence, is associated with a risk of oversimplification and lack of contextualisation of what lies behind these relations (Hoppe and Reinelt, 2010). The interpretation of the networks could gain from qualitative insights on the interactions (Oancea et al., 2017), the organisations, and the actual use of the scientific information, which calls for mixed methods (see Bellotti, 2014).

Third, while our analysis provides useful information on how research drives change within organisations, it only captures the situation at a particular point in time. For a more dynamic analysis, longitudinal data would be required to trace changes over time. Furthermore, and related to the research design, we have examined research impact along the dimension of organisational change. However, both research impacts and "impact delivery processes" can be of multiple types (Reed et al., 2020), and therefore there could be alternative ways of capturing and representing impact from the use of science. Last, we recognise that there may be different kinds of research, partnerships, and research outputs, resulting in multiple directions of information flows, with information flow to research organisations helping for instance to define research activities, and some cogeneration of knowledge. Our design and method did not allow us to capture this level of complexity, and all the multiple aspects of co-creation (which could potentially be captured by other approaches, like the Institutional Analysis and Development (IAD) framework (McGinnis, 2011)). Yet, our method is highly valuable and interesting for this particular study, which aimed to observe the flows of information among organisations at a particular time. It will however be interesting to re-run the survey in a few years in order to understand whether these flows of information are inverted, changed, or became more multi stranded, as more co-construction is expected to have occurred in the future of the programme.

The main advantage of SNA is that it offers the possibility of tracing complete network structures, providing a good overview of the 'system' in place (Otte and Rousseau, 2002; Zhang, 2010). Thus, this study provides an understanding of how information flows in science-policy networks can explain reach and significance of impact from environmental research. It offers insights on ways to foster change in organisations through sharing of science. In practice, our findings show that: boundary organisations that connect producers of science to target organisations are crucial for effective sharing of science that leads to impact of research. In our case these are mainly regulatory bodies. Regarding optimizing the type of change induced in an organisation, three strategies can be suggested based on our findings. First, because at present providers of science are not aware of the ultimate impact of the information they provide, it is necessary to improve the communication between organisations and increase transparency in terms of specific needs/requests of information. This will also help understand how existing information in the network can meet particular needs. This work is best done by knowledge brokers who could help select and finetune information to address specific organisational challenges and needs (such as, staff capabilities, updating of procedures or protocols). Secondly, formal collaboration can be effectively used to facilitate change, increasing organisations' capacity to absorb and diffuse information received from others. Collaboration among actors from different sectors or fields is deemed particularly relevant in environmental planning and catchment management where the design of solutions implies a broad approach and holistic understanding of the problem at hand and of the different interests (Lyles, 2014; Farr et al., 2018; Prell et al., 2008a, 2008b). Third, fostering the implementation of impact monitoring routines and their integration within research protocols would help better understand the actual reach and significance of research impact. This would require adapting funding approaches in ways that allows post-research follow-up and monitoring, as environmental impact often occurs after research projects end (Lindenmayer and Likens, 2009).

The results of our study are place-based and field specific, meaning that the shaping of impact is partly conditioned by the physical boundaries within which the analysis occurs. However, our findings show the important role that science-policy networks and transdisciplinary partnerships more broadly play in addressing environmental problems. The legacy of such networks depends on a continuous learning processes among actors (Newig et al., 2010), which contribute to increase social capital, mutual understanding, cooperation in decision-making, and consequently the design of suitable solutions and interventions, and sustainable behavioural change (Markantonatou et al., 2016; De Lange et al., 2019).

6. Conclusion

This study aimed to understand how interactions and flows of scientific information among organisations lead to and shape research impact. In a place-based science-policy network composed of public, private and non-governmental organisations working on land and water management in a catchment in the UK, we examined how the nature of flows of information led to impact, conceptualized as change in awareness, operational change, and strategic organisational change. Organisations took up different and multiple roles in this science-policy network, including providers of scientific information, knowledge brokers, and users of science. Those occupying central positions in the provision of science initiate and control initial diffusion of science and the process of change induced by the use of science.

We confirm the critical importance of the exchanges between researchers and research users as key component of the mechanism through which impact is delivered, but add that the mere existence of such relationship is not sufficient of itself. Our study highlights the pivotal role of boundary organisations. Indeed, the effectiveness of the transfer of information and the generation of impact highly depends on boundary organisations that enable more extensive flows throughout the network. We also note, in the case of environmental networks like ours, the role of the main regulatory organisation as a primary knowledge broker and change maker. Thus, this research contributes to a better understanding of the role of interactions and flows of knowledge between scientists and policy actors in delivering and shaping impacts from research. It provides valuable insights on how to facilitate transformation of environmental research into impact by intervening on information flows between organisations. Practically, this could mean that, in a context of budget constraints, directing actions more specifically towards boundary organisations of a network can be an efficient way to contribute to delivering impact and resolve specific issues. Further research could be focusing in revealing essential intrinsic characteristics of boundary organisations, and further explore the brokering mechanism. Performing this analysis again in a few years using a new snapshot of the iCASP network, and comparing the network across time might help answer these questions. It will be particularly interesting to account for more contextual aspects and organisations' dynamics in future analyses.

Credit author statement

MF, JMO, MG, MD: Ideas; formulation or evolution of overarching research goals and aims, MF, JMO, MG, MD: Development or design of methodology; creation of models, MF, MG: Programming, software development; designing computer programs; implementation of the computer code and supporting algorithms; testing of existing code components, MF: Verification, whether as a part of the activity or separate, of the overall replication/ reproducibility of results/experiments and other research outputs, MF: Application of statistical, mathematical, computational, or other formal techniques to analyze or synthesize study data, MF: Management activities to annotate (produce metadata), scrub data and maintain research data (including software code, where it is necessary for interpreting the data itself) for initial use and later reuse, MF, JMO, MG: Preparation, creation and/or presentation of the published work, specifically writing the initial draft (including substantive translation), MF, JMO, MG, MD: Preparation, creation and/or presentation of the published work by those from the original research group, specifically critical review, commentary or revision – including pre-or postpublication stages, MF: Preparation, creation and/or presentation of the published work, specifically visualization/ data presentation, JMO: Oversight and leadership responsibility for the research activity planning and execution, including mentorship external to the core team, JMO: Management and coordination responsibility for the research activity planning and execution, JMO: Acquisition of the financial support for the project leading to this publication

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix 1. - survey

Your Details									
Name	Position	Organisation			Department/Unit/Team (if relevant)		How Long have you worked for you organisation?	Your email address	
Has your organisation **regularly exchanged information** on land and water issues relevant to the Yorkshire River Ouse Basin with other organisations in the last 12 months? (Yes or No)									
With which organisations has your organisation **most regularly exchanged information** on land and water issues relevant to the Yorkshire River Ouse Basin in the last 12 months? Please list as many organisations as you can in the rows below. For each, please indicate the type of exchange.									
Organisation	Specify Unit/ Department/Team (if relevant)	Direct informal exchanges (e.g. sharing information/ documents/reports by email, phone, at workshops or meetings, etc.)			Exchange through formal agreements (e.g. consultancy, commissioned work, secondments or joint research projects)		Other type of exchange (please specify)		
Name	…	×							
Has your organisation **received relevant scientific information** on land and water issues relevant to the Yorkshire River Ouse Basin from another organisation in the last 12 months? (Yes or No)									
From which organisations has your organisation received relevant scientific information on land and water issues relevant to the Yorkshire River Ouse Basin in the last 12 months? Please list at least the most important organisations.		How does your organisation use the scientific information that you received? Tick all the apply							
Organisation	Specify Unit/ Department/Team (if relevant)	Don't use	To increase awareness and	To change day to day activities	For practical adoption of new models	To change policies or strategies	For cultural change within the organisation (e.g. change attitudes)	As the basis of follow on activities (e.g. consultancy, commissioned	For other uses (please specify)

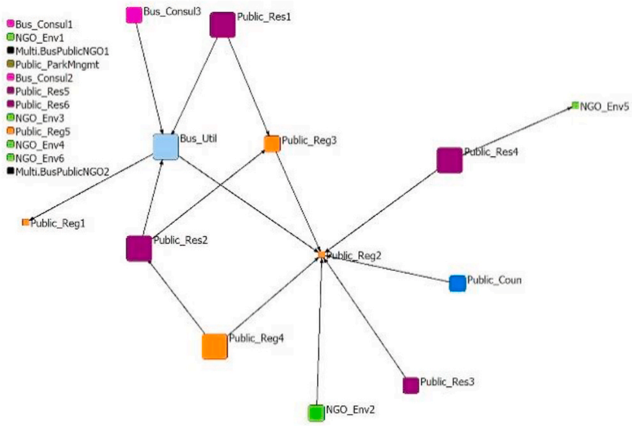
(continued on next page)

(*continued*)

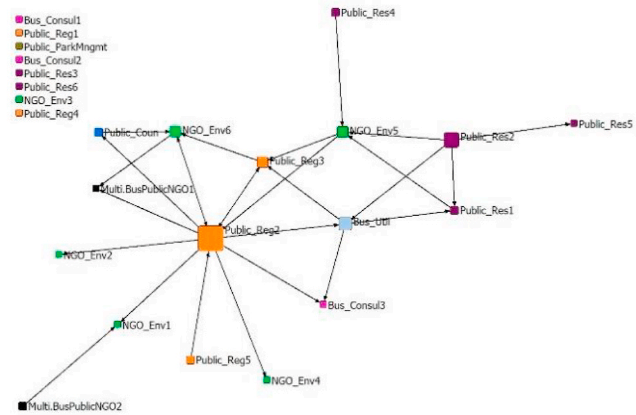
Your Details									
Name	Position	Organisation		Department/Unit/Team (if relevant)			How Long have you worked for you organisation?	Your email address	
			understan ding		methods or tools			work joint research projects)	
Name	…		×		×		×		
Has your organisation **provided scientific information** related to water and land issues relevant to Yorkshire River Ouse Basin to any other organisation in the last 12 months? (Yes or No)									
To which organisations has your organisation provided scientific information related to water and land issues relevant to Yorkshire River Ouse Basin in the last 12 months? Please list at least the most important organisations.		With what purpose does your organisation provide scientific information? Tick all the apply							
Organisation	Specify Department/Unit/ Team (if relevant)	To respond to a request for informatio n	To increase awareness and understan ding	To change day to day activities or operations	To promote practical adoption of new models, methods or tools	To change policies or strategies	To generate cultural change within the organisation (e.g. change attitudes)	As the basis of follow on activities (e.g. consultancy, commissioned work or joint research projects)	For other purpose s (please specify)
Name	…	×			×				

Appendix 2. – intended versus reported organisational changes

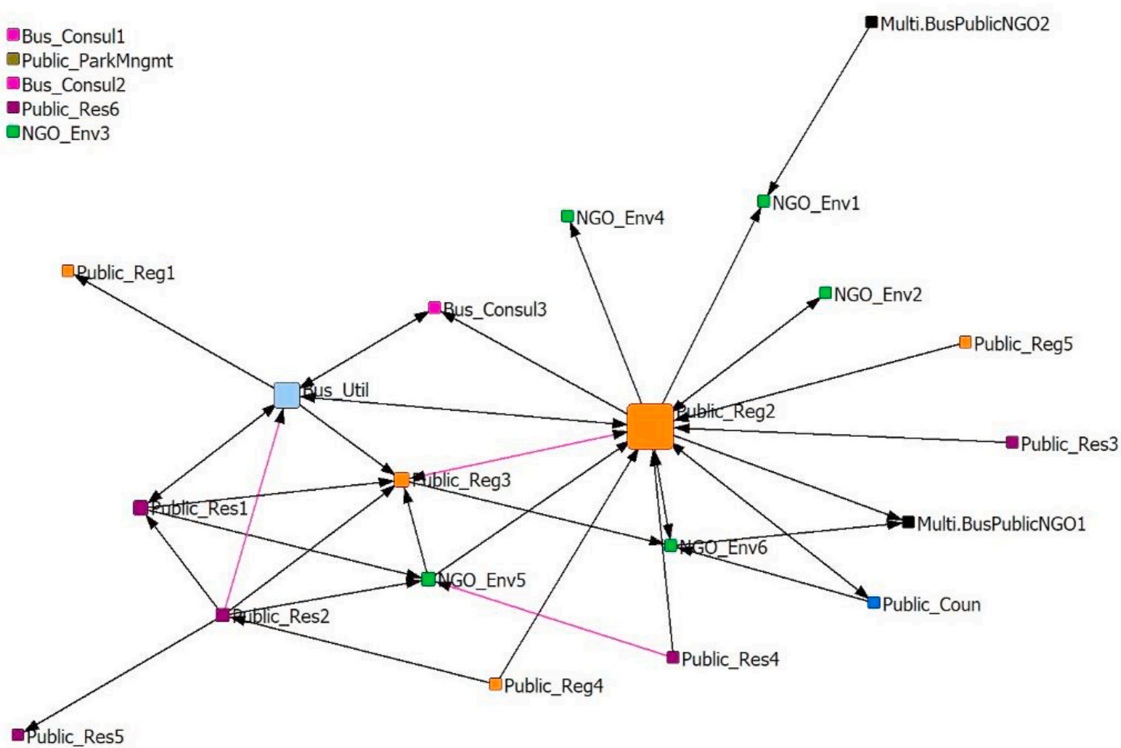
2.1Increased awareness



a. Intended awareness change



b. Reported awareness change

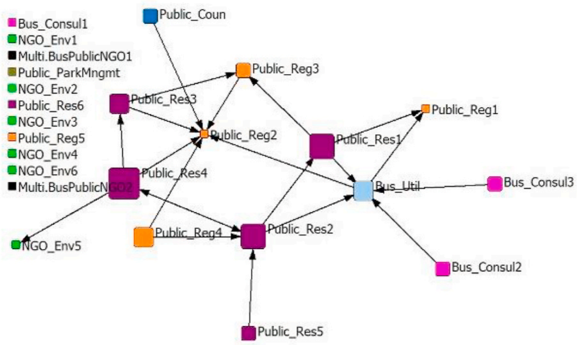


c. merged network highlighting acknowledged links (in pink) (nodes size proportional to betweenness)

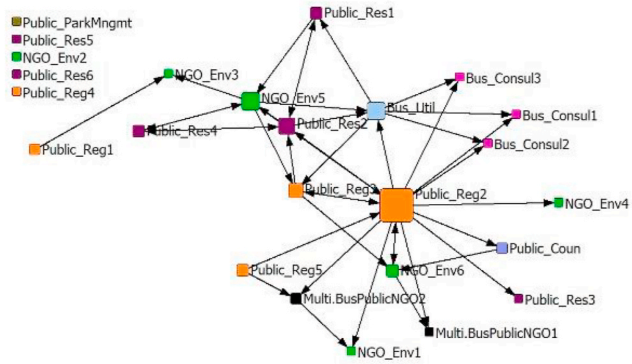
Figure: Flow of scientific information targeting (providers' perspective, Fig. a) and resulting in (receivers' perspective Fig. b) increase in awareness (nodes size proportional to outdegree).

Figure. Flow of scientific information targeting (providers' perspective, Fig. a) and resulting in (receivers' perspective Fig. b) increase in awareness (nodes size proportional to outdegree).

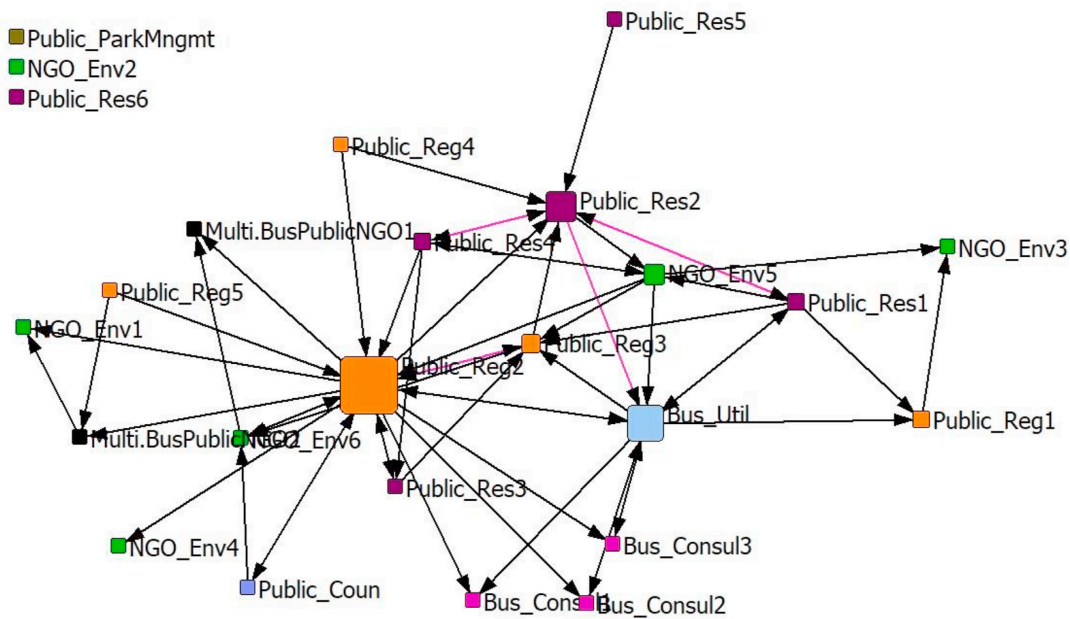
2.2 Operational change



6a. Intended operational change



6b. Reported operational change



c. merged network highlighting acknowledged links (in pink) (nodes size proportional to betweenness)

Figure: Flow of scientific information targeting providers' perspective, Fig. a) and resulting in operational change (receivers' perspective, Fig. b) (nodes size proportional to outdegree)

Figure. Flow of *scientific* information targeting providers' perspective, Fig. a) and resulting in operational change (receivers' perspective, Fig. b) (nodes size proportional to outdegree)

2.3. Strate

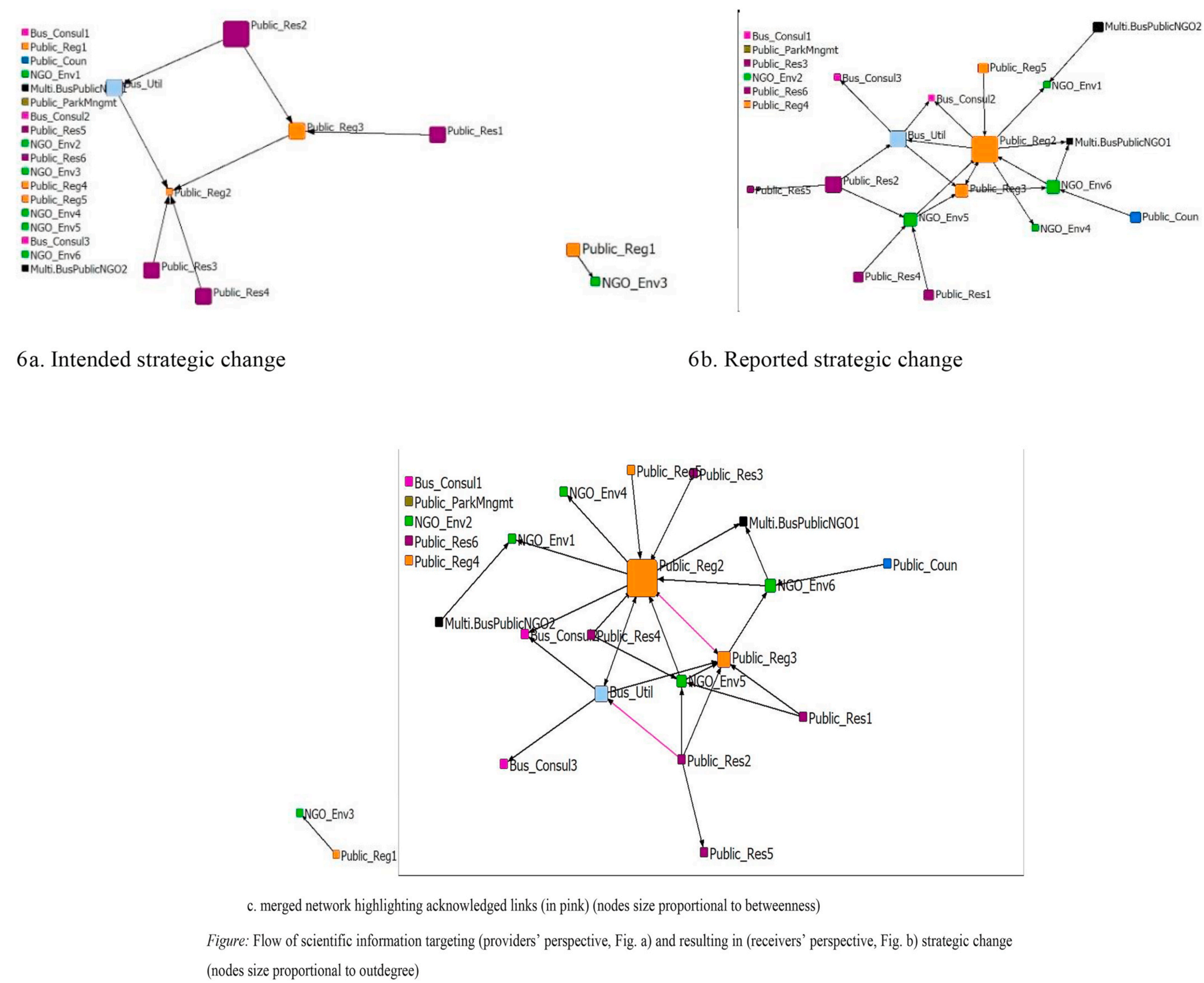


Figure. Flow of *scientific* information targeting (providers' perspective, Fig. a) and resulting in (receivers' perspective, Fig. b) strategic change (nodes size proportional to outdegree)

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