Exploring the Scope of a Cross-regional Knowledge Network. The Case of a Green Chemistry Research Federation in France

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Abstract: Competition in research has led to the emergence of numerous consortia of laboratories, designed to improve their participants' visibility. This article aims to understand the determinants of these new structures through the case study of a French federation of laboratories in green chemistry. Working from bibliographic and qualitative data, we examine this federation's geographical and institutional scope, highlighting the importance of i) prior collaborations in French chemistry, ii) interpersonal relations between consortium members, and iii) policy and scientific incentives. This research highlights the role of the territorial scope of the consortium not only as an argument for the consortium to emerge but also as a resource for its development and visibility among academics and industrial partners.

Keywords: scientific alliances, network formation, embeddedness, territorial organization, green chemistry.

JEL codes: I23, I28, L65, O30, R12

1. Introduction

In the current context of academic competition, research organizations are attempting to improve their visibility (Yudkevitch et al., 2016). This quest for international profile can be pursued through at least three strategies: being big (size effects associated with the notion that "big is beautiful"), being in the right place (according to the idea that location matters) or being in the right network (strategic alliances and knowledge flows). The former two strategies often work in combination, in a context where scientific concentration policies tend to favour large laboratories based in metropolises (Grossetti et al., 2016). The latter strategy is best adapted for medium-sized networks in non-central locations. Such strategies are often driven by public policies as they serve the purposes of deconcentration and territorial planning in higher education and research.

In this context, a growing number of mergers or ventures have been developed between universities – which have seldom been studied due to their novelty, and whose objectives include enhancing member institutions' visibility and centrality (Youtie et al., 2017; Liu et al., 2018). The geography of the entities that emerged as a result of this process has rarely been investigated, although it appears to be increasingly diverse. For instance in the UK, John Harrisson focuses on the development of university alliances, noting that recent policies have been characterized by "a move from promoting collaborative activity within a predetermined regional template – defined by the state and where participation is predetermined by an institution's geographic location – towards allowing universities to actively (re)invent regions based on their own collaborative practices" (Harrisson, 2016). In France, similar observations could be made regarding recent site policies, as well as some of the structuring tools

developed by the Centre National de la Recherche Scientifique (CNRS)[1] or the move from Local Productive Systems to competitiveness clusters (Crespy et al., 2007). Whether the purpose is to create an academic community, a thematic network or a local ecosystem, local higher education, science and innovation stakeholders are encouraged to join forces on a geographic basis, without necessarily having to comply with the administrative boundaries of their respective territories. These opportunities have led to the emergence of "new regional spaces and imaginaries" (Harrisson, 2016).

These new "constellations", to quote again Harrisson (2016), appear interesting to investigate as well as the relations that underpin their emergence. What are the determinants of their institutional and geographic scope? While the notion of "organizational design" can help capture the organizational processes that impact the construction of new collaborative spaces in science and innovation (Barrier and Musselin, 2016), it would be interesting to complement this approach by considering the social, scientific, economic and geographic factors that shape the emergence of these bottom-up coordination mechanisms and determine their boundaries. Since the 1990s, literature on science and innovation has focused either on synergy effects between science and innovation stakeholders on a city-wide or regional scale (Cooke et al., 1997; Asheim and Coenen, 2005; Liu et al., 2013; Catini et al., 2015), or on complementarity effects achieved through the networking of clusters, cities and regions on a continental or global scale (Bathelt et al. 2004; Sebestian and Varga, 2012; Morrisson et al., 2013; Wanzenbok et al., 2015). In this literature, exchanges of knowledge that are not intra-local or intra-regional are categorized as "non-local links" (Meyer et al., 2011) and their geographic coherence is hardly ever discussed, except by analyzing complementarities between "distance effects" and "network effects" (Bergman and Maier, 2009; Ter Wal and Boschma, 2009; d'Amore et al., 2013; Bergé, 2016). A few studies suggest however that a more in-depth study of the geography of scientific exchanges can reveal interesting patterns: for instance, the decline of border effects in the organization of European exchanges (Hoeckman et al., 2010); the enduring role of the national scale in the global organization of scientific activity (Maisonobe et al., 2016); or the importance of geographic proximity for science-industry partnerships (Ponds, 2007).

In this line of research, this study focuses on the intermediate geographic scale between the regional and the national. It aims to examine the geographic coherence of a cross-regional scientific network in green chemistry. It is important to stress that our approach stands apart from Harrisson's (2016) in that the object of this study is not a network of higher education and research institutions, but a network of research laboratories. Such coordination mechanisms are more reliant on research practices, and in particular on prior or potential scientific collaborations between network members. By adopting a spatial approach, our intention is to better assess the role of these coordination mechanisms and for instance, their ability to fix "network failures" (Lucena and Vicente, 2017). Such "failures" can be the product of long-term spatial processes, or path dependencies, that shape and restrain the organization and evolution of inter-urban scientific networks.

The scientific network studied in this article is a French green chemistry federation named INCREASE. Led by the CNRS, it comprises of six laboratories and a club of industrial businesses based in Western France. This research federation provides an interesting field to test our research questions. Section 2 presents some background information on the French green chemistry sector, as well as the theoretical framework used to investigate the emergence and geographic scope of this research federation. Section 3 presents the data used for this case study, including both bibliometric data as well as information collected through qualitative interviews with consortium researchers. The findings obtained from

[1] The French National Center for Scientific Research (CNRS) is a multi-disciplinary public research body placed under the umbrella of the Ministry of Higher Education, Research and Innovation. Created in 1939, it currently employs 33,000 people in over 1,100 research laboratories, with a budget of 3.3 billion euros.

processing this data are discussed in Section 4, and provide the grounds for public policy recommendations (Section 5). Through these diverse materials, we highlight the three types of determinants that shape the consortium's geography: structure effects (impact of past activities on the geography of collaborations); network effects (role of pre-existing inter-individual relations); and policy effects (link between policy incentives and cognitive factors).

2. Studying the structuring of a scientific network in green chemistry

2.1. Green chemistry research in France

Along with nano-chemistry, green chemistry is one of the groundbreaking sectors that have over the past fifteen years transformed the way chemistry is taught, organized and practiced (Morris, 2011; Firtion & Rupp Dalhem, 2015; Milard & Grossetti, 2017). Although fossil fuels remain the main raw material used by the chemical industry, alternatives to petro-chemistry are the object of a growing number of studies, drawing mounting interest in the industry (Moiseev, 2016; Marion et al., 2017). Unlike nano-technology research, which developed in a limited number of scientific hubs due to the spatial concentration of dedicated funding (Bozeman et al., 2007; Robinson et al., 2007; Meyer, 2011), green chemistry in France has benefitted from support mechanisms that encouraged the creation of cross-regional networks. In this area, no less than four programs have been supporting the clustering of researchers and industries on a geographic basis:

- *Instituts pour la Transition Energétique* (Institutes for the Energy Transition, or ITE), including PIVERT (a flagship institute of excellence on low-carbon energy created in May 2012 by *Université de Picardie Jules Vernes*, *Université de Technologie de Compiègne* and *Université de Technologie de Troyes*) and the IFMAS (*Institut Français des Matériaux Agrosourcés*) launched in 2013 in the North of France in association with *Université de Lille* and local partners;
- *Institut Carnot* 3BCAR, created in 2006 with institutions based for the most part in Bordeaux, Toulouse and Montpellier;
- Competitiveness clusters, including AXELERA, created in 2005 in the *Rhône-Alpes* area which now counts 345 partners (industries and laboratories); the IAR cluster (Industry and Agro-Resources), created in 2007 in the same geographic area as PIVERT (Northern France); and Trimatech, a cluster involving Southern cities including Montpellier, Aix-Marseille and Nîmes;
- and finally, the INCREASE Research Federation led by the CNRS, involving several laboratories based in Western France (Table 1), which forms the object of this study.

Table 1. Presentation of INCREASE members and their respective urban areas

Laboratories				Urban areas			
Name	Number of permanent staff	Number of INCREASE members	Scientific contribution to the Federation's scientific program	Lab location	Demographic ranking amongst French urban areas	Scientific production ranking across all disciplines (SCI, 2013)	Scientific production ranking in chemistry (SCI, 2013)
IC2MP	150	7	Catalytic conversion of biomass to fine chemicals	Poitiers	41st	20th	16th

ISCR	300	32	Organometallic homogeneous catalysis and molecular valorization of raw materials	Rennes	10th	9th	8th
LGC	160	24	Chemical engineering and process chemistry	Toulouse	4th	4th	4th
LCPO	40	10	Synthesis of polymers and development of functional polymeric materials	Bordeaux	5th	7th	6th
ISM	130	2	Life-cycle assessment and integrative frameworks for environmental management				
BIA-INRA	190	2	Biopolymers within the biomass and physical chemistry	Nantes	8th	13th	12th
LIENSs	100	21	Assessment of the chemical contamination of coastal areas	La Rochelle	48th	39th	39th

INCREASE (International Consortium on Eco-conception and Renewable Resources) is a public-private collaborative network that was inaugurated on May 13, 2016. Sponsored by the CNRS, it is dedicated to eco-design and renewable resources, with the aim of developing green chemistry by using biomass – a renewable carbon source – as a raw material. It involves firms from different sectors in the chemical industry (cosmetics, agri-food and detergents) as well as eight academic research centers based in Western France (Poitiers, Rennes, Toulouse, Bordeaux, Nantes and La Rochelle). Another of INCREASE's objectives is to promote the training of young researchers and the dissemination of knowledge in the field of green chemistry through the organization of the International Symposium on Green Chemistry (ISGC), which takes place every two years in La Rochelle.

The INCREASE network is the latest addition to a range of institutional programs. According to its participants, the consortium aims to fill a gap in the geography delineated by prior programs. These programs had shaped two major active areas in green chemistry: the *Rhône-Alpes* area, organized around the city of Lyon, and the North-East area between Amiens and Reims. In addition, laboratories in Toulouse, Bordeaux and Montpellier (Greater South-West region) participated in several large networks such as 3BCAR led by the *Institut Carnot*. This map produced the impression that laboratories in the South, East and North of the country were more visible thanks to their integration to large networks, while laboratories based in the West were more isolated. The latter group appears disconnected from existing administrative units as it associates cities located across four different regions: *Occitanie*, *Nouvelle-Aquitaine*, *Pays de la Loire* and Brittany. However, although this territory has no administrative existence as such, it more or less coincides with the area known as the "Atlantic arc" and whose territorial cohesion has been the object of many debates.

The question of whether it would be useful to support the structuring of the "Atlantic arc" has been discussed at length by geographers and territorial planners in the early nineties (Brunet, 1993). At the time, it appeared that France's polarization around Paris was detrimental to the development of transversal relations along the Western and Southern coastal corridors. In addition, while Mediterranean regions had claims to a shared culture inherited from the trade and migration flows that had thrived in the area since Antiquity, the Atlantic arc's identity appeared much more fragmented. The coastline running from Brittany to the Greater South-West region is dotted with medium-sized cities of limited influence including Poitiers, which hosts the headquarters of the INCREASE Federation and has the region's oldest university (Soumagne, 1993). Poitiers is located near several other medium-sized cities with more recently established universities: in the sixties in the case of Angers, Limoges and Orléans,

and in the nineties for La Rochelle (Milard & Grossetti, 2017). The resulting network of higher education and research institutions is relatively dense, with a positive scientific momentum, in particular in chemistry, both in terms of output, diversity and visibility (Milard, 2012).

While the leadership of chemistry researchers in this area is unquestionably an asset, this does not suffice to conclude that the territory delineated by the boundaries of the INCREASE consortium is necessarily characterized by an outstanding scientific cohesion in chemistry, or for that matter in green chemistry. However, the geographic scope of the INCREASE consortium appears to be, at least in part, the product of preexisting relations between its members. As explained by Harrisson (2016), it is interesting to understand how the boundaries of these "constellations" are set by their founders, and to identify the criteria that determine whether or not a site is integrated into a consortium.

2.3. Framework and hypotheses

We developed an analytical framework to examine the scientific cohesion of the territory formed by the INCREASE federation and to understand the determinants that shaped its emergence, looking at different levels of interpretation. In line with the analytical framework presented by Gulati and Gargiulo (1999), we worked from the idea that the embeddedness of relations is decisive in understanding the emergence of inter-organizational networks. To investigate the specific case of the creation of a cross-regional research and innovation network, our framework considers three levels of explanation (Figure 1).

First of all, to understand the context in which INCREASE emerged, we need to examine the French map of chemistry – and in particular, special relations in this field. Economic sociology literature on the concept of "embeddedness" (Granovetter, 1985; Grossetti, 2008) explains that the emergence of new social and institutional structures derives from pre-existing interpersonal relations, but that reversely interpersonal relations develop within a certain social and institutional setting, by which they are in part shaped. Similarly, we consider that the network of scientific collaborations in chemistry that existed prior to the creation of the Federation partly explains the decision of federating laboratories in Western France, as well as the fact that this decision originated from Poitiers researchers. Using a map showing the national organization of scientific activity, we can test the hypothesis that there was indeed a need for a better coordination of laboratories in this part of France. For this purpose, we carried out a bibliometric analysis of scientific collaboration networks between French cities. Along with Katz (1994), we consider that relations of scientific collaboration can be assessed from data on the co-authoring of scientific articles.

H1: The state of scientific collaborations in chemistry between French cities shows a lack of coordination in the "Atlantic arc", which justifies the federation's creation (structure effect).

Secondly, we focused on interpersonal relations that existed prior to the creation of the consortium, and that could explain its emergence. The presumed need for cross-regional coordination can only be fulfilled if there is at least some level of acquaintance between the parties involved in the emerging network. To assess these relations, we used data collected through interviews with federation members and through data on these members' scientific collaboration networks, which we extrapolated from a corpus of bibliographic data from the *Web of Science* (the contents of this corpus are detailed in Section 3).

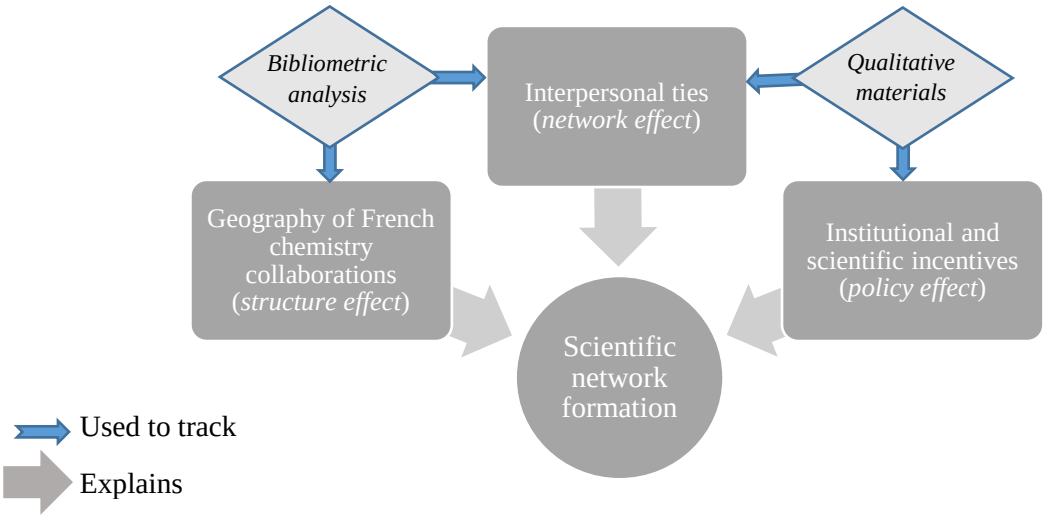
H2: The federation's geographic scope derives from prior relations of acquaintance and from projects of future collaborations between its members (network effect)

Finally, although the federation is a "bottom-up" construct, its existence depended on it being signed off by national authorities. As a matter of fact, the consortium would not have any official existence without the CNRS's moral and financial backing. This means that its scientific agenda is in line with the CNRS's scientific and organizational objectives. The consortium benefitted from a context that made it possible, acceptable and even desirable in the eyes of CNRS leadership. These circumstances are not just the product of the CNRS's internal policy, but also of a range of political, scientific and socio-environmental priorities on various scales (local, regional, national, European). To examine the policy level, we used qualitative materials including interviews, reports and grey literature.

H3: The consortium's emergence was made possible by its alignment with a number of scientific and political priorities (policy effect).

By considering these various levels of causality, as represented in Figure 1, we can identify the social, scientific and historical factors that impacted the integration of specific members and organizations into the consortium, the choice of its geographic scope and therefore its geography.

Figure 1. Framework of scientific network formation



3. Data collection

3.1. Capturing prior networks through a bibliometric analysis

The bibliometric corpuses analyzed in this paper are from the *Science Citation Index Expanded* (SCI), which contains data from over 10,000 science and technology journals. All the main French chemistry journals are in the database. For the purpose of comparison and to assess the cohesion of the territory shaped by the INCREASE consortium, we considered three corpuses of publications obtained through an agreement with OST-HCERES (Figure 2):

- The first corpus (*corpus A*) includes all contributions to journals listed in the *Science Citation Index Expanded*, regardless of their discipline. Within this corpus, we specifically focused on publications whose author(s) were based in one or more of the six member cities of the INCREASE Federation (see Table 1).

- The second corpus (*corpus B*) includes all contributions to publications listed as chemistry journals in the *Science Citation Index Expanded*. Within this corpus, we specifically focused on publications whose author(s) were based in one or more of the six member cities of the INCREASE Federation.
- The third corpus (*corpus C*) includes all contributions published by consortium members. To delineate this last corpus, we asked the representatives of each team involved in INCREASE to give us a list of all the members whose current work is consistent with the research agenda of INCREASE. As a result, we obtained a list of 98 INCREASE members, unevenly distributed across seven research units (see Table 1). This uneven distribution can be explained both by the diverse sizes of the teams and by the diverse interpretations that team leaders have of the INCREASE research agenda.

For all three corpuses, we considered publications from 2007 to 2014. 2014 was chosen as a point of reference because data in the *Science Citation Index Expanded* is updated regularly by its editors, and it usually takes between two and three years for information on more recent publications to be up-to-date. 2007 was chosen as a starting point because a large number of initiatives aimed at structuring green chemistry in France were delivered after this date (Schultz, 2016). Those include in particular the launch of a new call for projects, and the creation by the CNRS of a national network of green chemistry researchers (CPDD for Chemistry and Processes for Sustainable Development).

To obtain a global overview of these datasets, we used the spatial bibliometric method developed by one of this article's authors in collaboration with a team of geographers and sociologists to process the entire contents of the *Science Citation Index Expanded* on the scale of urban areas (Maisonobe *et al.*, 2016). Urban areas were chosen as our resolution level because the administrative boundaries of cities are not comparable, and that the scopes of universities and laboratories are very heterogeneous from a place to the next. In order to localize and explore the geography of scientific activities, we chose to delineate urban areas by using homogeneous criteria (the distribution of population density and the distance in km between sites from where scientific publications are signed). Knowing that the majority of co-authoring links happen within a single urban area, we considered that it was interesting to focus on co-authoring links that develop between different urban areas. These links are indeed more exceptional, and are associated with collaborations that contribute to structuring scientific communities beyond the local scale (regional, cross-regional, national, macro-regional and global scale). To analyse co-authoring links, the value of a link is fractioned according to the number of distinct urban areas that contribute to each co-publication. This method is referred to as "whole normalized counting" in Gauffriau et al. (2008).

3.2. Understanding the emergence of the Federation through stakeholder interviews

In order to understand the set-up of the INCREASE federation and to qualify the relations between INCREASE members as well as their integration into national and international green chemistry networks, we conducted two stages of interviews.

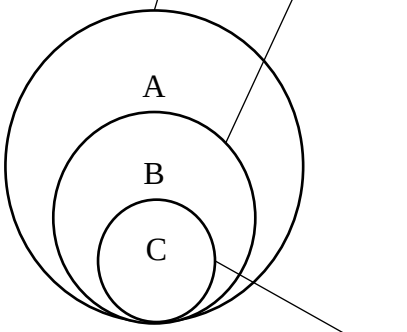
The first stage focused on INCREASE stakeholders: seven research lab representatives, three industry leaders as well as three institutional partners (University of Poitiers, Poitiers' Regional Council and the CNRS's chemistry department). 13 interviews were completed in 2016, of an average duration of 90 minutes. Their objectives were to question the stakeholders on the consortium's genesis, history and objectives, as well as on the benefits derived by each organization from participating in the network.

The second stage took place during the ISCG (International Symposium on Green Chemistry) organized by INCREASE in La Rochelle in May 2017. At the end of this week-long conference which brought

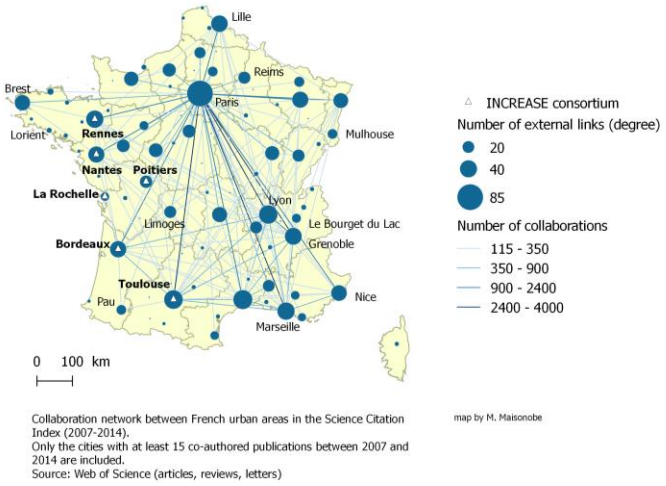
together over 800 participants from 48 different countries, we completed 20 interviews of an average duration of 20 minutes, including 7 with academic members of INCREASE (who had not been interviewed during stage 1), and 8 with researchers or industrials who had co-authored a publication with an INCREASE member. These interviews were conducted using data from the bibliometric analysis of publications by INCREASE members. Interviewees were asked questions on their co-authoring networks and on their participation in national and international green chemistry networks.

These interviews led us to refer to grey literature on the history of green chemistry as a specialism and on the organization of chemistry in France. For instance, we studied the creation and positioning of the other French green chemistry networks mentioned above in section 2.2, as well as the other networks and activities in which INCREASE researchers had taken part in the past.

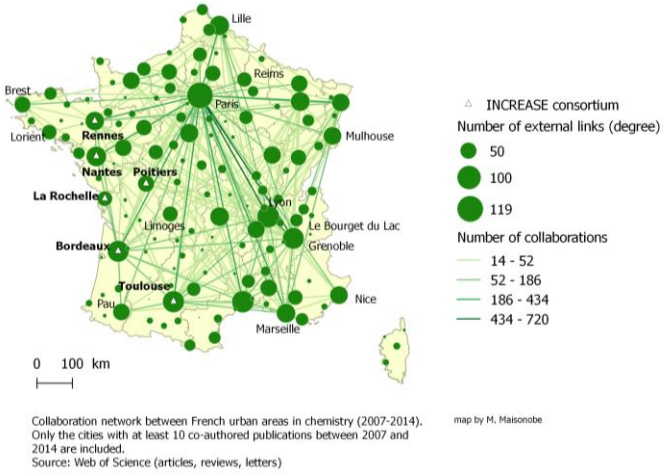
Figure 2. Geography of French inter-urban collaborations in the three bibliometric corpuses



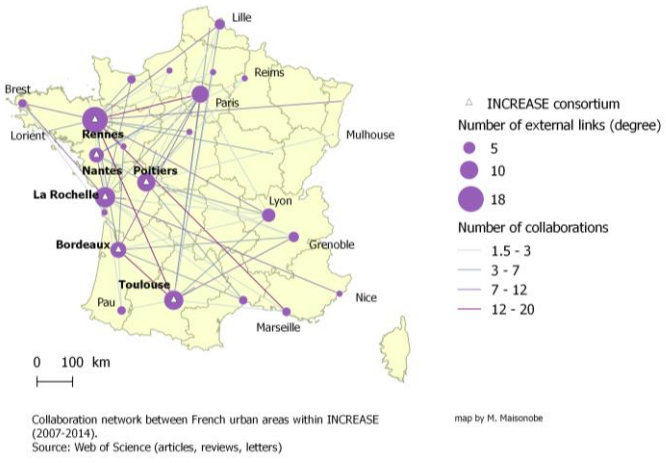
Corpus A, 313,165 French publications in the SCI between 2007 and 2014.
Figure 2.A. Collaboration network between French urban areas in the SCI.



Corpus B, 37,790 French publications in chemistry between 2007 and 2014.
Figure 2B. Collaboration network between French urban areas in chemistry.



Corpus C, 1,813 publications written by at least one INCREASE member between 2007 and 2014
Figure 2C. Collaboration network between French urban areas within INCREASE.



4. Results

4.1. The organization of the chemistry field in France

For many stakeholders in the French chemistry sector, the choice of federating laboratories based in the West of the country was coherent with this discipline's national structure. While laboratories in the Eastern half of France appeared well connected and inserted into diverse networks, those based in the West had little interaction between them in spite of their visibility and notoriety in the field of green chemistry. According to the founder of INCREASE located in Poitiers, whom was interviewed shortly after the launch of the federation in 2016, the French map of green chemistry networks was organized as followed: to the North-East, "*a giant banana-shaped area*" spanning from Lille to Reims (the PIVERT institute); to the South-East, "*Lyon's chemical industry hub, with the Axelera competitiveness cluster*"; and further South, Montpellier with the 3BCAR *Carnot Institute*, and Toulouse with the TWB (Toulouse White Biotechnologies); "*but the whole of the Greater West was left out, with isolated laboratories*". For this reason, the idea of structuring this field in the "Atlantic arc" emerged, which led to the creation of INCREASE.

To confirm this interpretation and understand the national context in which this research federation emerged, we studied empirical data on the co-authoring of chemistry papers. Our analysis embraced urban areas, measuring the number of co-publications associating two different urban areas over the 2007-2014 period, just before the launch of the INCREASE consortium. Figure 2B shows the spatial distribution of the most significant French collaborations in chemistry. The cities with the greatest number of collaborations in chemistry are Paris and Lyon. It also appears that the French map of chemistry is multi-centered, and that the two leading cities do not polarize the majority of relations. Each French region has a relatively dense network of cities that contribute to the national network. Participating cities are not necessarily metropolises: they also include small and medium-sized cities like Pau in the South-West, Le Bourget-du-Lac near Grenoble, Lorient in Brittany, Le Mans in the *Pays de la Loire* region, Limoges, Avignon, etc. Reversely, some university cities with a high ranking in other disciplines (Figure 2A) appear to lag behind on Figure 2B, like Dijon and Marseille that rank much higher in biomedicine.

In order to identify the specificities of relations between the six cities involved in the INCREASE chemistry consortium, we compared the spatial distribution of cross-urban collaborations in chemistry with that of scientific collaborations across all disciplines. Suppose that x_{ij} is the number of co-authored publications between urban areas i and j in chemistry (corpus B), and y_{ij} the number of co-authored publications between urban areas i and j across all disciplines (corpus A). By construction, one of the two cities in the pair ij is necessarily one of the six INCREASE cities. In order to compare x_{ij} with y_{ij}, we weight these values with the sum of the weighted degrees of the cities considered[2]. We thus obtain: $X_{ij}= \frac{x_{ij}}{x_{i.}+x_{.j}}$ for corpus B, and $Y_{ij} = \frac{y_{ij}}{y_{i.}+y_{.j}}$ for corpus A.

We then measured the deviation between X_{ij} and Y_{ij} using a measure of deviation from independence. The value of this deviation from independence indicates the degree of representativeness of co-authoring

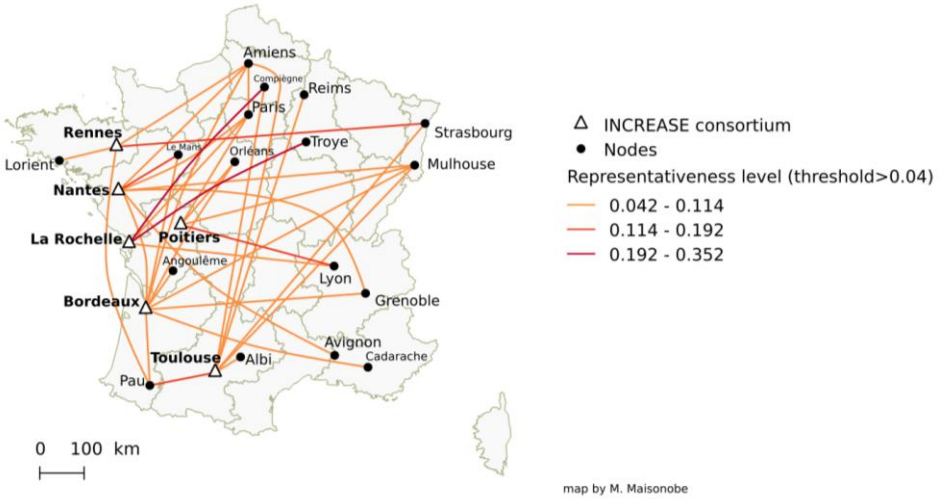
[2] As noted by van Eck and Waltman (2009), there are various ways of normalizing collaboration data. In this article, we chose to normalize values based on the sum of weighted degrees for each city involved in a collaboration. We opted for this method after checking that the findings obtained through other normalization methods did not differ much from these.

links between two cities in chemistry in comparison with their level of collaboration across all disciplines. This indicator of representativeness is noted as p_{ij}, with:

$$p_{ij} = \frac{X_{ij} - Y_{ij}}{\sqrt{Y_{ij}}}$$

If p_{ij} is greater than zero, then the intensity of relations observed in the field of chemistry is greater than what could have been expected in light of scientific collaborations between the two cities across all disciplines. Figure 3 shows overrepresented relations (where the deviation from independence is greater than 0.04). This data indicates that the chemical industry hub around Lyon accounts for a relatively small share of relations with INCREASE cities, in comparison with the intensity of relations across all disciplines. Only researchers from Poitiers and La Rochelle have a special relationship with Lyon in chemistry. Aside from a few exceptions – Grenoble, Avignon and Cadarache where Commissariat à l'Énergie Atomique sites (Atomic Energy Commission) are based, as well as Strasbourg and Mulhouse, two major chemical industry hubs with good connections to Germany – the main collaborations with the six INCREASE cities in chemistry are mostly located in the North and West of France. This result reveals an East-West divide, which has been confirmed by the researchers in interviews, as well as the relative independence of Western France chemists from the "chemistry valley" (South-Eastern France).

Figure 3. Privileged co-publication links with INCREASE urban areas in chemistry versus all disciplines combined

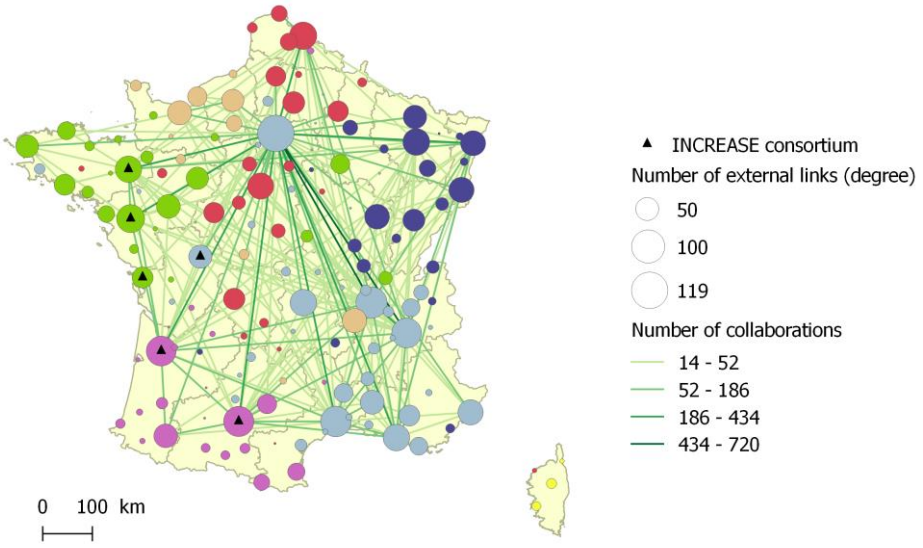


Privileged co-publication linkages of INCREASE urban areas in chemistry versus all disciplines combined (2007-2014). Only the cities with at least 5 collaborations with at least one of the six cities belonging to the INCREASE consortium are included.
Source: Web of Science (articles, reviews, letters)

This East-West divide in the distribution of special relations in chemistry is not sufficient to prove that, aside from their relative independence from the "chemistry valley", Western cities are traditionally rather isolated from each other. This appears to contradict our interviewees' claim that the isolation of Western cities was the main cause for the creation of the INCREASE consortium along the Atlantic arc. In order to ascertain this fact, we applied a community detection algorithm to the network of collaborations between French cities in chemistry. This algorithm partitions the network into several groups. Each group or "community" is characterized by a greater density of interactions between its

members than with external groups. By applying the "Louvain" method[3] we identified seven collaboration areas in chemistry, which are represented in Figure 4.

Figure 4. Community structure analysis of collaboration networks between French urban areas in chemistry.



Community structure analysis of the collaboration network between French urban areas in chemistry (2007-2014). Colored groups are Louvain communities: a community is a group of nodes more connected to each other than to the other groups.
Only the cities with at least 10 publications co-authored between 2007 and 2014 in chemistry are included.
Source: Web of Science (articles, reviews, letters)

map by M. Maisonobe

Regardless of the divide between Eastern and Western cities, we observed that INCREASE cities belong to different groups. Rennes, Nantes and La Rochelle are connected with the Brittany group as well as with a few medium-sized cities in the center of France (green group). Bordeaux and Toulouse are part of a group that includes the Greater South-West but not Montpellier (purple group). Located at the intersection of Brittany and Greater South-West, Poitiers is isolated and connected to the central network formed by Paris and Lyon (light blue group). In light of this result, it appears that Poitiers sits in a unique position, and that the choice of creating a Poitiers-based consortium to develop links between Western French cities is an ambitious one, as this initiative transforms established networks. Rather than being a satellite of Paris and Lyon, Poitiers aspires to become a bridge between the North and South of the Atlantic arc. According to the consortium's founder, Poitiers holds a particularly strategic position in this network of six cities: "*When you look at the map, Poitiers is at the center, so when we have meetings everyone is at about two hours' distance, which is pretty good for our operations. Proximity is important – you can always use videoconferences but they're not the same.*" This bottom-up decision, which was signed off by national CNRS leaders, was meant to "fix" the lack of connections between the North and South of the Atlantic arc in chemistry, while deeply transforming Poitiers' position in the overall structure (Lucena and Vicente, 2017).

[3] This method was applied using default resolution parameters (1). The result thus obtained is rather similar to that obtained with other clustering methods. In all cases, cities in Brittany and the South-West are categorized in different groups.

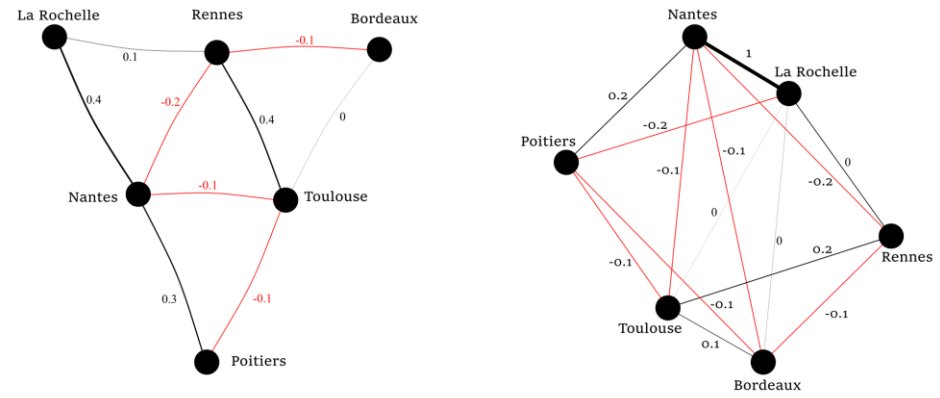
4.2. The role of interpersonal relations

Although INCREASE cities appear to lack connections in chemistry in comparison with other disciplines (Corpus B vs. Corpus A), a number of co-authoring linkages can be observed between INCREASE members prior to the launch of the network (Corpus C). By comparing the co-authoring network of INCREASE researchers (Corpus C) with the co-authoring network of chemistry researchers based in INCREASE cities (Corpus B), we highlighted a special relation between Toulouse and Rennes (Figure 5, left). This relation is due to INCREASE members' specialism in chemical engineering. This specialism is essential in scaling up and transferring lab findings into industrial processes. In addition, INCREASE members based in Rennes and Nantes appear to have a special relation with La Rochelle. The LIENSs Laboratory in La Rochelle is an interdisciplinary laboratory that studies marine environments. The chemists who work there have an interest in biochemistry. Co-authorship data also shows that INCREASE members based at the INRA in Nantes and the IC2MP in Poitiers already have special co-authoring relations in chemistry before the creation of the Federation (Corpus C). This connection is due to the Nantes INRA's expertise in "*everything to do with plant polysaccharides*", to quote to the representative from this laboratory. According to him, this link between Poitiers and Nantes was the product of a national green chemistry collaboration program, coordinated from Poitiers and Nantes between 2007 and 2009. This program was one of the four research sub-networks of the CNRS's national CPDD program (Chemistry and Processes for Sustainable Development) (see next section). According to him, although it is important to mention the existence of this collaboration, it is not the sole reason for the emergence of the federation. Rather, the federation drew its legitimacy from all the new collaboration opportunities that it had the potential to foster: "*This little collaboration with Poitiers is actually quite recent"*, and "*There haven't been any collaborations as yet with the other labs in the consortium*", although there would be "*potential for a genuine complementarity*".

A comparison between the co-authoring networks of INCREASE members and those of INCREASE cities across all disciplines (Figure 5, right, Corpus C vs. Corpus A) reveals a much more comprehensive network than that obtained when focusing only on collaborations leading to a publication in a chemistry journal (Figure 5, left, Corpus C vs. Corpus B). This discrepancy is due to the fact that some INCREASE members do not publish exclusively in chemistry. This specificity shows that green chemistry is not so much a sub-discipline of chemistry as a specialism or "working area" at the interface between several disciplines and sub-specialisms in chemistry. It involves a cross-cutting approach, both within chemistry – as it uses different types of catalysis, as well as polymers and formulation – and outside, with process engineering, biology and economics (for instance lifecycle analysis, to monitor the products and their environmental impact). In this context, the INCREASE consortium aims to bring together researchers from these diverse fields who had never collaborated before. For some of the members we interviewed, this thematic diversity played a more significant part in the consortium's creation than geographic proximity. Proximity is presented as "a plus", a factor that facilitated the delineation of the consortium's scope and further legitimated this choice in the eyes of national and regional authorities.

Figure 5. Representativeness of co-publications between scientists involved in the INCREASE consortium (2007-2014)

Representativeness level of co-publications between scientists involved in the INCREASE consortium (2007-2014)



Co-authoring linkages between INCREASE members in chemistry journals versus all co-authoring linkages between the six cities in chemistry

Co-authoring linkages between INCREASE members all disciplines combined versus all co-authoring linkages between the six cities all disciplines combined

The interurban link and its level of representativeness is computed only if there is at least one co-publication between two INCREASE members located in both cities in chemistry (left) and all disciplines combined (right). Source: Web of Science (Articles, Reviews, Letters)

In the absence of any prior intensive scientific collaboration between network members, other types of relations played a crucial and structuring role in the design and roll-out of the INCREASE network. In our interviews, we noted that several members of the consortium knew each other, or were at least aware of each other, before the federation's launch. These acquaintance networks were decisive in the partners agreeing to join INCREASE when they were contacted by the Poitiers laboratory. The interviews allowed us to distinguish between three types of relations: ties formed through researchers' professional mobility experiences; ties resulting from teaching and training functions (lectureships, thesis juries, etc.); and finally, ties formed between researchers belonging to the same field, by contributing to common institutions or participating in conferences and research programs. This confirms the importance of networking in the academia, which is organized as a professional system. Agrawal *et al.* (2006: 573) argue that "geography is likely to be less important in mediating social relationships between individuals in the same field since they have various alternative mechanisms through which to establish relationships. For example, individuals in the same community of practice or invisible college attend conferences and trade shows together, belong to common associations, and have other institutional settings in which to fraternize and share ideas". Temporary geographic mobility opportunities, involving a scientist's participation in professional events - visiting scholar positions, conferences, juries, etc. -, appear important in terms of linkage opportunities and network building. These events are characterized by a combination of organized proximity and temporary geographic proximity between non-co-located partners (Torre, 2008, 2011), and often lead to long-distance collaborations.

Relations can form over the course of an individual's career, including between laboratories that do not have a record of scientific collaboration. For instance, the Rennes and Poitiers INCREASE representatives met when they were both doing a PhD in Dijon, on subjects with no relation to green chemistry. Furthermore, the federation's founder briefly worked in Rennes before taking up his post in Poitiers. For this reason, although the Rennes and Poitiers laboratories have never as yet collaborated on green chemistry projects, they will be able to do so in the future thanks to their relation of trust and to the consortium's incentive mechanisms.

Similarly, although the relation between Poitiers and La Rochelle had not produced any scientific collaborations prior to the federation's launch, this relation is well developed – if only because both

cities used to belong, unlike the other four, to the same administrative region. The La Rochelle INCREASE representative explains: "*I've never published with anyone from Poitiers* (…) *I've never published with anyone from IC2MP* [Poitiers research lab]. *But I do keep in touch with them: I take part in their recruitment days, I teach in a training course we run in common and we were in contact at the time of the creation of the Green Chemistry Institute.*" The Poitiers laboratory has indeed long specialized in green chemistry, and has done so even before the arrival of the INCREASE co-ordinator in Poitiers. An initiative led by the previous generation of researchers had helped position the Poitiers laboratory in this emerging field by contributing to the national CPDD program (2007-2009), and federate local researchers with an interest in this field into a local program with support from the Region.

Incidentally, we also found out through the interviews that the Rennes INCREASE representative knew very well one of the La Rochelle INCREASE members, who "had been invited to Dijon in 2005" at the time when he was working there. These connections predated these researchers' decision to specialize in green chemistry. Several INCREASE members had met before they even started to work in the same field, simply because they had crossed paths in the course of their careers.

Aside from those who got to know each other through working or meeting in the same laboratory at a point in their career, or through contributing to common training programs or thesis juries, others are well known to others because of their prominence in the field. For instance, two INCREASE researchers explained that they knew each other before because they had been members of the same regional branch of the *Société Chimique de France*. This is also the case with the Bordeaux and Toulouse INCREASE representatives, who are known for having sat on the CNRS's National Committee and on the National Research Agency (ANR), an agency in charge of the evaluation and selection of calls for projects. After 2007, some programs led by the CNRS and the ANR contributed to the national structuring of the field of "sustainable" chemistry. These programs played an essential part on three levels: they helped the teams working on this subject to become aware of each other; they helped foster links with industrials; and they contributed to setting a scientific agenda.

4.3. Policies supporting the emergence of a regional multi-skill network

The networking of research institutions, as observed in this study through the creation of INCREASE, can be motivated by purely scientific motives: the network is often seen as a way of solving research problems by cross-pollinating skills and knowledge from fields with little communication between them. The development of green chemistry is a good illustration of this need for cross-pollination: today's challenges require connections between chemistry (reaction, catalysis), processes (chemical engineering), biomass issues (biology) and lifecycle analysis (environmental impact). The main barrier to the pooling of skills is the scientific communities' poor awareness of each other, due to their respective institutional processes (recruitment, conferences, journals, etc.) which keep them isolated from each other: several interviewees reminded us that chemistry itself is deeply divided into silos according to the type of catalysis the researchers specialize in (homogeneous vs. heterogeneous vs. enzymatic catalysis).

Two recent initiatives launched by the CNRS and the ANR between 2006 and 2012 contributed to promoting sustainable chemistry's development and organization in France (Schultz, 2016). In 2006, the CNRS launched a cross-disciplinary program (CPDD), aimed at drawing an inventory of the teams working on the development of sustainable chemistry in France and organizing them into four thematic sub-networks to contribute to their national structuring. The CPDD program was led by three laboratories that later formed the core of the INCREASE consortium: Poitiers and Nantes in the sub-

network on sustainable resources, and Toulouse which was a key player in the sub-network on sustainable process development (chemical engineering). This initiative offered little funding but created a momentum amongst CNRS researchers. For instance, the Toulouse INCREASE representative reported that this program had given him the opportunity to launch a thematic summer school and an international conference on sustainable process engineering, which are still regularly taking place today. Shortly after this, the ANR launched a large-scale call for projects: "Chemistry and Processes for Sustainable Development". This call targeted the whole French scientific community, beyond CNRS researchers. This time, some funding was available to support selected projects and the program offered strong incentives for multi-partner projects. The first phase was successful but its outcomes in terms of building links with the industry were disappointing. A second phase was therefore launched in 2010 under the title: "Sustainable Chemistry – Industries, Innovation". The program supported research projects with the ability to produce technology transfers that could benefit the industry, and focused on two aspects: improving communication between chemistry, processes and biotechnology; and assessing the costs and environmental impacts associated with resources, reactions and processes (Schultz, 2016).

These incentives oriented the selection of institutions contacted for the creation of the INCREASE consortium. The issue of impacts was first built into the agenda of the ISGC international congress, organized bi-annually since 2013 by the Poitiers laboratory. The individuals who expressed their interest in this aspect of the congress were then invited by the founder of INCREASE (who was also the organizer of the congress) to join the consortium. As explained by the La Rochelle INCREASE representative, "*At the congress, he* [the creator of INCREASE] *wanted to have ethical and environmental impacts on the agenda. In parallel, two teams working on these aspects were invited to join INCREASE. The Bordeaux team (Molecular Science Institute), which specializes in lifecycle analysis, and us, who are working on eco-toxicology and on the impact of pollutants on ecosystems. He was really keen to include these aspects.*" Other interactions also played a central part in the creation of the consortium – including in particular the relation between chemistry and processes. As summed up by the La Rochelle INCREASE representative, "*I hope the federation really helps build bridges between process and synthesis experts, and also between lifecycle analysis and environmental impact experts".* By involving chemists from Rennes, Nantes and Poitiers, the consortium also brings together specialists on all three types of catalysis, which are hardly ever associated (enzymatic, homogeneous and heterogeneous). This diversity of research subjects is the reason why the various teams had never had the opportunity to collaborate much before. Combining diverse specialties has both scientific and economic benefits: the joint objectives are to further sustainable chemistry *and* to create a "toolbox" that industrials can access by directly contracting with the consortium rather than having to negotiate with each separate team.

Reversely, some teams may not have joined the consortium if they had been contacted at another time. Timing played a decisive role in the consortium's emergence and configuration. As mentioned above, there are many coordination mechanisms in green chemistry, and it is not always possible to be a member of all of them at the same time. Being part of a network requires a certain time commitment from researchers. The Bordeaux INCREASE representative (LCPO) adds that belonging to multiple networks can be difficult to manage for researchers: for instance, in cases where a collaboration might lead up to a patent, researchers must preserve the secrecy of their findings. For this reason, the current environment must be taken into account when creating a new coordination mechanism: its leaders need to ensure that its scope does not overlap other existing programs. When a researcher wishes to be part of several consortia, it is important to make sure that their themes are sufficiently distinct so as to avoid any conflict of interest.

The interviews produce the impression that the INCREASE consortium's geographic coherence is more the result of multiple decisions than that of a clear intention to stay within the boundaries of a pre-defined geographic perimeter. According to the consortium's leader, geographic proximity was not initially perceived as a must. It was even envisaged for the consortium to be "international" from the outset and to include foreign laboratories. Some interviewees explained that the Lille team could also have been part of the consortium due to its prior connections with Poitiers and Rennes, to its scientific specialism in characterization and to its international reputation in sustainable chemistry. Similarly, Montpellier has a significant collaboration record with Bordeaux in the field of polymers and could legitimately have been part of the consortium. However, geography appears to have gradually become perceived as a resource on different levels.

First of all, geographic coherence facilitates the consortium's thematic positioning, by placing the focus on the specificity of local natural resources exploited by green chemistry and on linkages with local industries. For instance, the decision to focus on the use of lignocellulosic biomass was influenced by the presence of the lumber industry in Western France (De Cherisey, 2015). A company that uses Landes pine resin expressed interest in the consortium and supported its work. Xylofutur, a Bordeaux-based competitiveness cluster has also been working for the past few years to promote the economic aspects of the transformation of lignocellulose.

The consortium's geographic coherence is also interesting from the perspective of environmental impact reduction, which is at the heart of sustainable chemistry. The consortium supports local supply chains, to ensure researchers and industry leaders do not travel to the other side of the planet to find the skills they need when those can be found locally. The idea is not to abolish long-distance collaborations. However, promoting the development of local partnerships fits within the objectives of sustainable chemistry. The Federation's local focus is not incompatible with cooperation on other scales (European, global), in particular when skills or natural resources can only be found in a remote location. For instance, a Poitiers-based chemist mentions a collaboration with Colombia, where "*Poitiers' expertise in catalytic reactions was combined with the presence of natural materials in Colombia"*; in parallel, this researcher uses INCREASE to source "*chemical engineering skills of interest to the LGC for the synthesis of catalytic materials*" – which provided the opportunity for an intern from Poitiers to spend a month at the LGC in Toulouse, in the Fall of 2017.

Finally, and more importantly, the consortium's geographic coherence is a strong asset to rally support from national and international institutions and from industry partners. This coherence makes the French map of green chemistry more readable. It also contributes to the international visibility of member universities, especially as Western France is already recognized globally thanks to the International Symposium on Green Chemistry (ISGC), which has been taking place in La Rochelle every two years since 2013. In a context of growing international competition with the emergence of new congresses on this theme in Germany and New-Zealand, it appeared relevant to anchor the Poitiers group into a structured local network with an established reputation for its diverse skill base. In terms of science-industry transfers, this geographic coherence is also an asset. The industry was consulted during the creation of the consortium, which presents itself as a means of facilitating interactions and cutting down the red tape attached to contracting with each laboratory. From the perspective of large industrial partners, the consortium ensures that their negotiations with their usual contacts in Western France take place on a level where skills and resources have already been pooled. Overall, the emergence of INCREASE responds to a trend that is broadly encouraged by today's public authorities and policies: clustering and/or networking research institutions located within one same area that offer a combination of diverse resources and skills. This response to existing needs is driven by the founder of INCREASE, who wants to develop his leadership in a context where the CNRS is keen to train professional research

executives. According to the Head of Chemistry at the CNRS, "*the CNRS needs leaders like him, because there are many situations where we need scientific managers. Here at the CNRS headquarters, it is our mission to identify 2-3 persons per year and detect executives with a high potential, train them and offer them personalized support in their career.* [The founder of INCREASE] *is part of the people I call identified research executives*". Ultimately, the creation of INCREASE owes as much to his skills as a researcher as it does to those as an academic entrepreneur (Jain et al., 2009; Perkmann et al., 2013): an entrepreneur who took advantage of geography to build a consortium that could in turn transform the geography of connections.

5. Discussion

This article had a three-fold objective: better understanding the creation of the INCREASE cross-regional thematic network; examining the level of scientific structuring of the cross-regional space shaped by this network, or "Atlantic arc"; and studying the determinants of its delineation and of its scientific and geographic scope. For this purpose, we examined the recent evolution of scientific collaborations in chemistry (structure effect – H1), the various types of existing relations between consortium members (network effect – H2) as well as the impact of policy incentives, scientific and socioeconomic issues, and timing (conciliation with existing programs) on the scope of this inter-organizational creation (policy effects – H3). These three levels of explanation shed an interesting light on the structuration processes that affected this cluster of Western France cities in green chemistry.

As noted by Harrisson (2016) concerning university alliances in the UK, it is rare for all the members of an alliance to have equal interest in joining it: some members may draw more advantages from these clusters than others. The case of the INCREASE consortium is unusual, as it brings together researchers from different laboratories – rather than universities and doctoral schools – around a single theme, and reflects a diversity of interests. Quite clearly, the consortium was designed and rolled-out from Poitiers. This laboratory is a pioneer in green chemistry, but in a context of growing competition, Poitiers researchers led by a CNRS manager found it particularly useful to identify close allies in other neighboring labs, in order to preserve their leadership and visibility in their field. While according to Harrisson's vision (2016), small universities tend to benefit less from university alliances, in this case the consortium is driven by a laboratory based in a medium-sized university town, which occupies a central place, both geographically and scientifically, in this network.

Unlike the alliances studied by Harrisson (2016), which are initiated by the government to facilitate the allocation of higher education and research funding and let alliance members distribute the funds between themselves in proportion with their weight or evaluation scores, the instrument we studied is a flexible one, born from the scientists' desire to federate around a common theme. Member laboratories retain their full autonomy and freedom to work with any other laboratory. If a collaboration is developed between two of the seven labs involved in the consortium, then this collaboration can benefit from the federation's support in the form of a PhD grant, internship, industrial contract, etc.

Our study showed that the levels of interest and motivation varied between consortium members, due in part to the fact that each member is entitled to a different level of financial support. However, none of the members interviewed appeared to have been subjected to any constraints, or had their scientific autonomy threatened by the federation in any manner. All members interviewed appear to perceive the INCREASE consortium as an opportunity. Some members may question the consortium's boundaries and wish that such or such laboratory had been included; others are not very convinced by the need for

geographic coherence (as discussed above, this coherence is a resource more than a necessity); but all understand the benefits of a consortium of this type.

If a lesson had to be drawn from this study, it would be that it is not for geography to constrain public policies, but instead for public policies to facilitate the activation of connections on different geographic scales. No single level of structuring should be privileged above others – for instance through pooling all efforts into the development of local synergies (as was the case with the development of "technopoles"), or into the consolidation of international links. On the contrary, the INCREASE case shows that cross-regional links can also be productive. As shown by recent studies on "network failures" (Lucena and Vicente, 2017), scientific collaboration policies should not set constraints but instead ambition to support researchers and industrials. This involves giving them the instruments they need to facilitate connections that appear to have potential but that are challenging to implement for historical reasons to do with collaboration habits and institutional boundaries (such as the administrative unit of the region). The creation of the INCREASE network was made possible by the flexible model of the "research federation" proposed by the CNRS, which appears particularly adapted to this type of approach.

6. Conclusion

Green chemistry refers to a drive in chemistry towards adopting more environmentally friendly practices (Marion et al., 2017). These practices, which can be expected in term to spread across all of chemistry, are today becoming structured as a specialism – or at least, as a cross-disciplinary area of work. Its development parallels that of nano-chemistry, which has also contributed to transforming the discipline. In both areas, change does not only affect major international hubs. The French case shows that chemistry as a discipline is very evenly distributed throughout the territory, due to its historical connection with industrial geography and with the location of natural resources.

The emergence of new perspectives in chemistry makes it necessary to move beyond old collaboration habits and to build links between teams that had not been accustomed to collaborate in the past. Coordination mechanisms, such as national or European calls for research projects, were created for this purpose. Another structuring initiative in France has been the opportunity to form consortia of laboratories around specific themes. This opportunity, although rarely taken up, is one of the mechanisms developed by the CNRS to structure the national map of scientific activities. It can facilitate the emergence of cross-regional networks whose boundaries are original in that they do not match existing administrative units – such as for instance the INCREASE consortium, which forms the object of this study.

Three levels of causality can explain this consortium's emergence as well as its geographic and scientific scope. Working from bibliographic data and interviews, we demonstrated how the need for the creation of this consortium stemmed from prior collaboration habits in chemistry. Following an assessment of the disconnection between cities in the North and South of the Atlantic arc, and of Poitiers's relative isolation from these other cities, it was felt that a support program was needed to enable large cities of the Atlantic arc to pool their skills in sustainable chemistry (H1 validated). Since the laboratories involved had no record of scientific collaboration, relations of acquaintance played a key role in the implementation of the network: those included interpersonal links deriving from career mobility; professional links formed through joint participation in training sessions, thesis juries or scientific events, which all involve a degree of thematic proximity; and finally, links associated with belonging to the same discipline, and with taking part in the discipline's national and regional institutions (H2

validated). Finally, the context in which the consortium's shape and scope were determined also played an important part, as the founders had to make sure that INCREASE did not overlap with the scope and specialism of other existing mechanisms, and that it took in existing policy and scientific incentives towards more cross-pollination between chemistry, processes and economic and environmental impact (H3 validated).

Looking at the first level of causality – the organization of exchanges within the discipline – disconnections are evident between chemists based in the East and West of France, and between those in the North and South. However, on all other levels of causality, geography appears more as a resource than a constraint for the co-ordination of scientists. The laboratories that joined the consortium did not do so because of their shared belonging to the "Atlantic arc", but rather because of their thematic diversity and of the complementarity they can see between their respective skills. Once the consortium is in place, geographic coherence helps define its thematic positioning, taking into account local natural resources and industrial networks; geography also consolidates the consortium's legitimacy and visibility in the global arena. Finally, geography can also be a resource, in the sense that researchers who are based within proximity of each other will find it easier to meet and collaborate; this will also contribute to reducing their collaboration's environmental impact, which can be of importance in the field of sustainable chemistry.

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