Departamento de Ingeniería Cartográfica, Geodesia y Fotogrametría

GEOSPATIAL SOCIAL NETWORK INNOVATION ASSESSMENT OF THE SPANISH HIGHER EDUCATION

TESIS DOCTORAL

AUTHOR

Arnau Fombuena Valero

SUPERVISOR

Dr. Jesús Manuel Palomar Vázquez

Valencia, Julio 2018

Resumen

El contexto actual es el de una crisis en la Unión Europea, especialmente en los países del sur. Para acabar con la crisis, la Unión Europea elaboró la estrategia *Horizon2020* que se centra en la innovación para abordar los desafíos socio-económicos.

La innovación tiene un impacto en la sociedad y por tanto también sobre el territorio en el que habitan las personas que forman dicha sociedad. El empleo de la perspectiva geoespacial permite llevar a cabo un tipo de análisis que es raramente utilizado por los expertos en Educación Superior que suelen centrarse en metodologías puramente estadísticas.

El objetivo principal de esta tesis es el desarrollo de un modelo que utiliza los Sistemas de Información Geográfica para evaluar la innovación desde el punto de vista de las universidades y el territorio. Además, a través de la aplicación de ese modelo para el caso específico de la innovación producida por las universidades españolas que forman parte de la Conferencia de Rectores de las Universidades Españolas en el año 2015, un segundo objetivo es identificar patrones y tendencias que puedan revelar nueva información.

Los resultados muestran dichos patrones así como la posibilidad de mejorar los métodos actuales de evaluación de la innovación. El modelo presentado en esta tesis provee una solución para entender mejor las redes de innovación y su efecto en el territorio.

En el caso específico estudiado, la evaluación provee una solución que es fácil de entender para las personas responsables de la toma de decisiones en cada una de las provincias españolas. Estas personas pueden identificar qué tipo de instituciones promueven la innovación y dónde se encuentran, qué conexiones tienen y cómo mejorar los resultados de innovación a través de la identificación de socios significativos. Además, la financiación de investigación e innovación podría dirigirse mejor hacia aquellas instituciones con mayor potencial de innovación.

Summary

The current context is one of crisis in the European area, especially in the southern countries. To put an end to the crisis, the European Union elaborated the Horizon 2020 strategy focusing on innovation to tackle the socio-economic challenges.

Innovation has an impact on society and, as a result on the territory inhabited by the people forming such society. Employing a geospatial perspective allows performing a type of analysis that is seldom approached by higher education experts, who tend to focus on purely statistical methodologies.

The main goal of this dissertation is the development of a model that uses GIS for innovation assessment from the perspective of universities and the territory. Then, through application of the model for the case of the assessment of innovation produced by the Spanish universities listed in CRUE in the year 2015, the secondary goal is to identify patterns that may unearth new significant information.

The results show spatial patterns and the potential of improving the current methods of assessing innovation. The model presented in this thesis does provide an innovative solution to better understand innovation networks and their effect on the territory.

In the specific case studied, the assessment provides an easy-to-understand solution for decision makers in the different provinces. The decision makers can then identify what type of institutions are driving innovation and where they are located, what connections they have and how to improve their innovation results through the identification of significant partners. Furthermore, the funding for research and innovation could be better directed towards those institutions with the higher potential.

Resum

El context actual és el d'una crisi a la Unió Europea, especialment als països del sud. Per acabar amb la crisi, la Unió Europea va elaborar l'estratègia *Horizon2020* que es centra en la innovació per afrontar els desafiaments socio-econòmics.

La innovació té un impacte en la societat i per tant també sobre el territori en el que habiten les persones que formen eixa societat. L'ús de la perspectiva geoespacial permet realitzar un tipus d'anàlisi que és rarament utilitzat pels experts en Educació Superior que solen centrar-se en metodologies purament estadístiques.

L'objectiu principal d'aquesta tesi és el desenvolupament d'un model que utilitza els Sistemes d'Informació Geogràfica per avaluar la innovació des del punt de vista de les universitats i el territori. A més, a través de l'aplicació d'aquest model per al cas específic de la innovació produïda per les universitats espanyoles que formen part de la Conferència de Rectors de les Universitats Espanyoles durant l'any 2015, un segon objectiu és identificar patrons i tendències que puguen mostrar nova informació.

Els resultats mostren aquests patrons així com la possibilitat de millorar els mètodes actuals de l'avaluació de la innovació. El model presentat en aquesta tesi proveeix una solució per comprendre millor les xarxes d'innovació i el seu efecte sobre el territori.

Al cas específic estudiat, l'avaluació ofereix una solució que és fàcil de comprendre per a les persones responsables de la presa de decisions en cadascuna de les províncies espanyoles. Aquestes persones poden identificar quins tipus d'institucions promouen la innovació i on es troben, quines connexions tenen i com millorar els resultats d'innovació a través de la identificació de socis significatius. A més, el finançament d'investigació podria dirigir-se millor cap aquelles institucions amb major potencial d'innovació.

ACKNOWLEDGEMENTS

There are several people and institutions that have contributed to this thesis in one way or another. I would like to write a few lines to all of them to thank them for their support and assistance.

First of all, I would like to thank my supervisor, Dr. Jesús Manuel Palomar Vázquez for his support, assistance and availability.

I would also like to thank Dr. José Vicente Pérez Cosín and the research institute *Institut Interuniversitari de Desenvolupament Local* in Valencia (Spain) for their trust and for providing a space where I have learnt so much.

Likewise, I would like to thank Dr. Elena Tsomko from the Computer Engineering Department and the Global Studies Institute at Dongseo University in Busan (South Korea) for their dedication and for sharing their applied knowledge.

I would also like to thank the Department of Spatial Information Engineering at Namseoul University, in Cheonan (South Korea), for their support and shared experiences. Specially, I would like to thank the department dean Dr. Hwangbae Kim for his trust in me and for his contribution to create a space where I could develop this thesis.

Finally, I would like to thank my family for their unconditional support, understanding, and the delicious meals that have given me the energy to continue until the end.

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ABBREVIATIONS

A&HCI: Arts & Humanities Citation Index
AAG: Association of American Geographers
AI: Article Influence
APTE: Asociación de Parques Tecnológicos de España
ARWU: Academic Ranking of World Universities
ASTP: Association of European Science and Technology Transfer Professionals
BoK: Body of Knowledge
CAD: Computer Assisted Design
CRUE: *Conferencia de Rectores de las Universidades Españolas*
DIUS: Department for Innovation, Universities and Skills
ESRC: Economic and Social Research Council
ESRI: Environmental Systems Research Institute
EU: European Union
FECYT: Fundación Española para la Ciencia y la Tecnología
GIS: Geographic Information System/s
GIS&T: Geographic Information Science and Technology
GLONASS: *Globalnaya navigatsionnaya sputnikovaya Sistema*
GNSS: Global Navigation Satellite System
GPS: Global Positioning System
HE: Higher Education
HEI: Higher Education Institution
HES: Higher Education System
JCR: Journal Citation Reports
I3: Impact Integrated Indicator
ICT: Information Communication Technology
IF: Impact Factor
INE: Instituto Nacional de Estadística
INSPIRE: Infrastructure for Spatial Information in the European Community
ISI: Institute for Scientific Information
KT: Knowledge Transfer
LBS: Location-Based Service
MOOC: Massive Open Online Course
NORMES: National Office for Research on Measurement and Evaluation Systems
NPR: Non-Patent Reference
NUTS: *Nomenclature des Unités Territoriales Statistiques*
OSBEDSPP: Oregon State Board of Education Decision-Support Pilot Project
R&D: Research and Development
SCI: Science Citation Index
SSCI: Social Science Citation Index

SJR: SCImago Journal Rank
SN: Social Network
SNA: Social Network Analysis
SNIP: Source Normalized Impact Factor per Paper
SSNA: Spatial Social Network Analysis
STEM: Science, Technology, Engineering, and Mathematics
TH: Triple-Helix
TWUR: Times World University Ranking
UAV: Unmanned Aerial Vehicle
UCGIS: University Consortium for Geographic Information Science
UN: United Nations
UN-GGIM: United Nations Committee of Experts on Global Geospatial Information Management
WoK: Web of Knowledge

1. INTRODUCTION

The current context is one of crisis in the European area, especially in the southern countries. To put an end to the crisis, the European Union elaborated the Horizon 2020 strategy (European Commission, 2014) focusing on innovation to tackle the socio-economic challenges.

Innovation has an impact on society and, as a result on the territory inhabited by the people forming such society. Employing a geospatial perspective allows performing a type of analysis that is seldom approached by higher education experts, who tend to focus on purely statistical methodologies.

Examining whether or not Geographic Information Systems (GIS) have been applied to assess the different issues of higher education and the triple-helix (TH), a systematization of the synergies that produce innovation with three main actors (university-industry-govrnment), the equation is decidedly straightforward. Considering that the relevance of research nowadays is mainly measured by the impact factor of a specific research journal, and the quartile in which it is classified (for example, by the Web of Science, as is the case here), it is justified to support that GIS has little impact on higher education research, specially, applied to analyzing higher education issues. The data employed to make such a bold statement is the result of searching on a globally significant scientific database for the convergence of two keywords: Higher Education (HE), and GIS (alternatively, Geographic Information Systems). The result shows, to date (February 22nd, 2015) and prior to initiating the research presented on this dissertation, that from the set of 573 papers employing such keywords none of them were published in any of the top reference journals in HE, ranking in the first quartile (Q1) of the Web of Science classification, reflecting the little impact of GIS in that field. Descending one level, and focusing on journals ranking from the second quartile (Q2), among those papers that do have a focus on GIS and HE a great majority revolve around teaching and learning GIS, or applying GIS for teaching in other fields. The remaining papers that do disseminate research applying GIS to HE issues represent only a tiny proportion of all the 573 papers returned. Furthermore, the fact that a great number of these remaining papers are published in a single journal limits the dissemination range of those papers. The journal in question is the Journal of Geography in Higher Education, which, although it has published some interesting research analyzing HE employing GIS,

"*was founded upon the conviction that the development of learning and teaching was vitally important to higher education. It is committed to promote, enhance and share geography learning and teaching in all institutions of higher education throughout the world, and provides a forum for geographers and others*" (Journal of Geography in Higher Education, n.d.).

This description indicates that its main mission focuses on educational issues in geography rather than in analyzing HE issues themselves.

Certainly, a more detailed study on the impact of GIS in HE research would be necessary to quantify what has been argued here with higher accuracy and even stronger arguments. However, this superficial study is indicative enough of the overall situation and shows the lack of attention from the HE research community to such a powerful technology such as GIS. The current situation alone justifies performing more research in this direction and until the leading journals, ranking in the first quartile in HE, will not publish GIS-based studies as regularly as they do publish purely statistically-based educational studies, the relevance of GIS in this field will not be taken seriously.

In the case of employing GIS for planning the application of the triple-helix, or assessing its results, the main topic of this dissertation, the search on SCOPUS on March 22nd, 2015, for the keywords triple-helix (alternatively, triple helix), and GIS (alternatively, geographic information systems) returned zero results in all cases.

Absolutely no results were found, which suggests that the type of research presented on this dissertation has not been performed before although this statement should be taken with caution. Nonetheless, it is a clear indicator that this inquiry's approach is remarkably innovative.

On a broad perspective, GIS is also an integrator of disciplines that facilitates the understanding and resolution of issues when approached including the knowledge of a variety of disciplines. Furthermore, Ellul (2015) argues that most real world problems cannot be identified solely in a particular discipline due to their intrinsic complexity.

2. OBJECTIVES

The main goal of this dissertation is the development of a model that integrates GIS and the triple-helix concept for innovation assessment from the perspective of universities and the territory. Then, through the application of the model for the case of the assessment of innovation produced by the Spanish universities listed by the *Conferencia de Rectores de las Universidades Españolas* (CRUE) in the year 2015, the secondary goal is to identify patterns that may unearth new significant information.

A more general goal is to facilitate the access of valuable information to decision-makers, as well as the public in general, through the visualization of maps.

3. STRUCTURE OF THE THESIS

The structure of this thesis is that of an inverted pyramid, starting from the general issues and moving gradually toward the specifics, narrowing down the topic of this dissertation as the discourse advances. The motivation to do so is to captivate an interdisciplinary readership both from geomatics engineering and social sciences disciplines. Consequently, the style of this dissertation is a combination of both traditions. On the one hand, an extensive literature review is performed and, on the other hand, an applied implementation of the theoretical advancement described is carried out in an attempt to take advantage of the best practices from both worlds while also effectively reaching scholars from both disciplines.

Particularly, this dissertation follows the conventional structure of scientific research, that is: introduction, state of the art, methodology, results, discussion, and conclusions. After clarifying the motivation and objectives of the thesis in the previous sections, the state of the art is explored. Then, the methodology is presented visiting the various disciplines that contribute to this thesis including geomatics engineering, sociology of innovation, and information communication science. The methodology section concludes with the proposition of the Geospatial Helix Innovation Assessment Model.

The next step in this dissertation focuses on the application of the Geospatial Helix Innovation Assessment Model for the case of innovation in Spain produced by its universities in the year 2015, which is followed by the presentation of the results section.

The results section presents the outputs of the applied Geospatial Helix Innovation Assessment Model. This includes a series of maps, tables, histograms and network graphs for the case of Spanish universities in the year 2015. These results offer a general view but also detailed results about the universities. Then, the discussion section presents the interpretation of the results. Following the results and their discussion, the conclusions section focuses on the dissertation as a whole rather than the specific case.

Finally, the future research section presents the potential research that could emerge from this dissertation.

4. STATE OF THE ART

4.1. GEOGRAPHIC INFORMATION SYSTEMS

4.1.1. Brief history of GIS

Geographic information systems were created in the 1960s by the Canada Geographic Information System (Lo & Young, 2007). However, some may argue that the first documented GIS was applied in France in 1832 by the French geographer Charles Picquet, who applied spatial analysis to the cholera epidemiology in Paris employing color gradients for each of the districts in Paris. Similarly, John Snow represented the cholera cases in the London of 1854. Snow's contribution is significant because it was the first time that someone employed maps, not only for displaying data, but also for argumentation (Morais, 2012). An interesting view of the GIS evolution is offered by Lo & Young (2007). In addition, the Center for Advanced Spatial Analysis (n.d.), from the Bartlett Faculty of the Built Environment in London, created a graphic timeline including GIS' milestones, the significant, and the minor events of GIS history ranging from the 1950s up to the year 2000.

To these days, GIS has evolved taking advantage of the evolution of computer science and geospatial technologies becoming a highly technical and demanding discipline. This evolution has caused the rise of a certain resistance among geographers (St. Martin & Wing, 2007; Leszczynski, 2009). On the one hand, geographers may argue that GIS is merely a tool, not a real discipline, and therefore that GIS should be closely tied to geography. On the other hand engineers argue that in order to properly apply and manipulate such a "tool" the GIS experts must be able to fully understand coordinate systems, relational databases and the geospatial data populating them (including the potential errors in the data depending on the source), and how to manage the geospatial data as well as present it in an effective and engaging manner. In addition, understanding and accurately applying geovisualization principles, spatial analysis, and computer science knowledge is essential (Wright, Goodchild, & Proctor, 1997).

Around the world, GIS is taught in geography majors as well as in specific GIS engineering majors. The names of the majors and the departments teaching GIS may vary according to the subtleties that each institution deems more significant but they are often used as synonyms. Some of these names include Geomatics or Geoinformatics and are often tied to Geodesy. Either way, nowadays every GIS expert needs to have an interdisciplinary perspective in order to correctly analyze the phenomena in hand. Be it physical geography, environmental issues such as climate change, or other issues more inclined towards the social sciences and the humanities. After all, knowledge is wider than the artificial divisions created between the scientific disciplines. For enlightening this discussion, Krishnan's (2009) work on academic disciplines, disciplinarity, and interdisciplinarity is remarkably interesting, specially, in describing the evolution of disciplines, and how they, and their boundaries, are constantly changing.

4.1.2. What is GIS?

There are many definitions for GIS. According to Worboys and Duckham (2004) a GIS is a computer-based information system for capturing, modelling, storing, retrieving, sharing, manipulating, analyzing, and presenting geographically referenced data (geospatial data). Similarly, the U.S. Geological Survey (2007) defines GIS as *"a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information"*. A slightly more practically-oriented definition is offered by the U.S. Environmental Protection Agency (2015) that describes GIS as *"a computer system that allows you to map, model, query, and analyze large quantities of data within a single database according to their location"*.

These definitions, however, are function-oriented. It is, therefore, necessary to consider that an information system is composed of four components: the data populating the system, the technology behind it, the applications, and the people employing it at different levels (Lo & Young, 2007). This is why GIS is often considered an ecosystem where the function side, the applications, described in the definitions above is only one of its determinant components. The data within GIS can be classified in three categories: the geodetic network that is the fundament of all geospatial data, the topographic base that is built upon the geodetic network by the governments' mapping agencies, and the graphic overlays that are created for specific GIS applications. As for the technology in a GIS, it can be divided into hardware and software where the hardware are, essentially, the computers and the smartphones or tablets together with the servers that provide cloud services. Both the clients and servers rely on the software to achieve the powerful functionality of GIS. The software is composed by an object-relational database at the core that can be exploited through geoprocessing and spatial analysis tools. An important part of the software are its customization options through the development of applications. Several programming languages such as C++, python or java are in use depending on the targeted environment of the application but these languages are not exclusive. The last component of the GIS ecosystem are the people. Three types of people can be identified in a GIS ecosystem considering their level of interaction with the system: geospatial information viewers, general GIS users, and GIS specialists. Employing a language similar to the one employed in computer science the geospatial information viewers are at the highest level. The viewers are the general public and their needs are focused on the accessibility and ease of use of the information. Then, the general GIS users are at a mid-level, and they would be the service providers for the viewers. However, their main characteristic is that they utilize GIS for their professional practice. Their needs revolve around extracting value out of their data to successfully achieve their business goal. At the lowest level are the GIS specialists, those who ensure the system works. They manage and maintain the databases, provide technical support, and develop advanced GIS applications and models for both general users and viewers.

Employing these definitions and considering the GIS ecosystem the relationship between HE, geospatial data, and spatial problems might not be straightforward. However, the word "Geographic" within GIS should be understood, not only as the concept of location or place uniquely in spatial terms, but also as the human activities linked to such location (Lo & Young, 2007). With this ampler perspective in mind, the aforementioned relationship between HE and GIS becomes more meaningful. In addition, from this point of view, it is possible to provide a simplified, and more accessible, version of GIS' definition aiming at a wider audience that may not have a technical background. It is, then, possible to simplify and describe GIS as the technology at the cross-roads between computer science and geography applied to a growing number of fields including environmental sciences, engineering, social sciences, and humanities (Goodchild & Janelle, 2010). It is, precisely, because of its central situation that GIS is *"intellectually challenging both as a field of academic study and as a profession"* (Lo & Young, 2007, p. 18).

There is, in fact, literature on GIS applied to social sciences, and GIS applied to the humanities. For example, Stimson's (2014) recently published work on research methods and applications in spatially integrated social science, or Travis' (2015) recent publication focused on applying GIS to literary, historical, and philosophical texts for supporting critical analysis through mapping language patterns, fictional landscapes, geographic spaces, and philosophical concepts. Prior to these works, Del Bosque-González, Fernández-Freire, Martín-Forero-Morente, and Pérez-Asensio (2012) published, in Spanish, a similar book on GIS for social sciences, and humanities research.

Going back to the technical side, GIS is, at its core, a database with attributes connected to geographically referenced (georeferenced) features by a unique identifier. The technical term of this type of database is geospatial database because it is populated with geospatial data that has been captured employing one or several complex geospatial technologies. Namely, land-surveying, remote sensing, photogrammetry, laser-scanning, or the, nowadays, popular global navigation satellite systems such as the American Global Positioning System (GPS), the Russian GLONASS (*Globalnaya navigatsionnaya sputnikovaya Sistema*), the Chinese BeiDou or the, not yet fully operational, European system known as Galileo. Handling each of these technologies in a way that produces high quality geospatial data requires a high level of expertise at, both, the capturing and post-processing phases before such data can be used in a GIS. Furthermore, each of the mentioned technologies is bound to errors from several origins. Understanding the existence of these errors, how to minimize them, how they are transmitted during the geospatial analysis process, and how to work with and merge geospatial data obtained from different sources is vital (Overman, 2010) for a GIS project to successfully produce correct and meaningful results. In order to achieve such results, mastering the transformations between the different reference systems, from which the data is georeferenced, as well as the particularities of the various projection types is equally essential.

4.1.3. What is GIS for?

In terms of purpose, GIS is intended for solving problems, making better decisions, planning successfully, making better use of resources, anticipating and managing change, managing and running operations efficiently, promoting collaboration, increasing understanding and knowledge, and communicating effectively. These objectives may seem very general. That is because they are. GIS is naturally interdisciplinary, the range of applications is extremely wide, and the number of fields attracted by GIS' capabilities continue to grow in an increasing number of diversified applications.

ESRI (n.d.a), the leading GIS software manufacturer, describes how to achieve such general purposes by outlining its software capabilities and GIS' potential by inference. Such capabilities are spatial analysis, big data mining, mapping and visualization, image management and analysis, 3D, support for open standards, web GIS capabilities, CAD (computer assisted design) and GIS flow, data management, geodesign, community engagement, and real-time GIS. Describing each and every one of these capabilities is not within the scope of this dissertation. However, spatial analysis is very significant and there is extensive literature covering this topic. A couple of examples are the books authored by Smith, Goodchild, and Longley (2007), and by Haining (2003) that are entirely devoted to spatial analysis. Therefore, the description offered here is only superficial. For a deeper understanding of what is spatial analysis and its various techniques and methodologies the cited references are recommended. But, what is spatial analysis?

4.1.4. What is (geo)spatial analysis?

On the one hand, the GIS dictionary created by ESRI (n.d.b) defines spatial analysis as

"the process of examining the locations, attributes, and relationships of features in spatial data through overlay and other analytical techniques in order to address a question or gain useful knowledge. Spatial analysis extracts or creates new information from spatial data".

On the other hand Smith, Goodchild, and Longley (2007, p.15) offer a more inclusive description of what is geospatial analysis by tying the geospatial aspect to whether or not the results are tied to a certain location. Specifically, they define geospatial analysis as "*the subset of techniques that are applicable when, as a minimum, data can be referenced on a two-dimensional frame and relate to terrestrial activities. The results of geospatial analysis will change if the location or extent of the frame changes, or if objects are repositioned within it: if they do not, then 'everywhere is nowhere', location is unimportant, and it is simpler and more appropriate to use conventional, aspatial, techniques*".

In short, it is possible to refer to geospatial analysis as the set of methods and techniques tied to a certain location aimed at identifying and quantifying trends and patterns, developing models for various phenomena, for predictions and simulations, and determining how two or more locations are related (ESRI, n.d.c). Geospatial analysis is, certainly, a complex process where the quality of the data, both geospatial and statistical, and the planning phase prior to the analysis itself are key to obtaining successful results.

4.1.5. Geovisualization

Another aspect that is remarkably relevant in GIS is the visualization of geospatial data (Maceachren & Kraak, 1997), also known as geovisualization. Specifically, geovisualisation is highly effective for communicating the outcome of an analysis in the form of maps (Kraak & Ormeling, 2003). On a more general view, by taking advantage of our built-in human visual system and it's natural ability to identify patterns, trends, and outliers, visualization aids understanding and mining data (Heer, Bostock, & Ogievetsky, 2010; Romero & Ventura, 2010). Concisely, geovisualization is the set of concepts founded on the cartographic rules, and their evolution to our days, aiming at visualizing geospatial data, performing geospatial analysis, and presenting such data in an attractive and persuasive manner (Kraak & Ormeling, 2003).

Considering, particularly, the dissemination of research outcomes that, too often, are as complicated to digest as the research itself GIS offers a solution to improve the communication, specially, from experts to non-experts. Ultimately, it might be the non-experts who will end up making the decisions to tackle the specific issues affecting our society. That would be the case, for example, of policy-makers and educational boards at universities or governments of any level.

4.1.6. What is special about spatial?

So far, the most important question has not been formulated. The question is: Why? Why is spatial so special? And the answer is simpler than what one could expect: Nearly all human activities happen in a place, located somewhere, and many of those activities involve a geospatial component that, often, may be decisive. In addition,

"*Geospatial analysis provides a distinct perspective on the world, a unique lens through which to examine events, patterns, and processes that operate on or near the surface of our planet."* (Smith, Goodchild, & Longley, 2007, p. 51).

Similarly, sociologist Beltrán-Llavador (2010), citing Lizcano (2006, p. 187) and Kant (1995), asserts the possibility of working with dynamic maps for "*redrawing*" our picture of the world and put ourselves in one another's boots, and reminds us that, sometimes changing our point of view also changes our view. Curiously, in English, that expression "changing our point of view" has the meaning of actually changing our prior conception. This, surprisingly, also happens in other languages such as Spanish ("*cambiar el punto de vista*"). It is interesting how language is noticeably connected to visualization, reinforcing the importance and relevance of geovisualisation and, by extension, GIS. Further research in this philological direction might produce compelling results and, from here, it is encouraged. Yet, such type of studies are not within the scope of this dissertation.

The United Nations (UN) recently created the United Nations Committee of Experts on Global Geospatial Information Management (UN-GGIM) for dealing with several issues concerning geospatial data and its management at a global scale. The gestation of the UN-GGIM began in 2009 but its creation was not fully accomplished until 2011. Among the ten working areas within the UN-GGIM the topics include the development of the global geodetic reference frame, geospatial information for supporting sustainable development, implementation of geospatial standards, legal and policy frameworks, and more. One of the most recent and significant accomplishments from the UN-GGIM is the resolution (2015) and the following press release (2015) by the UN General Assembly urging to sharing geospatial data for the benefit of both the people and the planet.

Prior to the UN's resolution and at a smaller scale, the European Commission, created the INSPIRE Directive (Infrastructure for Spatial Information in the European Community) in 2007 for facilitating the access to geospatial data across the EU and facilitating sharing environmental spatial information. The EU's motivation is the use of the European spatial data infrastructure for supporting decision-making across the European countries' boundaries. Although the initial idea was aiming at environmental spatial information, nowadays the applications of geospatial data include a wide range of disciplines. For example, Overman (2010) asseverates the advantages in economics for leading research towards unearthing data and discovering new information through GIS, which is the natural milieu for geospatial data.

The relevance of GIS is growing not only among experts but is also reaching more and more disciplines, including several aspects of HE. ESRI, the most important manufacturer of GIS software envisioned what has been named the spatial university, which should comprise four main characteristics (Sui, 2014):

1) Including spatial thinking throughout the curriculum facilitating the acquisition of spatial skills by the students.
2) Developing a geospatial workforce.
3) Geo-enabling research for enhancing the outcomes from multidisciplinary and interdisciplinary approaches.
4) Geospatial management of HE facilities.

The application of the spatial university in the real world is still at a very marginal level. In 2015, the University of Redlands has pioneered the inclusion of GIS throughout the curriculum, including social sciences and humanities majors (Yarbrough, 2015). This may be due to the short distance from ESRI's headquarters, also in Redlands, California, and the already existing relationship among the university and the GIS software manufacturer (Hardin, 2014). However, the feat is significant due to the innovative approach and more universities may follow this initiative once positive results are disseminated. The University of Redlands has started the dissemination task through its center for spatial studies where a few faculty projects from humanities and social sciences are portrayed on a more relevant position than the sciences ones (Center for Spatial Studies, n.d.). Other important universities such as Stanford University (Stanford Geospatial Center, n.d.), the Massachusetts Institute of Technology (MITLibraries, n.d.), and Harvard University (Center for Geographic Analysis, n.d.) also have their spatial centers, indicating the vigorous stimulus GIS awakes.

4.1.7. GIS Research

4.1.7.1. Ubiquitous GIS

The number of studies employing GIS has not ceased to increase. More and more disciplines are adopting GIS for enhancing their research. The underlying motives behind this situation may be due to GIS capabilities; namely, decision-making support through geospatial analysis, and geovisualization.

The complex process of decision-making, nowadays, is highly influenced by the big data (and big geodata), and is reflected on the availability of large datasets and surveys that make the task of assessing the better approaches for the matter at hand highly arduous. In addition, despite the availability of computerized assistance, the human factor is to be considered (Wang & Ruhe, 2007). In order to tackle the situation, many researchers, decision-makers, and policy-makers find GIS as an effective assistance solution. Moreover, in order to overcome the limitations of the statistical data applied to decision-making support, among other tasks, some improvements are necessary (Pérez-Gómez, 2012).

In terms of research, a few authors assert the benefits of GIS as the integrative cornerstone for interdisciplinary research. Specifically, strategic planning is strongly influenced by locations and geospatial patterns, making the geospatial technologies the essential piece of the interdisciplinary endeavor (Goodchild & Janelle, 2010). Most humanities disciplines, however, have not seen the spatial critical thinking as a priority (Goodchild & Janelle, 2010) but Jessop (2008), and Rumsey (2009) both agree that geospatial information is indispensable in the humanities. The latter also proposes a roadmap to change the current situation where employing GIS technology would be challenging for the humanities traditional scholarly practices. In a similar direction, Boonstra (2009) agrees with the need for more GIS in the humanities but recognizes the lack of effort from the former to adapt to the humanities needs to exploit location data to the fullest.

GIS is employed in a large range of research topics. Traditionally, the fields where GIS has been more commonly applied involve the military and environmental issues although other disciplines quickly adopted it. For instance, urban planning, transport, real estate, and geomarketing, to mention a few, are fields where GIS is commonplace. The expansion of GIS application to research has not ceased to expand since its conception to several other disciplines.

In health, Odisho, Nangia, Katz and Smith (2014) performed a study for identifying geospatial trends in male factor infertility while Turi, Christoph, and Crigsby-Toussaint (2013) focused on understanding the spatial distribution of underweight, overweight and obesity among women and children in Uganda. Taking advantage of GIS' capabilities Schweikart, Henke, Maumbuko, and Poppschötz (2008) developed a GIS-based system for monitoring health infrastructures in Tanzania. In tourism, Olya and Alipour (2015) employ GIS for the spatial risk analysis of excessive rainfall based on the tourism climate index in northern Cyprus. In the world of renewal energy, a geospatial approach was employed for selecting photovoltaic power plants considering the possible obstacles affecting the visibility (Fernandez-Jimenez *et. al.*, 2015). Another study in a similar direction was the evaluation of shadows on rooftops for the potential development of solar photovoltaic energy in Taiwan (Ko, Wang, Chen, & Tsai, 2015). In archeology McCool (2015) developed a methodology for facilitating basic spatial analysis to archeology professionals. Cooper and Green (2016) employed GIS' spatial binning techniques on their project case of the English landscape and identities. Visser (2015) studies the evidence on large-scale road building along the Roman lines in the Netherlands through geospatial analysis performed on open source GIS software. Hill and Bekker (2014) study the use of language as a demographic variable in their GIS-based analysis centered on the residential space and inequality in Cape Town, identifying geo-social patterns according to three main languages. In social welfare an inquiry was performed with GIS to assess the proximity and availability of social services (Dorch *et. al.*, 2010). The findings led the authors to recommend an annual GIS analysis on community services availability and proximity to their potential users. The geospatial analysis approach has been also used in historical research. For instance, Seifried (2014) merged demographic data in a GIS to unearth population and settlement distribution patterns.

The number of scientific papers published every year is so broad that it is difficult to make a short but fully representative summary of GIS research. However, it is compelling to observe the one common aspect of all the examples cited above: the predominance of georeferenced data and geospatial analysis integrated in a GIS with other types of data for obtaining new information.

In non-academic environments GIS is also growing. A good example is the "Memorandum for the Heads of Executive Departments and Agencies" published by the White House where the high value of the concept of 'place' is accentuated and the principles for developing effective place-based policies are described (Orszag, Barnes, & Summers, 2009). The recent publication by the Spanish National Institute of Statistics (Instituto Nacional de Estadística or INE) (2014) is of significant interest since it is the first time that the institute publishes their data also through maps. This document portrays 25 maps with socio-economic indicators of the 2011 census distributed in areas of one square kilometer. The elaboration of the maps has been possible thanks to georeferencing buildings. The initiative occurred thanks to a European regulation that pushed the EU countries to employ the same methodologies, definitions and statistical tables for promoting consistency in future comparative studies across the union. The president of the INE presents the document as an added value to the obtained results (Instituto Nacional de Estadística, 2014, p.2). From the point of view of the wide public maps have become commonplace in newspapers (El Mundo, 2013; Russia Today, 2014; Grasso, 2014; BBC Mundo, 2015), and online magazines and blogs featuring maps are often disseminated through social media. A few of these maps, include the 25 maps that explain the English language (Nelson, 2015, March 3), the 38 maps that explain Europe (Yglesias, 2014), the 40 maps to explain World War I (Beauchamp, Lee, & Yglesias, 2014), the 40 maps to explain the Middle East (Fisher, 2014), or the interactive European language map (Arnett, 2014) as part of a curious trend of what could be called the "maps of the most" displaying, for example, the most densely populated countries (index mundi, n.d.), the most popular music genres (Feeney, 2015), the most expensive countries to live in (Bradford, 2015), or the locations where the most pictures are taken (Pincus, 2015). Prestigious magazines such as Forbes also participate in this trend publishing maps, both interactive and static, whenever the topic covered permits (Bruner, 2012; Jurney, 2015; McCarthy, 2015). The number of these "maps of the most" is enormous and growing, covering various topics.

4.1.7.2. GIS and Higher Education research

The GIS research related to HE could be divided in three categories. The first is the GIS in the classroom either focused on GIS teaching issues, the benefits of learning GIS, or employing GIS for enhancing the learning process both in geography and in other disciplines. The second category is centered on HE facilities planning and management with a strong influence on the decision-making process. The third category, within which this dissertation falls, revolves around the analysis of HE issues. Be it for analyzing the effects of the knowledge triangle (introduced in section 4.2.1), analyzing student retention patterns, student mobility or any of the many issues concerning HE, and its role, in the current globalized changing environment.

4.1.7.2.1 GIS in the classroom

The relevance of the GIS approach among a growing number of disciplines, the media's dissemination, and the increasing possibilities for the private sector have resulted in a large number of inquiries focusing on such topics. The geographers and GIS experts' interest on expanding the knowledge-base concerning teaching and learning GIS, or with GIS, have been a significant drive as well. As new methodologies and technologies, such as smartphones and the Internet, evolve the use of GIS in the classroom and its effects are becoming a growing research field (Hong & Stonier, 2014). This field intends to understand and tackle related issues such as teaching GIS and how students acquire the related contents, experimenting for finding best practices when creating new GIS-focused curriculums, or using GIS to teach outside of geography.

Before initiating studies in Higher Education Institutions (HEIs) the students' exposure to GIS is limited. In order to bring GIS to the classroom in high schools and middle schools Hong (2014) identified WebGIS tools as the easiest to implement and use. However, teachers' training is also necessary along with an evaluation of their improvement in terms of GIS knowledge and skills. With the combination of teacher training and WebGIS, Hong & Stonier (2014) argue, GIS may become an essential skill. Achieving the conditions described by the previous authors requires tackling the challenges that make the current use of GIS in the classroom a rare event (Radinsky, Hospelhorn, Melendez, Riel, & Washington, 2014). Some of these challenges include the need of access to technology, the need of training teachers, and the distraction from the course objectives in favor of the technology itself. But also, as Ellul (2015) mentions for the case of HE, the different levels of digital literacy are an issue at pre-college levels as well. Some authors such as Şeremet and Chalkley (2015) remind us that teaching opportunities with GIS are not being exploited.

At the HE level there seems to be no agreement in whether GIS/Geomatics education is increasing or decreasing. On the one hand, Lunkibeal and Monk (2015) argue there is an increase of master's programs teaching GIS in the USA but to do so they compare their findings with the Association of American Geographers (AAG). That is, they searched for all the programs where GIS is taught while the AAG only identified those taught within the Geography departments. It does not seem rigorous to compare their results with those of the AAG for the outcome may be simply due to the different extent of their research. However, Bearman, Munday, and McAvoy (2015) employ a reliable source, referencing the British Economic and Social Research Council (ESRC) (2012), to argue in favor of the GIS growth in the UK. On the other hand, Aina, Aleem, Hasan, AlGhandi, and Mohamed (2014) argue that there is a reduction and they note the significance of several Geomatics programs having closed or restructured in the USA. They consider this problem to be rooted at the lack of awareness and understanding of the geomatics field. They identified other issues that may also be causing this situation: the relative novelty of the geomatics field, the competition with other fields such as geography and civil engineering, the difficulty for recruiting and retaining highly qualified faculty, and the weak financial support from HEIs. In Spain, the situation is also difficult with the recent decrease in the number of students in geomatics engineering programs (Diario de Ávila, 2015) although the academic community, aware of its value, promotes it (Europa Press, 2015; Universia, 2015). In Asia, Ota and Plews (2015) report that geographic information technologies have not yet reached maturity in academia although a certain recognition of their importance has been accomplished. This situation may have started to slowly evolve with the significant change in the classification of instructional programs of Geographic Information Science and Cartography to a Science, Technology, Engineering, and Mathematics (STEM) program by the National Center for Education Statistics (2012) in the United States. This also shows the need for a larger workforce with GIS skills (Lukinbeal & Monk, 2015; Xie & Reider, 2014).

In spite of the difficulties mentioned above there is an agreement on the benefits of GIS in the classroom. Several authors agree that acquiring GIS skills improves the student's employability (Abastroiu, Felea, & Vasiliu, 2014; Bearman *et al.*, 2015; Ferrandino, 2015; Pirogov, 2014; Şeremet & Chalkley, 2015; Xie & Reider, 2014). The recognized employability improvement may be due, as Xie and Reider (2014) note, to the ubiquitous nature and diversity of GIS applications that have resulted in an annual market growth rate of 35% and the commercial subsection growing at a 100% rate in the United States. It is important to consider the source of this data, the United States Department of Labor (2010), might be slightly outdated. However, a sharp increase of GNSS (Global Navigation Satellite Systems) adoption is expected until 2020 with growth percentages of 59% in the USA, 48% in the EU, and 40% in Brazil for agricultural applications with UAVs (Unmanned Aerial Vehicles) alone (Barba-Polo & Sanchis-Muñoz, 2015). Many of these applications will involve GIS expertise in order to take advantage of the data acquired by means of photogrammetry and remote sensing from UAV platforms. Hence, GIS will grow accordingly. Considering the mentioned market growth, Abastroiu *et al.* (2014) warn about the increasing gap between the number of GIS experts available and the market demands, and point to the reduced number of GIS/Geomatics university programs as the main cause. Perhaps, the high market growth will also drive the growth of existing GIS/Geomatics programs but, as mentioned above, there is no agreement on this topic yet. However, the benefits of learning GIS reach further than simply increasing the students' chances of finding a job.

The interdisciplinary nature of GIS facilitates its application in contexts that matter to the students, therefore, increasing their engagement in the case of study while improving their skills in systematizing and processing knowledge for problem-solving with modern technology (Xie & Reider, 2014). Furthermore, employing GIS enhances the students' analytical skills; specifically, their spatial thinking, spatial statistics and planning skills as well as their environment awareness (Bearman *et al.*, 2015). For the students with a non-technical orientation learning GIS implies the acquisition of skills in spatial data management; a special kind of data that is often intertwined with other alphanumeric data from multiple sources in order to identify possible solutions for a given problem (Bearman *et al.*, 2015). In short, GIS skills enable the students' integration in Information Communication Technology (ICT) environments that would, otherwise, be out of reach for them (Ellul, 2015; Ferrandino, 2015; Xie & Reider, 2014).

The benefits of learning GIS are many but so are the challenges for teaching it properly. To enlighten the situation, in 2006, the American University Consortium for Geographic Information Science (UCGIS) had the initiative, in collaboration with the AAG, to publish the Geographic Information Science and Technology (GIS&T) Body of Knowledge (BoK). It is important to note that the GIS&T BoK does not pretend to regulate GIS&T education but rather assist on closing the gap between academia and professionals in GIS&T education and training (DiBiase *et al.* 2006). In spite of the GIS&T BoK dating back to 2006 Wallentin, Hofer, and Traum (2015) argue that it is still considered a relevant guidance for curriculum design for the fields involved in geospatial technologies. Nonetheless, they do report three demands from the workforce: 1) pushing aside the data acquisition in favor of spatial data management, 2) a stronger focus on programming and application development, and 3) an expansion of web-related skills. Wallentin *et al.* (2015) identified two trends to correct the situation. On the one hand, in the US the UCGIS targets the update of the GIS&T BoK itself while, on the other hand, Europeans target updating the BoK according to the workforce demands under the European Union funded project "Geographic Information: Need to Know" integrated by 31 partners and 25 countries (GI-N2K Consortium, 2013). While the update of the GIS&T BoK takes place, Baker *et al.* (2015) propose a research agenda to develop the best educational practices with a noticeable multidisciplinary perspective. Specifically, this agenda includes four aspects: 1) the evaluation of geospatial thinking skills as opposed to assessing the use of specialized software packages, 2) the learning of geospatial technologies that is, for the most part, covered by the GIS&T BoK with a special focus on the emerging research field on web-based learning platforms, 3) the professional development of teachers with geospatial technologies in the classroom, and 4) expanding the number and size of inquiries on the subject for better insight. Connecting with the third aspect of Baker *et al.*'s (2015) agenda, Hong and Stonier (2014) remark the need of developing evaluation methods aimed at the teachers in order to assess their progress in GIS&T. Strangely, privacy and ethics issues are not included in the proposed agenda but, Goodchild (2011) affirms, their importance in the field will increase. These serious issues are mentioned in the BoK within the context of GIS&T and Society. Yet, as Scull, Burnett, Dolfi, Goldfarb, and Baum (2016) point, many (if not most) of the GIS&T educators dismiss the subject and do not include it within their courses. Either way, the GIS&T BoK's application in a classroom environment, especially in pre-college levels, will require the development of more teaching materials as many teachers recognize the potential of GIS (Hong, 2014).

Besides the existing GIS/Geomatics programs, be it within Geography courses or specific, GIS is also being used in other educational contexts. That is, learning with GIS. For instance, Radinsky *et al.* (2014) employed webmaps both at middle-school and college levels for teaching migrations. Abastroiu *et al.* (2014), Bearman *et al.* (2015), Pirogov (2014) applied GIS in HE classrooms for business-related topics such as management and process automation. Ferrandino (2015) used it in an undergraduate criminal justice program and highlighted the need to go beyond crime-mapping and towards the development of geospatial thinking. In this sense, Baker *et al.* (2015), and Bearman *et al.* (2015) coincide with Ferrandino's (2015) view on promoting geospatial thought rather than teaching "buttonology" for it implies performing tasks with a certain software without the necessity of understanding the underlying GIS concepts and techniques. The button-pushing learning defeats the purpose of the geospatial perspective altogether and does not provide the advantages described above.

The popular WebGIS offers an easily accessible tool for teaching GIS (Hong & Stonier, 2014), it is necessary to recognize its usefulness resides in its ease of use for displaying, querying data, and visualizing the results (Duan, Yang, Yang, & Zhao, 2014). The accessibility offered by the web has led to the realization of Massive Open Online Courses (MOOCs) under the premise that they facilitate access to HE at a global scale while reducing the costs (Pappano, 2012). Against this premise Emanuel (2013) argues that it is the already highly educated students who register in MOOCs, therefore, debunking the idea of increasing accessibility, or reducing costs. Specifically for the case of GIS, MOOCs offer the possibility to provide a sneak peek into the GIS world but the advanced topics require an interaction student-teacher that, today, is not possible within the MOOC platform (Robinson *et al.*, 2015). Furthermore, Ooms *et al.* (2015) recommend the web lectures, such as those in the MOOCs, as a complement but not as a substitute of traditional lectures. This approach has been employed in the Colton High School, located in Redlands (USA), which already had a GIS program since 2008. In this High School, the GIS MOOC's web lectures were viewed in class with the teacher's support in the form of guidance resulting in 65% of students earning the MOOC's certificate (Kerski, 2015).

Another tool with recognized usefulness in teaching is the smartphone (Teo, Wu, Shih, & Tsai, 2014). The smartphones in GIS/Geomatics education, with their multiple sensors and available apps, provide an accessible platform for exploring the data acquisition process despite its low accuracy. Although the accuracy provided by a smartphone's GPS is far from the needs of a professional surveyor it does facilitate what Jones (2015) calls "*the democratization of accuracy*" granting an easily available platform for Location-Based Services (LBS) application, use, and development. Teo *et al.* (2014) identified four categories of apps in smartphones that could be employed in GIS/Geomatics education: Surveying, Remote Sensing, GPS, and GIS; and they found a total of 31 apps for either Android or iOS mobile operating systems.

UAVs, popularly known as drones have reduced the cost of aerial imaging and several applications already exist (Greenwood, 2015; Irwin, 2015). Two of the most well-known manufacturers of surveying instruments, Trimble (n.d.) and Leica Geosystems (n.d.), as well as others have already developed their own UAV systems denoting their importance for the geomatics engineering profession. In geospatial technology education Lim (2015) reports on the Urban Atlanta Geospatial STEM Academy free summer program aimed at high schoolers (Hawthorne, n.d.), where they used both smartphones and drones for geospatial data acquisition but the latter was rather anecdotal and limited to an introduction to aerial photography. In the Social Sciences Britchnell and Gibson (2015) view drones as an opportunity for research but point several challenges for teaching human geography with them, specifically, the increasing number of regulations, the need for training to use them safely, and, as Goodchild (2011) and Scull *et al.* (2016) commented, the privacy and ethics issues. The research opportunities they mention do not revolve about the drones themselves but rather about the areal imaging resulting from their use. It is then arguable, that social scientists may be interested in the analysis of geospatial data as what Lo & Young (2007) describe as general GIS users. Britchnell and Gibson (2015) do not seem concerned with the process of geospatial data acquisition perhaps because that has not been, traditionally, the role of geographers. However, the risk of not fully understanding the underlying principles of geospatial data acquisition by means of photogrammetry, in the case of UAVs, may be a cause for substantial errors in the data, thus, leading to misleading results in the posterior spatial analysis. The relatively new software such as the proprietary Pix4D (n.d.) or the open source VisualSFM (n.d.) may be a welcomed aid to avoid such errors in the acquisition of geospatial data but its post-processing, prior to its inclusion in a GIS software, is still a complex process. If anything, drones have attracted social scientists' attention towards geospatial technologies and, as much as interdisciplinary approaches are beneficial to the resolution of spatial problems, the geospatial data acquisition remains the expertise of geomatics engineers, especially when high accuracy is required.

The classification of instructional programs of GIS&T as a STEM discipline denotes the technical orientation of the GIS/Geomatics field within the ICTs. In relation to this, in the UK Singleton (2014), warns geographers that they may soon be unable to accurately manage and analyze geospatial datasets regardless of their size. In order to minimize this challenge, Singleton recommends geographers to learn how to code. Similarly, Şeremet and Chalkley (2015) identify the lack of GIS expertise among Geography scholars in the UK as one of the main obstacles for GIS to grow in British Geography degrees. Before them, Longley (2000), already pointed out that

> *"The G in GIS has led some geographers to feel that the discipline has some kind of proprietary interest in the subject, yet it is important to remember that geographers have actually played a negligible role in the development of most proprietary systems"* (p.39).

Five years earlier, Pickles (1995) had gone even further denying the geographers the legitimacy to question what will be of the geography profession with the evolution of GIS. These comments project the image of a geographer that is only a General GIS user rather than a GIS specialist, according to Lo and Young's (2007) classification of GIS users. It is also true, however, that the situation of American geographers might be slightly different considering their involvement in the development of the GIS&T BoK. Nonetheless, considering the central position of geomatics engineers that are involved in the whole process of collecting, storing, managing, and analyzing the data with GIS, and connecting with Lo and Young's (2007) vision described above (GIS is at the crossroads between geography and ICTs), it seems there is an opportunity for the geomatics engineering field to grow in academia for they possess a widely diversified skillset, both on the technical and non-technical sides. As mathematicians and computer scientists teach in a myriad of disciplines, geomatics engineers, similarly, have the chance to export their knowledge and apply their skillset to the plethora of fields that could take advantage of the spatial approach towards problem-solving.

4.1.7.2.2. GIS in Higher Education management

There are a few universities employing GIS remarkably for managing several issues concerning HE including planning and construction of new campuses, the maintenance of HE facilities, campus sustainability, safety and emergency issues, and orientation within the campus. The Kuwait University has planned a new campus entirely based on GIS technology. Before its construction it was esteemed necessary to understand the impact of design on the everyday life on campus. Employing 2D and 3D GIS it has been possible, for example, to establish before construction the size of the offices assigned to a certain type of faculty members or to consider the time required to go from one classroom to the next in a way that aids managing the allocation of facilities for each study program. On the construction phase the logistics involving where things are and when they are needed as well as updating the progress on a daily basis has been also managed through GIS. This way of optimizing space inside and outside within a single system has been possible thanks to GIS' capabilities. Besides, the system is dynamic so it can be expanded when needed. Moreover, after the construction concluded, the GIS system allows to keep adjusting the facilities management and optimization while taking care of the maintenance in an effective manner (ESRI, 2012). In a similar direction, the University of Rochester, in USA, is employing 3D GIS for the 3D virtual campus master planning. This 3D virtual campus permits envisioning the future interaction of the buildings with the surrounding environment. One of the main advantages behind the idea of the virtual campus master plan is the reduction of the information silos, hence, facilitating better informed management (ESRI, 2012). The University of Calgary, in Canada, has expanded its use of GIS from the academic environment to the institutional administration and has created a smart campus as a result. The use of 3D GIS data, like in the mentioned universities, has been fundamental for optimizing the available resources and improving the decision-making process. The outcomes of this management approach have been extraordinary and thousands of dollars have been saved allowing to redirect those monies towards more important issues (ESRI, 2012). In terms of sustainability the Pomona College, in California, is a good example of GIS success. After applying GIS for reforming the campus landscape and improving energy efficiency the reduction on water needs has been tremendous, therefore, improving the sustainability of the campus (ESRI, 2012).

Researchers are also interested in GIS for managing HE facilities. For instance, Jie (2013) studied the walkability of educational public service facilities in Wuhan, China, and Ma (2013) modeled and implemented WebGIS-based inter-campuses equipment for optimized management. On a wider scale GIS has been employed for rationalizing the distribution of spatial resources through the study of the layout and structure of HE at the regional level, and providing scientific support for decision-making (Liu & Wen, 2013).

It is relevant mentioning that there are not many universities applying GIS to their campus management or, if there are, they are not explicitly publicizing it. Therefore, the cases publicized by ESRI have been the most relevant found so far. It is also significant mentioning that not many research papers covering this topic were found when browsing the SCOPUS scientific database for a combination of keywords such as GIS, Higher Education, and Management.

4.1.7.2.3. Research with GIS for Higher Education analysis

There is a massive volume of research on higher education. Yet, the number of studies taking advantage of the GIS potential are very limited. In order to enhance the decision-making procedures, increase the benefits resulting from it, and broadening the understanding on HE a few scholars have performed geospatial analyses. For example, Liu and Wen (2013) studied the layout and structure of HE facilities at a regional level for a better distribution of resources while providing scientific support on decision-making. To achieve their aim the relationships between HE and the local economy, population, and geographic environment was explored. On another dimension, employing GIS and analytical databases together with demographics and socioeconomic factors, the financial performance of operations at a Higher Education Institution can be studied highlighting, as a result, where solutions may be applied to maximize investment for promoting enrollment (Zahorjanski & Veljovic, 2011). Geospatial analysis has also been applied to inquiry student retention patterns to, similarly to Zahorjanski and Veljovic's work (2011), identify where to initiate specific support programs or where successful students live. Due to the expansion of globalization to HE, geospatially analyzing student mobility is a straightforward manner to make GIS capabilities visible to the university policy stakeholders (Perkins & Neumayer, 2014). Furthermore, Singleton, Wilson, and O'Brien (2012) modelled the participation in HE through the connection of spatial interaction with demographic classification aiming at testing potential policies, and simulating the effects on participation according to each institution and the neighborhoods where the students lived.

As it has been already mentioned, decision-making is one of the highlighted capabilities GIS provides. A few authors and institutions have been interested in this area. Perhaps, the most interesting GIS-based decision-making support system implemented so far is the one Wang, Guo, Xu, Jia, and Wen (2009) developed at the

Peking University, in China, since it considers the need for the public to be familiarized with the decision-making process while providing useful information from various sources to researchers, and educational stakeholders. The (American) National Office for Research on Measurement and Evaluation Systems (NORMES), within the 'No Child Left Behind' policy, also employed GIS for web-based interactive exploration of state-wide educational data at the school level. Especially, GIS was used to create thematic maps and for the posterior visual analysis aimed at identifying spatial relationships and patterns within the educational data. Hence, facilitating a deeper understanding to administrators and allowing policy analysts to pursue more effective policies (Mulvenon, Wang, McKenzie, Airola, & Anderson, 2006). The Oregon State Board of Education, the Oregon University System, and the Oregon State University carried out a pilot GIS-based decision-making system named Oregon State Board of Education Decision-Support Pilot Project (OSBEDSPP). The main objective for this project was to advocate in favor of analyzing demographic and statistical data through a GIS-based system directed towards aiding in the decision-making process, specifically, for developing workforce and funding colleges (Oregon State Board of Education 2004; Wang *et. al.*, 2009).

It is important noting that research approaches employing GIS as the integrative element for improved spatiotemporal studies, for example, monitoring changes and policy impacts on HE, remain scarcely researched. In this sense, it has been considered interesting to briefly present a couple of papers where such an approach could be highly beneficial and, most likely, produce enhanced results. Warren, Hoffman, and Andrew's paper (2014) on identifying patterns and trends in grade retention rates in the United States could, likely, be substantially enhanced were they to employ a spatial approach on student retention patterns based on, or similar to, Hanewicz's (2009). The multi-temporal inquiry on trends in educational advantage by area performed by Smith and Smith's (2014) represents one of the types of research on HE where GIS would be most advantageous. It comprises some of the components where GIS capabilities are the most outstanding: Multi-temporal scale and pattern spotting by areas through geospatial analysis, while it would allow for other capabilities to step in, namely, geovisualization.

4.1.7.2.4. The Spatial University

The spatial university, briefly introduced above, is a combination of four aspects (Sui, 2014). First of all, the spatial university would extend the spatial thinking across the curriculum providing spatial abilities to students for increasing their chances of succeeding, first, in STEM courses and, later, in their careers. This principle has been supported recently by Kim and Bednarz's (2013) study on the development of critical spatial thinking through GIS learning. The second characteristic is the development of a geospatial workforce. Geotechnologies were pointed as one of the three most important emerging fields by U.S. Department of Labor (2011), and job opportunities have been rising for several years. This statement has been supported by Gewin's (2004) paper published on the prestigious journal Nature but also, more recently, by the famed economics newspaper Forbes (Mejide, 2014) in its version in Spanish stating that both geomatics engineering in general and GIS specifically are in the top 10 professions that will be demanded in the future. Other Spanish media have noted the employability of geomatics experts as well (Méndez, 2011; Radio Televisión Española, 2015; Sucasas, 2014). The third characteristic of the spatial university is the Geo-enabled research. As it is supported on this dissertation and by several other authors as well, GIS integrative approach and its spatial perspective are of special interest for enhancing both multidisciplinary and interdisciplinary research. The fourth, and last, characteristic a spatial university must have is the application of GIS in a smart campus environment for supporting the management of campus planning, operations, maintenance, and sustainability. In short, for managing campus infrastructures, and human and economic resources leading towards more efficient institutions. A good example of the application of GIS smart campus is the University of Calgary, in Canada, that has saved thousands of dollars as a result (ESRI, 2011).

A few universities mentioned above have benefited from GIS management so far and only one is known to have expanded GIS throughout the curriculum. In terms of research, many scholars are realizing the power of GIS and its reliability to aid the obtainment of new interesting data. Leading this trend, the University of Redlands is boosting GIS across the curriculum applying it in all disciplines. By doing so, this university is, *de facto,* geo-enabling the students graduating from their programs that will become the future workforce in the labor market. Teaching with a geospatially focused vision also requires the faculty to update their skills prior to transferring their knowledge to students. Moreover, once the faculty learned GIS the following logical step has been the development of GIS-based research, once again, across all disciplines. A short introduction to such research can be found on the story map website of the university's faculty projects (Center for Spatial Studies, n.d.). The only aspect of the spatial university that is not explicitly, nor properly, publicized at the University of Redlands is the geospatial management of operations. In spite of this situation, the following sentence *"We use spatial reasoning to enhance our curriculum, research and operations"* found on their spatial programs website (Spatial Programs at the University of Redlands, n.d.) suggests that GIS is also employed for managing operations but it is not enough to confidently confirm the University of Redlands as a spatial university, precisely, due to the mentioned lack of publicity on the managerial aspects of its facilities that do not provide the necessary unquestionable information to make such a statement. In that sense, the University of Minnesota has been clearer about the usage of a spatial approach. To achieve the aims of the spatial university the U-spatial consortium has defined the four cores providing support to spatial sciences and other creative activities: 1) the central core focuses on the development of the spatial science community while providing technical assistance, training, and facilitating the coordination of resources. 2) The imaging core is centered on photogrammetric analysis from both aerial and satellite sources. 3) The data core services revolve around the development of shared computing infrastructure as well as data archiving and discovery. 4) The analysis core infrastructure puts its attention on mapping, geodesign, and, foremost, spatiotemporal modeling (Harvey, 2012; University of Minnesota, n.d.).

The relevance of the University of Redlands becomes very noticeable in this section. The underlying motives of this relevance is the consequence of the university's leading innovation on adopting a spatial university approach. So far, no other university promotes the geospatial technology at every level in such a vigorous manner. The University of Minnesota also thrives to expand its spatial vision but it seems to be less developed than at the University of Redlands. Besides the aforementioned benefits of the geospatial methods, the privileged location of the latter, at a very short distance to ESRI's headquarters also located in Redlands, and the influence of the GIS software manufacturer may have been one of the decisive motivations behind the establishment of the current policies.

4.2. HIGHER EDUCATION

Traditionally, HE has had two missions: teaching and training in order to develop human capital, and research to expand the knowledge-base of a certain field. As of late, a third mission has emerged. The third mission focuses on the relationship between HE and society to favor the exploitation of the research produced in HEIs for the society's benefit as a whole (E3M Project, n.d.; Saad, Guermat, & Brodie, 2015). This relatively new mission is also known as knowledge transfer (KT), which is key to innovation.

In this section, first the situation of HE around the world is explored. Then, the focus switches towards the assessment of universities and journal impact factors and their influence on research and university assessments. Understanding the current situation in this domain is essential due to its effects on KT.

4.2.1. Higher Education around the world

Higher Education plays a major role in the prosperity of a nation by means of its effects on the economy and society in the form of skilled individuals with higher income but also in higher added-value companies that are often started in universities. Society also benefits from the higher tax-revenues of a well-educated society that can be used for funding social programs, thus reducing inequity issues. Furthermore, HE favors social mobility and its graduates register lower levels of criminality and, in contrast, higher levels of civic participation, all of which, translates in a prosper and economically sound society (Boston College board, 2005; European Commission, 2011b).

The current situation of HE around the world is one with an extensive myriad of challenges and a rapidly increasing globalization with the ambivalence of the local needs. This situation is making it harder and harder for educational institutions to make decisions and choose their strategic priorities, hence, requiring thoughtful leadership and data-based analysis. Precisely with that aim the "Shanghai Statement" (Boston College Center for International Higher Education, 2014) was created. In short, the "Shanghai Statement" lays down its commitment to the mission of HE research as the key for an adequate and practical policy-making, and its implementation. (Boston College Center for International Higher Education, 2014).

The European Union (EU) also created its own strategy although it has a wider range of action and involves other factors beyond HE. The current situation in Europe is challenging at social, economic, and political levels where decisions need to be made in order to ensure growth and face the unemployment issues in a difficult moment due to the global crisis of 2008. Such decisions need to be put in place as effective structural reforms that will support growth in innovation and the creation of more jobs (European Commission, 2014). However, the task is remarkably difficult. The *Horizon2020* strategy was created as a roadmap for reviewing the existing policies and initiatives that promote a new improved economy within the framework of a better, smarter, more sustainable, and more conciliatory society (European Commission, 2014). The European Commission (2011a) also links the modernization of HE to achieving economic and social goals in a knowledge-based economy where

"Universities are key players in Europe's future and for the successful transition to a knowledge-based economy and society. However, this crucial sector of the economy and of society needs in-depth restructuring and modernization if Europe is not to lose out in the global competition in education, research and innovation" (European Commission 2011a, 8).

Furthermore, the European Commission (2012) describes how HE leads its graduates to improved employment opportunities. In fact, HE graduates integrate twice as fast into the job market, the percentage of graduates working is higher and their jobs have a much lower level of temporality bringing, therefore, a higher job stability to HE graduates (European Commission 2012). Moreover, the European Commission (2011b, 7) states that *"the contribution of higher education to jobs and growth, and its international attractiveness, can be enhanced through close, effective links between education, research and business – the three sides of the 'knowledge triangle'".*

Countries within the EU also have their own concerns and face their own challenges in HE. The case of Ireland, with the deep effect of the crisis on its public funds, focuses on the efficiency of its resources and extending the currently existing research in the field in order to obtain the necessary knowledge for addressing the issues of HE while focusing more on the overall quality of the system rather than the performance of each of its institutions (Hazelkorn, 2014). In the same direction, Middlehurst (2014) points the significance of the relationships between HE research and policy development for preserving, when not improving, the quality and efficiency of UK's HE as well as maximizing the contributions from the government, and consider the changes that are already affecting the HE environment.

Beyond the EU, Jones (2014) advocates for the development of an infrastructure aiming at supporting better informed decision-making and policy guidance including the assessment of significant trends and issues. In addition, the need for more international comparative studies directed towards finding solutions for the lack of useful strategies and approaches on the matter is asserted by Jones (2014) in concordance with Hazelkorn (2014). Likewise, Jackson & Crabtree (2014) acknowledge the Australian HE needs support for effective policy-making and assessing HE's impact on society. In the same direction, the biggest player in Asia, China, and its HE system, present dichotomies at several levels requiring assistance for obtaining effective solutions. China's enormous population has led to the problem of massification versus quality, and other policy issues revolving around the advantages and disadvantages of internationalization versus localization, and centralization versus decentralization, that will affect the future of China, and its HE system (Bie & Yi, 2014).

In the developing countries, as well as in many of the former members of the Soviet Union, education as a whole, and HE in particular, is a major component for their development and the reduction of the current inequity. For example, Tajikistan's context emphasizes the importance of a glocal (simultaneously global and local) approach in policy-making (Lo & Maclean, 2014). This, however, is not an easy task.

In Africa the situation is complicated too but the challenges are centered on opening and broadening strategic horizons towards a long-term and global perspective via HEIs. This implies that a wider collaboration channel between HEIs in developed countries and African HEIs needs to be addressed since the economic growth in African countries will bring, in the near future, new opportunities (Boeren, 2014). Furthermore, the development of a better HE in Africa will reduce the economic and social inequities existing today. However, this change in the global scene is not always easily visible and a strong support by means of robust evidence is demanded in order for changes in decisions concerning strategic sectors, such as the HE, to happen (Boeren, 2014). It is important to highlight that in some countries the access to high-quality journals is restricted by the limited resources available in their HEIs for granting the access to such journals, which require expensive subscriptions (Rumbley, Stanfield, & De Gayardon, 2014). This, in particular, is a very limiting factor for the quality of HE to improve in developing countries as well as their capacity for global impact.

It is worthwhile noting, in terms of inequity, that one must be aware of how globalized HE may mirror the already existing socio-spatial inequalities in developing countries due to the promotion of new differentiation assets, such as already privileged groups benefiting from international exchanges or participating in HE education programs abroad, and, therefore, keeping or even increasing their current privileges (Perkins & Neumayer, 2014). The case of the developing countries inequality concerns is an example of how understanding the flow of mobility students is relevant for policy-makers and their effect on HEI (Perkins & Neumayer, 2014).

The authors above-cited present a general trend of HE globalization. In contrast, there is a concern for the local policies and the specific local situation in each country. This is genuinely evident when examining the situation in the EU. The EU as a whole is working to implement new policies and understand the impact of such policies. However, each country in the EU has its own debates, its own approach to HE, its own policies, and is more focused on their particular situation rather than the EU's. Furthermore, the EU's policy approach to societal challenges as a means to alleviate the social needs as well as limiting the risk of social exclusion while developing the economy takes advantage of the local development for satisfying the specific social demands, with education as a cornerstone, and creating new jobs with the final aim of raising the standards of the European population's quality of life (Pérez-Cosín, 2009). This, at a European level, is the concept of glocalization, where the search of a meaningful integration of both the local and global dynamics is pursued (Brooks & Normore, 2010). Outside the EU, on a world-wide scale, glocalization is a reality in HE. The inevitable global trends are influencing the countries' local (national, and subnational) policies, and their approaches towards knowledge transfer to their societies. The recent rise of the knowledge society envisaged for innovation, and economic and social development is a clear example. Even in the cases where projects are implemented for obtaining solely local benefits the influence of global competition in HE is inherent (Koch, 2014). However, Hazelkorn (2014) reminds us to focus on the quality of the system as a whole rather than on each of the HEIs alone.

A rather recent trend in HE is the policy of creating and developing scientific parks aiming at promoting the interaction between academia and the industry to facilitate the creation of spin-offs (the popular synonym start-up might also be employed) that would take advantage of such a synergy to produce innovative solutions that would, consequently, become private companies and boost the economy.

These scientific parks may receive different names, for instance, in Spain, they are known as Scientific Park but in South Korea they are often referred as Technovalleys and, in the latter case, they may be linked to a university, that is the case of the Advanced Institutes of Convergence Technology that is strongly tied to the Seoul National University, but in other cases these Technovalleys are spaces where only private companies are found. In Spain these spaces seem to be strongly tied to universities but the names differ from one another, perhaps, with an underlying marketing strategy.

The existence of the Scientific Parks is the visible result of a policy focused on shifting the universities towards the model of the so-called entrepreneurial university. A concept strongly tied to the aforementioned knowledge triangle where HEIs, the industry, and governing agencies work together for a common purpose: innovation.

4.2.2. World University Rankings and Impact Factors

World university rankings, also known as university rankings, are a significant initial framework for this dissertation in terms of accurately grasping how HE is currently being assessed. Strongly connected to the international rankings, impact factors are, nowadays, an indispensable indicator for assessing research output. However, the question of whether or not rankings and impact factors are enough for evaluating research quality and significance is a blurry one. In fact, there seems to be a general agreement in academia on criticizing the validity and usefulness of such metrics but in the current situation scholars need to give them proper attention for keeping and developing their academic careers.

4.2.2.1. World University Rankings

The emergence of world university rankings (or rankings for the sake of simplicity) is fairly recent with the publication of the first ranking, the Academic Ranking of World Universities (ARWU) popularly known as the Shanghai ranking, by the Center for World-Class Universities of the Shanghai Jiao Tong University in China in 2003. Initially, the ARWU was focused on assessing the global standing of Chinese universities but the international media, governments, and universities from all over the world quickly adopted its methodology to the point that by 2005 it was the most used ranking and was considered the most influential ranking as well (Academic Ranking of World Universities, n.d.a), although similar statements are made by other rankings too (Times Higher Education, n.d.; Quacquarelli Symonds, n.d.). The media also echo the relevance of the rankings (Álvarez & Marín, 2014; Luxbacher, 2013; Trillo, 2015) and, occasionally, question them (Marszal, 2012).

The official aims of the rankings may slightly differ from one another. However, the shared goals focus on being a powerful reference for students, academics, and governments (Anovar *et al.*, 2015; Boulton, 2011; Stergiou & Lessenich, 2014; Times Higher Education, 2014). Specifically, the rankings crave to influence the growing global market of international students by pointing them in the direction of the so-called World-Class Universities (classified on the top positions of the rankings). Similarly, helping academics assessing where is it more interesting for them to apply for research collaborations, job applications and the like is of great interest to the rankings. The third goal revolves around assisting governments to identify how to improve their HE systems in order to scale positions within the rankings and increase their international relevance.

Nowadays, rankings have become very popular due to the simplicity of their metrics with a single score determining the value of a university in the international scale (Boulton, 2011). The current global context exposed on the previous section, and the competition between universities for different kinds of funding, and for attracting the best students and scholars has molded the rankings into a tool that many HE administrators and governments can, and actually do, easily employ (Aguillo, Bar-Ilang, Levene, & Ortega, 2011; Boulton, 2011; Stergiou & Lessenich, 2014). For example, some universities employ the positioning on world university rankings as one of the relevant indicators to assess whether or not to establish an international students' exchange program with another university.

An indicator of the growing popularity of rankings and their influence in HE is the increasing number of available international university rankings. According to Stergiou and Lessenich (2014) more than twelve rankings of these characteristics exist. However, four of them are considered to be more relevant than the rest: The Times World University Rankings (or Times Ranking for simplification), the QS World University Rankings, the aforementioned AWRU, and the Webometrics ranking. A different type of ranking that does not assign a single number score named U-multiranking is considered of relevance here as well for its methodology and underlying concept differs from the previous four. Other rankings exist as well, for instance, the Leiden ranking, the CHE (Center for Higher Education) ranking, and the US News & World Reports ranking are a few examples of the many world university rankings.

On the following table, the summarized methodologies of the five most relevant rankings are presented:

TWUR		ARWU		QS Ranking		Webometrics		U-Multirank	
Concept	***%***	***Concept***	***%***	***Concept***	***%***	***Concept***	***%***	***Concept***	***%***
Teaching	30	*Quality of education*	10	*Academic reputation*	40	*Impact*	50	*Research*	Very good to weak
Research	30	*Quality of faculty*	40	*Employer reputation*	10	*Activity*	50	*Knowledge transfer*	Very good to weak
Citations	30	*Research output*	40	*Student-to-faculty ratio*	20			*International orientation*	Very good to weak
Industry income	2.5	*Per capita academic performance*	10	*Citation*	20			*Regional engagement*	Very good to weak
Internationality	7.5			*International faculty ratio*	5				Very good to weak
				International student ratio	5				

Table 1. World University Rankings Methodology. (Source: Academic World Ranking Universities, n.d.b; QS Staff Writer, 2014, September 12; Times Higher Education, n.d.; U-multirank, n.d.; Webometrics, n.d.).

In the case of the Times World University Ranking (TWUR) the teaching aspect of HE is valued, in a big part, by the opinion of a set of unknown scholars over the reputation of a certain institution and the specific criteria to identify those scholars is unknown as well. Other teaching performance indicators are related to the extent of a specific institution's research community, and to the faculty-student ratio. However, the quality of the teaching itself is not assessed. Similarly, the ARWU considers the quality of education and the quality of faculty according to the number of alumni and faculty respectively awarded with the Nobel Prize or the Fields medals. When considering the quality of faculty the ARWU also considers the number of citations of their faculty members in high impact journals but these are not specific teaching-related assessments. The Webometrics ranking does not include any teaching-related issues and it also simplifies its vocabulary employing only two words to evaluate the presence of a university on the web: impact, and activity. The Webometrics ranking employs the impact indicator in a Google-like style, assigning higher values to the institutions with more external links directed at institutional websites. It is relevant to note that Google employs more criteria than the number of "incoming" links in its algorithm and is currently working on improving its search methodology towards trustworthiness rather than reputation (Hodson, 2015). For the activity indicator, the Webometrics ranking counts the number of websites within the institution's domain, the number of files available for download or online visualization and the number of highly cited papers within the Scopus scientific database. The approach employed by the U-multiranking ranking is based on the assessment of five dimensions of a HEI and a grade (A to E, or Very good to Weak) is assigned to each particular indicator. Then, the ranking allows to either obtain the information for a particular university or compare universities within the same range of activity. However, the possibility of assigning weights to each indicator and creating a ranking with a similar structure to other rankings is rather straightforward but the efforts of this ranking to offer a different perspective are significant.

The lack of clarification on the conflicts of interests of the rankings' agencies results in rankings that, at the very least, are questionable. For instance, the rankings are partnering with one of the two major scientific publishing agencies: Elsevier or Thomson Reuters. For the sake of specificity, the Times Ranking partners with

Elsevier, the ARWU partners with Thomson Reuters, the QS World Ranking partners with SCOPUS (the scientific database owned by Elsevier), and the Webometrics ranking extracts its data for assessing the level of excellence of an institution from SCImago Journal Rank (SCImago in short) that obtains its data from Scopus, hence, influenced by the same conflicts of interest as Elsevier. The U-Multirank, although it presents an improvement compared to the other rankings, also employs data from SCImago. The extent of these partnerships and collaborations with the ranking agencies is not public. This lack of transparency diminishes the credibility of the rankings and suggests that there is a clear interest from the publishers to favor the type of research-focused indicators that will be beneficial for their business. It is astonishing how the publishers push the scholars, and rightfully so, to acknowledge their conflicts of interests and funding sources while the same publishing agencies do not clearly state their conflict of interests when partnering or collaborating with the ranking agencies.

The visible conflict of interest of the participation of the aforementioned publishing agencies in the creation of rankings is their inherent interest to make of publishing in scientific journals an important aspect of the ranking evaluation; actually, benefiting for free from the scientists' work, who are also forced to give away their copyrights in order to publish, and where the only payment for the scientist is in terms of citations and, over time, reputation. However, from the billions of dollars earned by the publishers the authors and members of the editorial board get no economic benefit whatsoever directly linked to their collaboration with the publishing agencies (Stergiou & Lessenich, 2014). The motivation for scholars to keep on publishing is that the development of their career, promotion, and funding possibilities are strongly tied to publishing on journals with high impact factors and the journals wielding such impact factors are owned by the publishing agencies with Thomson Reuters and Elsevier leading by a large distance the domain of scientific journals. The rise of open access scientific journals may be a means to change the situation but as long as impact factors and their relevance, together with citations, are maintaining their weights in the university rankings and within the academic institutions the circumstances are unlikely to change.

The use of the scholars' opinions on the quality of other HEIs has been, in a burst of extremism, compared to a popularity contest among impressionable teenagers. Specifically, the US News & World Report Rankings was despised by the president of Trinity University (Washington DC, USA), Patricia McGuire, who stated that rankings are *"the equivalent of the 'American Idol' voting process"* (Stergiou & Lessenich, 2014, p.106) and advised her colleagues to *"Rip it up and throw it away"* (Stergiou & Lessenich, 2014, p.106) as soon as they received it. The German sociologists also decided to push aside the ranking created by the German Center for Higher Education Development, or CHE for its acronym in German, arguing that such a classification will end up dividing the academic teaching into winners and losers. Although scholars point out that a single number is unable to assess all the aspects of a HEI (Boulton, 2011; Anovar *et al.*, 2015) nowadays there is a global trend on employing the rankings that seems unlikely to change any time soon.

Overall, there is an agreement among academics (Stergiou & Lessenich, 2014) that the world university rankings lack rigor and are biased towards a research-oriented HE model that implicitly dismisses the importance of teaching as an essential mission of HEIs. Because the journals with high impact factors are published in English, the Anglo-Saxon institutions are favored, and the bias towards HEIs in the United States has also been often identified. Another weakness of university rankings often reported by academics is that the teaching quality is hard to measure and other non-related, and easier to assess, indicators are employed in its place. The Arts, the Humanities, and the Social Sciences are also harmed since these disciplines have traditionally valued more the publication of books than articles in scientific journals. As a consequence, these disciplines are somewhat under-represented. López-Illescas, Moya-Anegón, and Moed (2011) argued that it would be more accurate to evaluate the specialization of each university in order to properly assess its rank. As a response, several rankings have created special ranking tables according to disciplines in addition to their main university ranking that does not account for specialization but this situation may not satisfy the scholars working in the Arts, the Humanities, and the Social Sciences. Furthermore, the student-to-faculty ratio employed by some rankings could be initially considered as a good indicator of teaching quality for it implies that the faculty have more available time to devote to each of the students. However, such an indicator clearly favors the rich private universities where the elites can afford to pay the high cost of a high ratio (Taylor, Perakakis, Trachana, & Gialis, 2014). Another complaint voiced by the scholars is that only a small percentage of the total number of universities in the world are represented in the rankings, usually, such percentage is as low as 6% (Stergiou & Lessenich, 2014). A particular problem of the U-multirank is the difficulty to obtain comparable data between universities in an international scope.

The relevance of rankings has been favored by the international competition for economic and human resources at the global level (Aguillo *et. al.*, 2011) that has made of the rankings a marketing tool for institutions to appear more attractive, specially, to the growing number of migrant students. In spite of the scholars' comments, the university rankings have become very important in several aspects of HE: from reforming curricula, conditioning faculty recruitment as well as their promotion and wages or research funding, to the admission of students, the tuition fees they must pay, and their future job prospects. Nonetheless, as Peter Murray-Rust, from Cambridge University, noted HE needs to create its own metrics away from the university rankings to gain independence but he also notes that measuring scientific quality is a problem that has not been solved yet (Stergiou & Lessenich, 2014).

4.2.2.2. Scientific databases and impact factors

Impact factors have been around since their creation back in the 1880s but it wasn't until the late 1950s when their use began to gain relevance with the creation of the impact factor developed by the Institute for Scientific Information (ISI) that is nowadays administered by Thomson Reuters and accessible through the Web of Knowledge scientific database (WoK). To this day, the ISI WoK impact factor (IF) has dominated the scene but other impact factors exist as well. The purpose of the IF is to have *"a simple method for comparing journals regardless of size or citation frequency"* (Garfield, 2005, p.3). This numerical value is transformed into a journal ranking employed with a similar underlying idea as the world university rankings are, that is, as a means of research significance evaluation, or "perceived impact" depending on the IF of a certain journal. However, its creator, Garfield, warned that *"in the wrong hands it* [the IF] *might be abused"* (Garfield, 2005, p.1). This warning may have sank into oblivion according to the current adoption of the IF by governments, university administrators, and public funding agencies to assess research performance and consequently, similarly as with the world university rankings, employ such information for decision-making concerning hiring, promoting, and firing faculty as well as funding research projects, among others (Brems, Button, & Munafo, 2013; Chou, Lin, & Chiu, 2013; Choudhri, Siddiqui, Khan, & Cohen, 2015; Leydesdorff, 2013; Liaw, Chan, Fan, & Chiang, 2014). The importance of the IF has reached to the point where the prestige of researchers and the quality of their projects is often evaluated by this single numeric value (Oosthuizen & Fenton, 2014). There are other impact factors created more recently but they are employed in a similar manner as the IF, hence, reproducing the consequences created due to its use beyond its initial purpose. Many examples to illustrate this situation exist, for instance, in Spain the foundation for science and technology (*Fundación Española para la Ciencia y la Tecnología*, or FECYT) supported by the Spanish Ministry of Economy and Competitiveness considers publications to be of high quality only if they are published in journals with the highest SCImago Journal Rank impact factor (SJR), that is, within the top 25% of the ranking. Furtheremore, this foundation considers of scientific excellence only those documents within the top 10% of the most cited documents in the Scopus scientific database (Fundación Española para la Ciencia y la Tecnología, 2014). At this point, it is necessary to consider that employing citations for such a task has also been previously criticized by scholars that seem to agree in considering the citation distributions as skewed (Leydesdorff, 2013). It is no surprise that the Spanish situation is similar in other countries where the impact factor is taken as one of the most relevant metrics for assessing the quality of a researcher's performance.

4.2.2.2.1. Scientific databases

In the Internet era we are all currently living in, scientific databases have become a very relevant source of scientific knowledge where the most relevant journals are indexed and where scientific bibliometric analysis tools are available. Often, depending on which scientific database is employed, different results may be obtained, therefore, it is necessary to select the best fitting database for the analysis intended. There are several scientific databases but three of them stand out above the rest: the ISI Web of Knowledge (WoK) owned by Thomson Reuters, Scopus owned by Elsevier, and Google Scholar owned by Google Inc.

Scopus is the largest bibliometric database including over 17.000 scientific articles since 1966 and it is ran independently from Elsevier to reduce to the minimum any possible suspicion of conflicting interests. However, the underlying conflict of interest of supporting scientific publications and citations as an important part of the academic life remains no matter who runs the daily operations. Scopus offers a few significant advantages over its competitors beyond the number of indexed articles

(Choudhri *et. al.*, 2015). A unique feature of Scopus is the author identification and its affiliation, as well as coauthors, in a manner that every author has a unique identification within the database associated to his name and, in case of detecting mistakes, these can be reported to keep the consistency of the indexed data. Moreover, Scopus indexes *online first* articles that have not been assigned a specific volume within a journal yet. Furthermore, Scopus offers an API included in the subscription that allows its users to implement applications and services to access or retrieve data from within the scientific database.

The ISI Web of Knowledge is owned by Thomson Reuters and includes the journals listed in the Journal Citation Reports (JCR), also produced by Thomson Reuters, which is less inclusive than Scopus and leaves some highly prestigious journals outside of its database (Liaw *et. al.*, 2014). Considering that the JCR journals are often employed as a reference for research quality assessments this situation is problematic. Yet, if one is interested in evaluating research produced earlier than 1996 the WoK performs better than Scopus (Choudhri *et. al.,* 2015). The WoK also offers an API to access its data but in order to take full advantage of its capabilities it is necessary to subscribe to an extra service called In-Cites that many researchers may not be able to access if their institution does not consider such a service relevant.

The last, but not least, scientific database is Google Scholar owned by Google Inc. This database indexes almost every online source including books and conference proceedings as well as scientific articles. This is an advantage in comparison to its competitors since it facilitates accessing information, through its robust search capacity, that may otherwise remain hidden or, at the very least, very difficult to find. The biggest weakness of this database is the slow monthly update relative to the weekly update of its competitors, and to that the lack of citation analysis tools and author identification options are added (Choudhri *et. al.*, 2015). However, it is extremely significant to note that, as it happens with many services offered by this company, Google Scholar is free and may be a great alternative for scholars in under-developed or developing countries where the HEIs may not be able to afford the expensive subscriptions to Scopus and/or WoK, therefore, contributing to decrease the existing academic inequities.

In connection with Google Scholar, and perhaps to make up for the lack of bibliometric analysis tools, the software Publish or Perish (Harzing, 2015) allows to retrieve and analyze academic citations to attempt to assess an author's research impact. It is, as Google Scholar, free to download and use but its interface and the fact that articles under assessment consideration must be selected manually may be a burden to some scholars. It is curious how the name of this software seems to incarnate the current reality of a scholar's life in academia.

4.2.2.2.2. Types of impact factors

Strongly tied to World University rankings by means of research significance or "perceived impact" is the impact factor of a certain journal. Nowadays, the impact factor created by Garfield in the 1960s and currently managed by Thomson Reuters is dominating the scene. Yet, scholars have been very critical with the IF's performance and other impact factors have been developed as a consequence such as the Eigenfactor, the Article Influence score (AI score), the SCImago Journal Rank (SJR), the Source Normalized Impact Factor per Paper (SNIP) or the h-index.

The IF computes the mean citation per journal over the previous two years (Zarifmahmoudi, Jamali, & Sadeghi, 2015). Specifically, dividing the number of citations in a year to articles published in the previous two years by the number of source articles published within those same two years (Garfield, 2005). The concept of source articles is the origin of some of the critiques towards the IF since it allows editorials to select what articles are considered towards computing the impact factor and what articles are dismissed, even if the latter are frequently cited. This makes the IF very unlikely to be reproduced and suggests it could be manipulated (Brems *et. al.*, 2013; Oosthuizen & Fenton, 2014). Furthermore, according to Brems *et. al.* (2013) the Rockefeller University Press found discrepancies between the published results and the raw data of up to 19% and, also according to these authors, the International Mathematical Union agreed on concluding that the arithmetic mean employed by the IF as a measure of central tendency is not appropriate for such purpose. This type of impact factor is the one found in the Journal Citation Reports (JCR) index as well as in the Science Citation Index (SCI), Social Science Citation Index (SSCI), and the Arts & Humanities Citation Index (A&HCI). These indexes are considered to group the most relevant scientific journals and they differ from one another in the categories of the indexed journals and in the number of indexed journals with the JCR being the most restrictive to the point where Liaw *et. al.* (2014) argue that it excludes some prestigious journals. All these indexes are owned and managed by Thomson Reuters.

The Eigenfactor aims at measuring the overall importance of all the papers published in a journal for one year, it is computed with a similar methodology as the Google Page Rank, and it does not take into account self-citations that could be seen as a means to influence the results. The Eigenfactor favors the more widely read journals in detriment of the less popular ones (Choudri *et. al.*, 2015). Yet, by doing so, specialties and subspecialties may be harmed.

The Article Influence score aims at offering a vision of the repercussion of the scientific papers published within a specific journal for the first five years after publication. It is strongly related to the Eigenfactor because in order to compute, in a similar manner as the IF, the AI score the Eigenfactor is divided by the number of published articles in a specific journal. Because of its similarities with the IF for five years and its open access source Oosthuizen and Fenton (2014) consider the AI score a possible alternative to the IF.

The SCImago Journal Rank (SJR) was developed by the SCImago research group at the University of Extremadura in Spain and it is the impact factor considered by the Spanish government for the academic evaluation of the faculty and HEIs in the country although the journals in the top 25% of the JCR are considered to be the most relevant both in quality and impact (Fundación Española para la Ciencia y la Tecnología, 2014). The aim of the SJR is focused on prestige, hence, it computes the average prestige per paper within a journal for three years after publication and it limits the consideration of self-citation to a maximum of 33% in order to avoid intentional influence over the final result of its computation. Because the SJR obtains its sources from Scopus, the largest scientific database, it might be more comprehensive than the JCR but it has similar problematics as the Eigenfactor since it lowers the value for the less popular journals.

The Source Normalized Impact factor per Paper (SNIP) aims at providing a metric that will facilitate the comparison between journals, disciplines, and subdisciplines. To achieve that aim the weights of the citations are adjusted so fields that receive a higher number of citations decrease their overall weight and the fields with a smaller number, such as specialties ore subspecialties see their overall weight increase (Oosthuizen & Fenton, 2014). This impact factor offers advantages over the aforementioned in that it allows to observe how fast a manuscript is likely to impact a certain field, it limits the editorials influence over the final impact value and, as the AI score, is open-access. Nonetheless, should this metric be employed it is necessary to keep in mind that, according to Choudhri *et. al.* (2015), the weighting assigned to compute the SNIP is assumed to be fair to the different disciplines but this might not always be so. In spite of that, Oosthuizen and Fenton (2014) consider the SNIP to be a viable alternative to the IF.

The h-index is a highly popular index that aims to provide a holistic view about a specific journal's quality. It has been developed by Google Scholar and it is provided by the aforementioned scientific databases as well. Google Scholar describes the h-index of a publication as *"the largest number h such that at least h articles in that publication were cited at least h times each"* (Google Scholar, n.d.). In other words, an author's most often cited articles are considered to compute the h-index. This metric does not only consider the number of articles, hence, until the new articles are not cited enough times the h-index will not change. The h5-index is particularly popular and is no more than the h-index for the articles published in the last five years. The h-index also presents a few weaknesses such as the impossibility to ever decrease, the different h-index value computed depending on which database is employed for the scope of each scientific database is different, and the complete dismissal of articles that are only cited a few times (Choudhri *et. al.*, 2015). The difficulty of Google Scholar to index journals in a different language than English is another issue that weakens the h-index (Zarifmahmoudi *et. al.*, 2014).

4.2.2.2.3. Weaknesses of the impact factors

The impact factors have several weaknesses, some are specific to each indicator while others are common to all impact factors. The weaknesses of each of the indicators have already been commented in the previous section but a few of the shared weaknesses deserve attention as well. First and foremost, the existence of impact factors create social pressure on scholars due to the fierce competitiveness in the academic career. On the one hand, Choudhri *et. al.* (2015) consider that the high impact journals are more likely to receive manuscripts of high quality. On the other hand, Brems *et. al.* (2013) argue that the existing social pressure in academia rather than the quality of their articles pushes scientists to send their manuscripts to journals with high impact factors, and they even suggest that the wish of publishing in such journals leads those publications to an increased risk to being fraudulent and present less reliable discoveries.

The different nature and perspectives of the academic disciplines, and the journals disseminating their research outcomes, is a heavy burden for the impact factors capacity to accurately compare journals in different fields (Oosthuizen & Fenton, 2014). The impact factors are especially detrimental for assessing the knowledge production in the social sciences and humanities (Chou *et. al.*, 2013) as well as for the dissemination of interdisciplinary research that often attempts to push through the limitations of a discipline's perspective (Brems *et. al.*, 2013; Chou *et. al.*, 2013).

The existence of impact factors as an assessment tool for research performance and their use in the World University rankings have contributed for the creation of policies in HEIs towards promoting the scientific dissemination in journals with high impact factors. By doing so, the HEIs intend to escalate their position in the World University rankings and convey an image of high academic performance and quality (Chou *et. al.*, 2013).

4.2.2.2.4. Alternatives

It is significant to note that the current monopoly of the impact factors by Thomson Reuters, which has been recognized to present poor reproducibility, calls for alternatives. The most straightforward option is to simply employ another impact factor. That is the case in Spain, where the FECYT employs the SJR instead of the IF (Fundación Española para la Ciencia y la Tecnología, 2014). Similarly, other authors suggest to employ the AI score or the SNIP as viable alternatives to the IF, or a combination of impact factors (Oosthuizen & Fenton, 2014; Zarifhamoudi *et. al.*, 2014), for example, combining the IF, the h5-index, and the SJR. Unfortunately, the cited authors did not present a specific methodology for applying their idea.

There are, however, other alternatives available. Brems *et. al.* (2013) suggested to get rid of the impact factors and, instead, create an archival publication system, much like an open access library, where software, raw data, and peer-reviewed texts are stored and analyzed with scientifically tested metrics in order to promote a constant improvement and propel innovation forward. This idea, although very interesting, seems to not be in touch with the reality of the current academic performance evaluations. In a more conventional direction, Leydesdorff (2012a) proposes the Impact Integrated Indicator (I3) to create a normalized citation curve employing percentages rather than the currently employed statistical indicators such as averages. These percentages would be transformed into percentile ranks defined at the article level for evaluative purposes. The main advantages of the I3 metrics is that it is possible to apply it both to journals and HEIs, and, similarly to the h-index the citation and publication rates are also considered.

Considering the European strategy Horizon 2020 where the knowledge triangle takes a predominant role, and where the university is an important actor, a more innovation-oriented alternative to assess the impact of academic journals may be necessary. In this context, Liaw, *et. al.*'s (2014) non-patent reference (NPR) analysis becomes significant. Their analysis revolves around the idea of linking science and technology outputs, in other words, linking academic journals and patent documents. The purpose is to provide a metric to evaluate the technological value of academic papers produced by scholars and disseminated, in a scholarly manner, through publications in scientific journals. Their initial motivation to implement this methodology lied on the difficulty to properly compute impact factors for each journal. In order to provide a more complete view on journal impact the NPR analysis focuses on ranking journals, which employ non-patent references, according to their citations in patent documents.

It is important to mention that the cited authors consider that resources should be allocated according to technological value rather than to the purely academic value. This represents a shift that the authors recognize is not applicable to the Social Sciences and the Humanities disciplines that, consequently, are not eligible for implementing the NPR analysis. Perhaps, if the technological value is substituted by social value a similar NPR approach with social significance, rather than patents, could be applied. However, this raises the questions of what is social value and how to assess social significance. Another important weakness of the NPR is that different patent offices, for instance in the United States, the European Union, and Japan, require a different number of references in order to submit and grant a patent, hence, resulting in different outputs for the NPR analysis.

This dissertation, or at least a part of it, could be considered as an alternative to impact factors, however, assessing and ranking journals according to their academic output is beyond the purpose of this research that is, instead, directed towards the analysis of innovation and knowledge transfer considering the territory.

4.3. KNOWLEDGE TRANSFER

The Department for Innovation, Universities and Skills (DIUS) of the United Kingdom defines Knowledge Transfer (KT) as follows: *"Knowledge transfer encompasses the systems and processes by which knowledge, expertise, and skilled people transfer between the research environment (universities, centers and institutes) and its user communities in industry, commerce, public and service sectors"* (Research Councils UK, 2007, p.5). More than ten years ago Bathelt, Malberg, and Maskell (2004) already identified KT as an interactive process. This becomes visible when exploring the U-multirank, where the KT indicators include co-publications of academics and industrial partners, income from private sources, patents awarded, publications cited in patents, spin-offs from university, and continuous professional development revenues.

The Higher Education Systems (HES) as well as their KT activities vary from country to country. Therefore, the evaluation of such activities also differs depending on the specific countries. Not only are the methodologies different but also the depth in which the specific activities are assessed changes. Rossi and Rosli (2014) report on these methodologies and differences. Specifically, in USA and Canada the KT is understood as technology transfer focusing on the technology commercialization. In the EU the Association of European Science and Technology Transfer Professionals and the European Knowledge transfer Association, known as ASTP-ProTon, conduct surveys to enhance the impact of public research on society and the economy. In Spain, similar surveys are conducted by the CRUE. In the UK the Higher Education Statistics Agency surveys focusing on the HE-business and community interaction, with Australia following similar steps. This last approach coincides with Bathelt et al.'s (2004), who already viewed KT as the result of interactions between agents with diverse knowledge and skills. In this sense, five types of collaborations have been identified (Shin, Lee, & Kim, 2013): the conventional collaboration between scholars, the interdisciplinary collaboration, the collaboration between institutions, the collaboration between sectors that is known as the triple-helix, and the international collaboration between countries.

The three yearlong project funded by the European Commission and entitled European Indicators and Ranking Methodology for University Third Mission (E3M Project, 2012) aimed to provide a wide perspective on the KT activities of HEIs by creating a number of indicators for the measurement of said activities. This project, was conducted collaboratively by eight European HEIs from seven countries: the Polytechnic University of Valencia, the University of Helsinki, Donau-Universität Krems, University of Maribor, Universidade do Porto, Instituto Superiore Mario Boella, Dublin Institute of Technology, and Universidad de León. In addition, two experts affiliated to the University of Cambridge, and the University of London also participated in the project.

There is already an extensive literature on a diversity of aspects involved in knowledge transfer. Nonetheless, this dissertation revolves around the geospatial factor. In this regard, there are some publications considering space although, for the most part, the focus lays on the effects of proximity on KT with diverging results. On the one hand, Drucker (2015) found that distance from a HEI has a considerable influence across space up to 97 Km (60 miles) in the USA. Similarly, Ferrandes and Ferreira (2013) identified proximity to have the greatest effects on KT between universities and knowledge intensive business services. On the other hand, Ponds, van Oort, and Frenken (2010) reported that although proximity does have an effect on university-industry collaboration and knowledge spillovers its influence is not the determinant factor. Previously, Gaillé (2009) had also detected proximity to have an effect within the French sector of biotechnology although it was not significant at the international scale.

The knowledge triangle is promoted by the European Commission (2011b, 7) with the Horizon 2020 strategy because it is considered to boost the creation of economic growth through innovation and the creation of jobs. Nonetheless, Nielsen (2014) informs that the research on innovation through academic entrepreneurship has focused on studying the synergies leading to innovation. Furthermore, the indicators for measuring university's KT performance is under-investigated and the use of economic outputs is considered problematic (Daraio, 2008; Rossi & Rossli, 2014).

4.4. THE TRIPLE-HELIX INNOVATION SYSTEMS

The Triple-Helix is a result of the progress in the theory of scientific knowledge production. There are several scientific knowledge production processes as exposed by Carayannis and Campbell (2012). Mode 1 follows the traditional and linear research process initiated in universities with basic research, applied research, and the experimental development by the industry. Mode 2 revolves, instead, around the application following a non-linear process where universities and industry collaborate to obtain useful results. Mode 3 takes advantage of the principles of Mode 1 and Mode 2 and integrates university, industry and governance in a unique interconnected system. Mode 3 represents what is understood as the TH. The concepts for the evolution of Mode 3 towards a more accurate understanding of knowledge production were laid by Carayannis and Campbell (2006, 2009, 2012). Said evolution produced the Quadruple Helix innovation perspective, which also includes the civil society. That is, the users of knowledge and their contributions to further knowledge production. An additional perspective is the Quintuple Helix, which adds the natural environment.

The specific concept of the TH originates from the sociology of innovation and was introduced by Etzkowitz and Leydesdorff (1995). The thesis behind this concept is, as described by the Stanford University's Triple Helix Research Group (n.d.),

> *"that the potential for innovation and economic development in a Knowledge Society lies in a more prominent role for the university and in the hybridization of elements from university, industry and government to generate new institutional and social formats for the production, transfer and application of knowledge."*

The development of the original TH has prompted the Triple-Helix Innovation Systems, which will be referred to as TH from here on for simplicity, and are defined by Ranga and Etzkowitz (2013, p.237) as *"an analytical construct that synthesizes the key features of university-industry-government (Triple-Helix) interactions into an 'innovation system' format, defined according to the systems theory as a set of components, relationships and functions"*.

The components of such a system are known as the institutional spheres of university, industry, and government. That is, individual and institutional innovators, research and development (R&D) innovators as well as non-R&D innovators, and single-sphere as well as multi-sphere or 'hybrid' institutions. The geography, sector, and technology boundaries between the three spheres are permeable in order to facilitate the flow of people, ideas, knowledge, and capital.

The TH establishes the synergies required for the entrepreneurial university to flourish and expand in a successful manner. The principal element in these synergies is the active involvement of universities and other HEIs. In fact, the TH is the result of observing the synergies of the innovative processes in Silicon Valley. Particularly, these synergies are depicted as interactions among the system components. That is, market and non-market relationships focused on technology transfer and acquisition, collaboration and conflict moderation, collaborative leadership, substitutions, and networking as described by Ranga and Etzkowitz (2013).

The aforementioned authors assert that the functions of a TH innovation system revolve around the creation, dissemination and use of knowledge, and innovation. This is translated as TH spaces, which include the knowledge, the innovation, and the consensus spaces. These are achieved through various competences from innovation systems theory plus a set of additional ones. Specifically, the selective, organizational, technical, and learning competences from said innovation systems theory and the entrepreneurial, societal, cultural, and policy aspects are the additional competences.

The TH Innovation Systems theory endorses Bathelt *et. al.*'s (2004) perspective of innovation as the result of an interaction process. In said process there are three key features: 1) a multidisciplinary approach not only between disciplines of the same branch but also among disciplines perceived as disconnected from one another to facilitate the exchange of knowledge; 2) a multi-sector perspective, that provides extraneous knowledge, realized in the university-industry-government interactions to spark growth; 3) and an expansion of internationalization to promote information flow at larger volumes than local networks can provide. In short, this perspective relies on the principle that existing knowledge is a significant trigger for knowledge expansion. Hence, the more interactions occur, the more knowledge flows and promotes innovation.

One of the first TH international institutes opened in Madrid, Spain, in 2008 aiming to study the regional innovative processes. Soon after, it was moved to Silicon Valley (International Triple Helix Institute, n.d.). Nowadays, the Stanford University's TH research group led by Dr. Marina Ranga is one of the most influential groups worldwide. The Horizon 2020 strategy is, perhaps, one of the most visible results of Dr. Ranga's membership in the UN Economic Commission for Europe's Expert Group on Innovation and Competitiveness Policies (Stanford University, n.d.). In another group, The Triple Helix Association (n.d.), Professor Henry Etzkowitz directs and coordinates four research groups focused on KT and technology, university-industry collaboration, entrepreneurial universities, and national models and systems of innovation.

The importance of KT and the TH led to the creation of science and technology parks worldwide. As mentioned above, many studies exist in the literature focusing on the synergies needed to achieve significant collaboration among the three agents of the TH. For instance, in Spain the *Asociación de Parques Científicos y Tecnológicos de España* (APTE) promotes said collaboration. It is significant to note that the data published by the APTE (n.d.) for the year 2014 shows four variables:

the number of participants, the billing in euros, the number of employees, and the investment in R&D in euros. This suggests that the evaluation of success versus failure is purely economic despite Daraio's (2008) and Rossi and Rossli's (2014) reports on the problematics of using economic outputs for assessment. Nonetheless, the most appropriate indicators for performance evaluation are difficult to identify and the data is not always easily accessible. The case of South Korea is interesting for its divergence with other models. In the Korean case, the *Technovalleys* revolve around the industrial sector. In several of the *Technovalleys* there is a clear and direct involvement of HEIs while in others such involvement is not clearly visible. This situation suggests that at least in some of the Korean *Technovalleys* there are agglomerations of private companies but the participation of universities is not always considered a major requisite. Nonetheless, the situation is changing as of late. In fact, the Korean government has been promoting the industry-academia collaboration with new stimuli for HEIs and the construction of *Technovalleys* as a hub for research and innovation (Lee & Choi, 2014). However, the case of South Korea might be unusual from a worldwide perspective since *cheabols* (business conglomerates with global influence in a large variety of sectors e.g. Samsung, LG, Hyundai, etc.) invest vigorously in research and development across the nation. The *cheabols* are important players in the South Korean economy and they generate a strong pull towards innovation. In this particular case it is the industry rather than HEIs the agent that has had, historically, the leading role (Shin *et. al.*, 2012).

On a different level, it is significant to note that the frontiers in the terminology are somewhat blurry: KT and Third Mission are employed as synonyms, and the Knowledge Triangle and the TH are often employed indistinctively as well although they are not exactly equivalent. Furthermore, the term Knowledge Transfer tends to be employed as an umbrella encompassing all the other terms. In this thesis, KT and Third Mission are employed as synonyms. Here, these terms are considered to include the Knowledge Triangle and the TH. Nonetheless, the Knowledge Triangle and the TH are differentiated as the first employs sectors of society, while the second employs agents. For instance, the Knowledge Triangle considers education and research separately while the TH views the university as the social agent in charge of both items. In both cases, however, the HEIs are the leading agents of innovation in the knowledge society.

5. METHODOLOGY

5.1. TRIPLE-HELIX ASSESSMENT: EXISTING METHODOLOGIES

The Triple-Helix is a concept focused on the interactions between three agents: university, industry, and government. There are several approaches to measure the TH but there are two that stand out over the rest: 1) the computation of a TH indicator and 2) the social network analysis (SNA) applied to a network of agents. The first method is nearly exclusive to the information communication science discipline. However, the second one originates in the sociology discipline but was developed by computer scientists. SNA is currently being used for TH assessment (Swar & Khan, 2014) but it is also used in a wide variety of disciplines such as public health (Christley *et al.*, 2005) or biotechnology.

5.1.1. The Triple-Helix indicator

The TH indicator, consists on assessing the level of synergy between three or more agents by measuring their mutual information, which information communication scientists express as transmission and may be positive or negative, indicating the level of existing synergy or of its absence. Then, the synergy *"can be considered as a reduction of uncertainty in university-industry-government relations"* (Leydesdorff, Park, & Lengyel, 2014, p.29). The computation of uncertainty between two or more agents results in the transmission, which is expressed in bits of information. The computation requires the use of the Shannon's formulas (1948) that this author has obtained from (Leydesdorff & Zhou, 2014) and (Leydesdorff, *et. al.*, 2014).

The uncertainty for an agent is computed employing the following expression:

$$Hx = -\sum p_x * \; log_2 \; (p_x)$$

Expression 1. Agent uncertainty.

Where *Hx* is the uncertainty for an agent *x* and *p* is the proportion of appearances of a certain category within the data. Should there be two agents the uncertainty is computed employing the following expression:

$$Hxy = -\sum_x \sum_y p_{xy} * \; log_2 \, (p_{xy})$$

Expression 2. Multiple agents' uncertainty.

Then, the transmission *T* is expressed as follows:

$$Txy = (Hx + Hy) - Hxy$$

Expression 3. Transmission

For the case of the TH, with three agents, the transmission is expressed as:

$$Txyz = Hx + Hy + Hz - Hxy - Hxz - Hyz + Hxyz$$

Expression 4. Transmission for three agents.

The data employed with this method is any kind of data that depicts the relations between the three main agents and/or other alternative ones. In practical terms, due to the difficulty of collecting meaningful data, this method is typically applied with bibliometric data from scientific databases, such as Scopus or the ISI WoK. Bibliometric patent data available at national patent offices such as the US Patent Office or the European Patent Office are also traditionally included in the studies (Jaksić, Jovanović, & Petković, 2015; Ivanova & Leydesdorff, 2015;

Leydesdorff, 2004; Shelton & Leydesdorff, 2012). However, the availability of the data is not always free, which limits its access to researchers. Other types of data may include that of databases concerning the industry such as the data collected by national Chambers of Commerce. Although the Chamber of Commerce may display the data on its website, the download of the actual data is very often offered only at a cost.

5.1.2. Social Network Analysis

The Social Network Analysis (SNA) originates in the sociology discipline, hence the name, but its concepts and theories have been formalized mathematically, which facilitated its systematization and development by computer scientists.

SNA may be defined as *"the application of network and graph theory to the analysis and modeling of social systems, it combines the tools for analyzing social relations and the theory for explaining the structures that emerge from the social interactions"* (Complexity Labs, 2014). That is, SNA is about analyzing the interactions between actors (or agents) forming a network as well as the structure of such network, rather than analyzing the actors individually without further context.

In SNA, a network is formed by a set of nodes and a set of edges. The nodes represent agents, people, etc., and the edges represent the connections between the nodes. The edges may have an associated weight and a direction, although these are not compulsory.

In short, SNA is employed to measure the connectivity of the nodes in relation to others, the influence of such nodes within the network, and the diffusion of information (or ideas, diseases, etc) through the network. It is also used to analyze the structure of the network with the purpose of identifying patterns of segregation and clustering. SNA visualization often facilitates the analysis of the network.

There are several works assessing the TH synergies by means of the SNA but they are limited to a set of authors, often within a journal or set of journals (Chen, 2017; Chung, 2014; Hardeman, Frenken, Nomaler & Ter Wal, 2015; Swar & Khan, 2014). However, the SNA is multidisciplinary and many other disciplines also take advantage of its capabilities. For instance it is used in tourism (Khalilzadeh, 2018), air transport management (Çavdar & Ferhatosmanoğlu, 2018), social media studies (Komorowski, Huu, & Deligiannis, 2018), computer science (Lefevr, Margariti, Kanavos, & Tsakalidis, 2017), environment (Haak, Fath, Forbes, Martin, & Pope, 2017) etc. One of the most relevant group of disciplines employing SNA is that related to health, both from human and biologic perspectives, for example, to understand the spread of diseases (Elkin, Topal, & Bebek, 2017; Lefevr *et al.*, 2017).

A network, in mathematics and computer science is known as a graph. In this thesis both terms are used indistinctively. There are two main types of graphs: directed graphs and undirected graphs. Directed graphs have links with a set direction while undirected graphs have no direction whatsoever. For the case of this thesis a graph (or a network) is assumed to be an undirected graph as only undirected graphs are used. The nodes of a network are the agents (or actors) of the network and the edges are the links or connections between nodes. In SNA the neighbor of a node is another node that is directly connected to the node with an edge.

In general, most networks are complex and have similar properties independently of the purpose of the network (e.g. transport, web sites, innovation, etc.). There are, therefore, common features to complex networks (Zhukov, 2015).

Complex networks follow a power law distribution. This type of distribution in a network means that there are a majority of nodes with few links and a minority of nodes with a high volume of connections. A network with a power law distribution is also known as a "scale-free" network.

Complex networks have a small diameter, that is, an average path length rather short. In other words, the number of connections needed to connect any pair of nodes is small. This is the same concept as the famous six degrees of separation between any two people in the world (Milgram, 1967). Hence, this is also known as the "small-world" network. Complex networks also have a high clustering coefficient. This translates as networks with a large number of triangles.

Summarizing, complex networks share three common properties (Zhukov, 2015):

- They follow a power law distribution.
- They have a small diameter.
- They have a high clustering coefficient.

In any given network, there are three potential levels of analysis: element level analysis, group level analysis, and network level analysis. The element level analysis is employed to find what the most important nodes in the network are. To do so, the measures of centrality, defined below, are used. The group level analysis is used to define and find cohesive groups of nodes in the network. In other words, finding sets of similar nodes that are also dissimilar to other nodes. In the case of SNA the goal is to find cliques and communities. The network level analysis is focused on the topology of the network. That is, the arrangement of the network elements.

5.1.2.1. Element level analysis

The concept of centrality is straight forward. It is the number of direct connections that exist for a node with other nodes. However, there are different types of centrality considering how well nodes are connected, how well a node is connected to all other nodes, or how the information flows.

Degree centrality is defined as the number of neighbors of a node relative to the maximum number of neighbors the node could have. This may be computed including the node itself or excluding it. In this thesis it is computed excluding the node itself. A high degree centrality means that the node is significant within the graph. If degree centrality is computed for all the nodes in the graph it is possible to obtain the degree distribution of the graph. Defined mathematically, degree centrality is (Freeman, 1979):

$$C_D(n_i) = \frac{d(n_i)}{(g-1)}$$

Expression 5. Degree centrality.

Where $C_D(n_i)$ is the degree centrality, $d(n_i)$ is the number of neighbors of a node and g is the number of nodes of the network.

Betweenness Centrality is defined as the number of shortest paths through a node in relation to all the possible shortest paths. A high betweenness centrality means that the node has a high influence in the network because a lot of the information in the network passes through that node. Betweenness centrality is also applicable to edges.

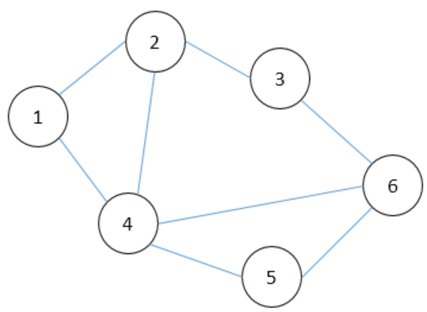
Defined mathematically, betweenness centrality for nodes is (Brandes, 2001):

$$C_B(v) = \sum_{s \neq v \neq t} \frac{\sigma_{st}(v)}{\sigma_{st}}$$

Expression 6. Betweenness centrality.

Were $C_B(v)$ is the betweenness centrality, $\sigma_{st}$is the total number of shortest paths from node s to node t and $\sigma_{st}(v)$ is the number of those paths that pass through the node v. Betweenness centrality is highly demanding from a computing perspective, especially for large networks.

Eigenvector centrality is another node influence measure. The underlying idea is that nodes connected to high influence nodes are more significant than nodes connected to low influence nodes. In this manner each node gets a score, with high influence nodes getting a higher score. It is similar to the PageRank algorithm employed by Google Search to identify website significance in the internet network. In fact, the PageRank method is a variation of the eigenvector centrality applied to directed graphs. In order to define the eigenvector, the adjacency matrix for SNA is needed. The adjacency matrix represents the connections of a graph. It assigns 1 if the connection exists between two nodes and 0 if there is no connection (e.g. Figure 1). For undirected graphs, the adjacency matrix is symmetric.



$$A = \begin{pmatrix} 0 & 1 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 & 1 & 0 \end{pmatrix}$$

Figure 1. Network and its adjacency matrix.

Mathematically, the eigenvector centrality for a given graph G with |V| vertices $G:=(V,E)$ and an adjacency matrix $A(a_{v,t})$ can be defined as (Newman, n.d.):

$$x_v = \frac{1}{\lambda}\sum_{t \in G} a_{v,t} x_t$$

Expression 7. Eigen centrality.

Where λ is a constant (eigenvalues). Taking the constant to the other side, it yields, in vector notation, the eigenvector equation:

$$Ax = \lambda x$$

Expression 8. Eigenvector equation.

5.1.2.2. Group level analysis

The concept of clique originates in the social sciences and is understood as a group of agents that share the same interests and have interactions with one another (Salkind, 2008). The underlying idea is that those agents forming a clique have more interactions within the group than outside (Tichy, 1973). From a graph perspective, this concept is translated as a set of nodes, within a graph, that are completely connected. The smallest clique is the triangle. A maximal clique is a clique that stops being a clique if one more node is connected. Maximal cliques in undirected graphs are known as communities. In order to obtain the maximal cliques, for the case of this dissertation, the Bron & Kerbosch (1973) algorithm with adaptations by Tomita, Tanaka and Takahashi (2006) and Cazals and Karande (2008). The identification of maximal cliques demands very high computational resources, especially in large networks.

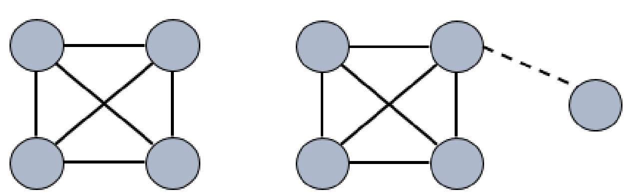


Figure 2. Clique and maximal clique.

5.1.2.3. Network level analysis

The term distance in a network is measured as the minimum number of steps needed to connect a pair of nodes. This is commonly known as the shortest path. To find the distance from a node to all the other nodes the breadth-first search (BFS) is employed. The BFS takes the initial node and finds all the new nodes, then all the new nodes for the previous nodes and so on "discovering" nodes as it advances. With every step, the distance increases. The result of the BFS can be visualized as a tree. In the example in Figure 3 the distance of node A to all other nodes is depicted: node B is at distance 1 from A, the nodes E, D, and C are at distance 2, the node F is at distance 3, the node G is at distance 4, and the node H, and I are at distance 5.

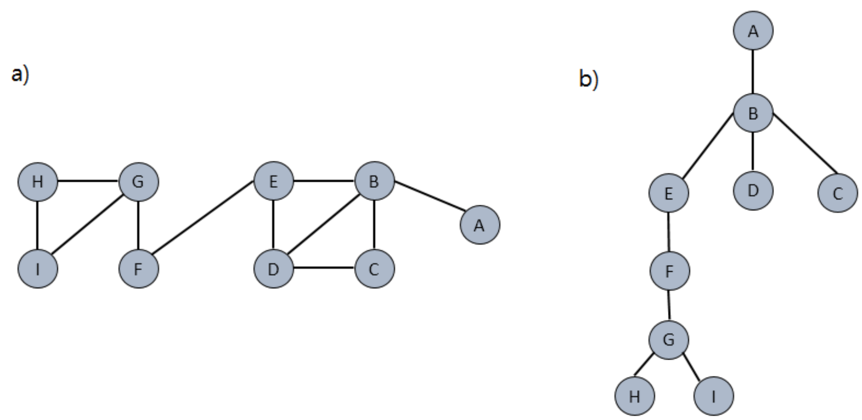


Figure 3. a) Network. b) BFS tree for the network a).

There are a few concepts employed to describe the topology of the network that use the concept of distance as exposed above. The average distance is the average shortest path length between every pair of nodes. The diameter is the maximum possible distance in the network.

An undirected graph is connected if for every pair of nodes there is a path between them. Similarly, connected components in a graph are subgraphs (a part of a graph) that have a path for every pair of nodes.

Clustering coefficient measures the degree to which nodes in a network tend to cluster to form new triangles (Wasserman and Faust, 1994). In other words, if node *a* is connected to node *b* and node *a* is connected to node *c*, the clustering coefficient measures how likely are nodes *b* and *c* to be connected. Clustering can be computed for a node (local clustering coefficient) or for the whole network (global clustering coefficient or transitivity).

The local clustering coefficient is the fraction of pairs of the node's neighbors that are neighbors with each other. That is (Saramäki, Kivelä, Onnela, Kaski, & Kertész, 2007):

$$C = \frac{number\ of\ a\ node's\ neighbors\ that\ are\ neighbors\ with\ each\ other}{number\ of\ pairs\ of\ a\ node's\ neighbors} = \frac{n}{(\frac{dc * (dc-1)}{2})}$$

Expression 9: Clustering coefficient.

Where C is the local clustering coefficient and d_c is the number of neighbors of a given node, and n is the number of a node's neighbors that are neighbors with each other. For example, in Figure 4, how likely are nodes E and G to be connected? Node H has four neighbors (d_c=4) node C has two pairs (D, B and B, H), node A has two pairs (B, H and E, H), and node G has one pair (H, F). Among node H's neighbors only A and E are neighbors with each other. Therefore, the local clustering coefficient of node H is 1/3.

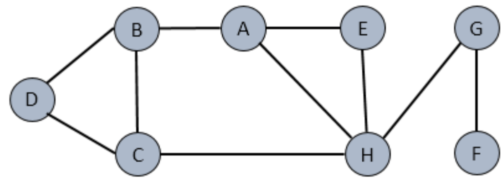


Figure 4. Graph.

The global clustering coefficient can be computed by two different methods: computing the average local clustering for all nodes in the graph, and computing the transitivity. The transitivity is the ratio of number of triangles and number of "open triangles" in a network. Open triangles are three nodes that are connected only by two edges, also known as open triad. Triangles (close triads) are three nodes connected by three edges. A triangle has three close triads. The average local clustering and the transitivity differ in that the latter tends to weight nodes with large degree centrality higher. Transitivity is computed as the fraction of the number of closed triads and the number of open triads in the network.

$$Transitivity = \frac{3 * number\ of\ closed\ triads}{number\ of\ open\ triads}$$

Expression 10. Transivity.

5.2. MODELING THE TRIPLE-HELIX

5.2.1. Modeling in GIS

According to Goodchild (2005, p.2) *"a model is a computer program that takes a digital representation of one or more aspects of the real world and transforms them to create a new representation".* In other words, a model is an algorithm used to understand phenomena in the real world. There are two main types of models: static and dynamic. The static models are fixed in a point in time while dynamic models attempt to simulate potential future scenarios.

Models may or may not take advantage of GIS capabilities but modeling in GIS is profitable when science must be multidisciplinary, integrated with policy, and when the spatial representation of phenomena is important (Goodchild, n.d.). In the case of this dissertation, a static model is presented. The input for such models is a mix of data, usually from various sources, combined to depict spatial variation. Often, the results of a static model become indexes or indicators for a particular phenomenon. Nonetheless, considering the problematics presented above with the use of singular indicators, it may be more beneficial to create instead models where the output takes into account multiple factors rather than summarizing them into a single indicator.

5.2.2. Spatial social network analysis

The Spatial Social Network Analysis (SSNA) is a methodology that provides an effective basis for achieving the goal of this thesis. Some works take into account the spatial dimension although it is often limited to proximity and GIS is not used (Meyborg, 2013). Therefore, it is reasonable to argue that this solution has been widely overlooked so far. Andris (2016) presents the challenges of integrating social networks in GIS and proposes a new solution. The solution presented focuses on the integration within the built environment and although it may offer valid solutions in certain scenarios at rather large scales it is not suitable for the particular case of this dissertation. Nonetheless, it offers a reference point for developing a specific solution.

The challenges of the SN-GIS communication revolve around the nature of the models employed, the connection typology, the existence (or lack of) spatial constraints, the distance measurement, the use of scale, and the necessary infrastructure of each model. A more detailed description of these issues is depicted in table 2.

Challenge	Social Network	GIS
Model Nature	Based on a node-edge graph structure	Based on layers
Connection Typology	Entities connected with edges	Entities connected with paths in the geographic space with a variety of shapes
Spatial constraints	No spatial constraints	Geographic and geometric constraints
Scale	Components independent of scale	Different component levels according to geographic scale
Infrastructure	Conceptual	Tangible: Technical and physical

Table 2. SN-GIS communication challenges. From Andris (2016).

5.2.3. Geospatial Helix Innovation Assessment Model

The goal of the Geospatial Helix Innovation Assessment Model is to exploit the advantages provided by the geospatial factor. Said factor is employed to provide a perspective of the innovation production on the territory through the collaboration of the three components of the TH: the university (in a wide sense), the industry and the government (or governance).

The model is created considering Goodchild's (2005) definition of a model in GIS presented above. That is, a model is an algorithm. The assumptions contemplated are those of the TH concept (Ranga & Etzkowitz, 2013). The most significant assumption is that the synergy between the components of the TH are represented as the interactions between said components. However, as mentioned above, the TH concept is not only applicable to three components but it can be extended to a quadruple, quintuple or N-tuple helix (Leydesdorff, 2012). The algorithm here presented has been developed taking into account the problematics of big data and data mining, the model scalability – possible application to global and local perspectives – the diverse dimensions of proximity (such as spatial, linguistic, etc.), and the territory itself. Through SNA it is possible to analyze and visualize large datasets, which may be applied to local or global perspectives. The dimensions of proximity are also tackled by SNA (proximity dimensions can be included as attributes of nodes and edges). Nonetheless, the territory is better handled by GIS. Therefore, the integration of SNA into GIS is included for this model (Figure 5).

The algorithm starts with the collection of data from both Scopus and Patent Office followed by the data cleaning process, which consists in assuring the data is consistent, addresses are complete, etc. Then the collaboration matrix is created. Said matrix contains the number of collaborations for each pair of institutions and is characterized for being a symmetric matrix with zeros along its diagonal. Simultaneously or immediately after building the matrix, the institutions are geolocated through the geocoding of their addresses. The location of institutions is also verified to avoid potential errors. At this point, the data collection process ends.

Once the data collection process is complete the nodes and edges are spatialized. In small networks this spatialization provides a first visualization but in large networks the benefits of visualizing the network at this step are limited. After the spatialization, the network is exported to the desired graph format. The format will depend on the specific tools to be used. After the graph of the whole network is generated, full network analysis may be performed. Alternatively, it is possible to extract subgraphs for their analysis.

The results of the SNA are integrated into GIS with external geospatial and/or alphanumeric data. Other outputs such as histograms and tables may also be obtained from SNA for their inclusion in a report. After the integration in GIS, geospatial analysis through visualization and/or other methods is possible. Then, the last step consists in the generation of maps and other outputs such as table and histograms that assist the acquisition of significant new information.

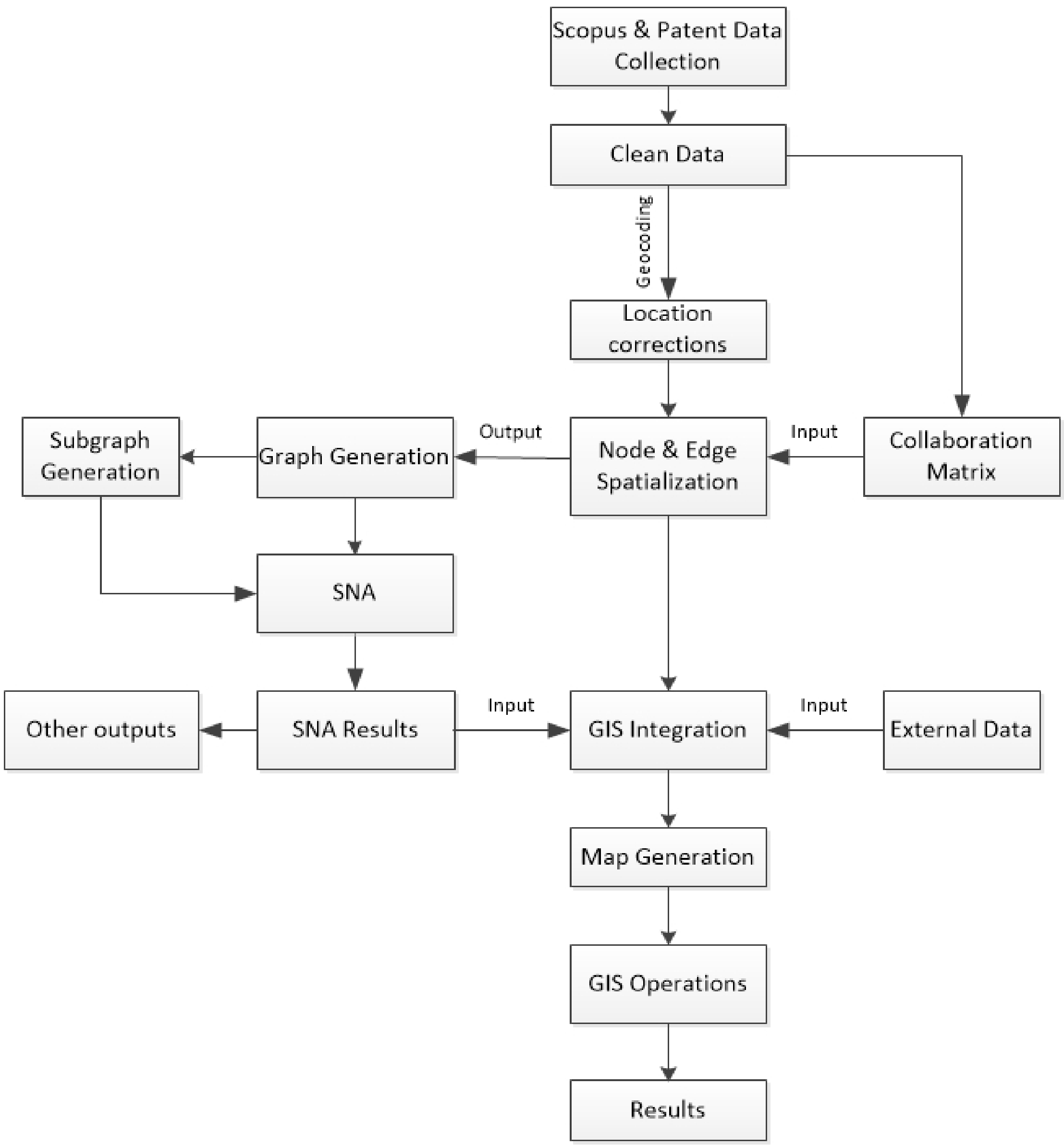


Figure 5. Geospatial Helix Innovation Assessment Model.

5.3. APPLICATION OF THE GEOSPATIAL HELIX MODEL

5.3.1. Case selection

The case is selected for 2015 because this was the only fully completed data set before initiating this dissertation. The selection of Spain was based on three factors: First, the doctorate program where this dissertation is presented is offered by Spanish universities. Second, collecting patent data for the whole EU was possible but economically infeasible. Third, as mentioned above, the first TH institute was created in Madrid, which could suggest that the TH is active in Spain.

5.3.2. Goal

The goal of this case study is to report the output of the Geospatial Helix Innovation Assessment Model, developed in this thesis, for the case of Spain in the year 2015. Specifically, the model introduces new metrics that include not only the institutions but the whole network produced by the Spanish HE system. The underlying idea is that the significance of a given institution is relative to the context where it is evaluated. Furthermore, the EU's Horizon 2020 strategy is focused on boosting the role of the universities towards a higher engagement in society through innovation. Through this case of study, an attempt to assess the impact of the TH to the territory is made.

5.3.3. Assumptions

The main assumptions used in this case study are a direct result of the TH concept (Ranga & Etzkowitz, 2013). Said assumptions are listed as follows:

+ Universities have an important role for innovation and economic development in a Knowledge Society.
+ The presence of scientific documents and/or patents authored by agents of two or more TH components denotes TH synergy.
+ The presence of funding institutions in scientific documents and/or patents denotes TH synergy.
+ Relationships within an institution do not denote TH synergy.

5.3.4. Methodology

The methodology employed for this specific case diverges from the typical TH measurement methodology in that the typical TH indicator is dismissed in favor of SNA in combination with GIS. The justification of this divergence lies on three main aspects:

1. The TH indicator measures the TH output with megabits of information transmitted as their unit. Despite the wide use of this unit among experts, it is an abstract unit that is not intuitive for non-experts in the discipline.
2. Most TH studies employing SNA focus on a set of authors.
3. The assessment presented here includes the territory.

5.3.4.1. Data

The data employed for this case is the typical data present in scientific publications focused on analyzing the TH output. That is, bibliometric data of scientific publications and patents. The scientific publications data has been obtained from the Scopus database for the universities listed by the *Conferencia de Rectores de las Universidades Españolas* (CRUE, n.d.) while the patent data has been obtained from the Spanish Patent Office (Oficina Española de Patentes y Marcas, n.d.).

The initial geospatial data has been obtained from Eurogeographics (n.d.) for European boundary data and from the ArcGIS Online Feature Service within the ArcGIS Desktop software for global data. Specifically, European country data has been downloaded for levels NUTS 0 and NUTS 3, corresponding to country and province levels, with a 1:100.000 scale in ETRS89 and geographic coordinates last updated in January 2017. The region level (NUTS 2) has been dismissed because it represents areas that are considered too large for the purpose of this case.

Data for world countries boundaries has been obtained from the ArcGIS Online Feature Service embedded in the ArcGIS Desktop software. This data has been downloaded in layer package format, last updated in January 2015, and its metadata describes its scale as "to be used at large scales", which is precisely the purpose it fulfills. The coordinate system is WGS84 in geographic coordinates.

5.3.4.2. Data collection and management

The data from Scopus has been collected employing the Scopus APIs with python. Considering the universities as the central piece of the knowledge society an iterative process has been established to obtain Scopus data for each of the 73 Spanish universities listed by the CRUE.

First, the documents of a given university are searched employing the same name as that listed by the CRUE. Then, the metadata of the found documents is stored. In order to avoid storing the same document twice, a list of the found documents' IDs is stored and updated with each iteration.

Second, the metadata is filtered to obtain only the documents where collaborations are present, that is, the documents where there are at least two authors signing the documents and they are affiliated to different institutions.

Third, a list of unique institutions is created for each university as well as a general one, which is updated with each iteration. The list of unique institution serves as the indices of a collaboration matrix that is generated for each university from the filtered documents obtained in the previous step and is stored in NumPy format. In order to build the collaboration matrix each pair of institutions present in a given article is considered. The institutions funding the research are also included as collaborators and no explicit differentiation is made. For example, an article with three affiliations *a*, *b*, and *c* would form the collaborations *ab*, *bc*, and *ac*. Then, the matrix "cells" corresponding to the indices *ab*, *bc*, and *ac* would include a value corresponding to the number of times these collaborations occurred within the dataset. The resulting collaboration matrix is a symmetric matrix with zeros in its diagonal and with the same number of rows and columns that correspond to the number of unique institutions collaborating with the given university.

Fourth, the metadata of each institution is obtained and corrected if necessary.

The same method employed to collect data from Scopus is employed with patent documents but the process is not iterative because the data was downloaded in bulk. However, the documents are filtered by the existence of two or more patent applicants but the difference lies in that at least one of the applicants must be affiliated to a university (or be a university) listed by the CRUE.

The institutions from both Scopus documents and patents are classified in seven categories by their type. Originally, the TH includes only three main types:

university, industry, and government. However, the reality is that other types of institutions are participating in both scientific research and patents. The categories employed here are: university (univ), research institute (resi), company (comp), hospital (hosp), government (govt), non-profit (nonp), and triple-helix (trih). The categories include the obvious institutions but also other institutions due to their similarity. The category university includes HEIs but also schools and high schools. The category hospital includes also primary care centers and clinics. The category non-profit includes non-governmental institutions as well as foundations. In most cases, these institutions are funding research and patents. The triple-helix category includes those institutions that attempt to integrate the collaboration of the three basic elements of the TH. Often, these institutions are named as Technological Park or similar. Most of the institutional metadata obtained from Scopus and the Spanish Patent Office did not include the type of institution. This classification is difficult to automatize since it may not be done solely using the name of the institutions. For instance, the Royal Technical Institute is not a research institute but a university located in Stockholm, Sweden. In some other cases, distinctive elements are included in the name such as the word "hospital" or indicatives of company registration such as "S.A." or "Inc.". In such cases automation using python has been performed. Nonetheless, most of the classification has been done manually by searching the institutions online and identifying their purpose. Due to the size of the dataset (Table 3), the institution classification process has taken an extensive period of time. Similarly, the geocoding of institutions' addresses has been problematic as many addresses are incomplete or simply wrong. Although most of the geocoding has been automatized through the Google Maps API in python a large number of institutions were corrected manually.

The downloaded geospatial data has been projected to web Mercator to facilitate the integration of said data with the geocoding results and avoid further potential sources of error. The data collected from Scopus and the Spanish Patent

Office has been converted to Feature Class datasets within a geodatabase specifically created for this specific case. Specifically, three point feature classes have been created with ArcPy: one for institutions obtained from Scopus documents, one for institutions obtained from patents and one that is the result of merging the institutions obtained from both Scopus and patents documents. At this stage, the location of institutions is verified by selecting the institutions that have coordinates that do not fall within the country listed in their attribute country. Once identified, the correct coordinates are obtained manually through Google Maps and modified in the Feature Class with an ArcPy script. ArcPy is a library in python used for interacting and automating processes with ArcGIS. A line Feature Class was also created derived from the collaborations' matrices created. Considering that several universities collaborate with over 1,000 unique institutions the automated process of creating the line feature class is highly time consuming. For example, a university with 1,200 collaborating institutions would have a collaboration matrix of 1,440,000 values. Since the matrix is symmetric only half of those values need to be checked, that is, 720,000 values. However, there are 73 universities listed by the CRUE, which has resulted in a process that lasted well over five days of continuous processing.

In spite of having the line feature class of the collaborations, its visualization is detrimental to the goal of identifying patterns because there is such a large number of lines that nothing is visible. Therefore, it is not displayed in this dissertation. Instead, it has been used as an intermediary step to identify duplicates and export the data to both network specific software as well as python-ready format. In this case, the chosen software has been Gephi due to its open source nature and rather low use of computer resources compared to other network analysis software. In order to export the data, an automatized procedure has been programmed in python.

5.3.4.3. Analysis

The analysis of the network at element level and at the network level has been mostly performed with python employing the NetworkX API while the visualization, group level analysis, and the computation of some indicators for the network characterization have been carried out with Gephi.

The element level of analysis, has consisted in computing all three centralities for each node present in the network: the degree centrality, the betweenness centrality, and the eigenvector centrality. The distribution of the centrality values suggests the existence of the power law distribution (Figure 47). In this case, it means that a large number of institutions have low centrality values and only a small set of institutions have large values. This will be significant later on for computing the centralities of the Spanish provinces. The network level of analysis has been employed to identify the potential new collaborators for each university by employing the concept of open triangles in the network. In other words, for recommending new collaborators to each university. However, in order to avoid recommending all the nodes that do not form a triangle with a given university, certain constraints have been applied in a manner that to recommend connecting with a collaborator of a collaborator the relationship with the initial collaborator has to be significant. This has been quantified in ten collaborations considering the distribution of the number of collaborations per connection (Table 5). Also, with the purpose of connecting with institutions of a certain importance and to ensure the potential collaboration, the new institution should be connected to at least ten of the already existing collaborators of the university. For example, in Figure 6 a university U is connected to an institution A, which is connected to institutions B, and C. In order to consider B, or C as potential collaborators the number of collaborations between U and A has to be of at least ten. Then, in order to recommend the connection of the university U with the institution

C at least ten collaborators of U also have to be connected to C in a similar manner as represented in Figure 7 where institutions A and D are collaborators of U and C.

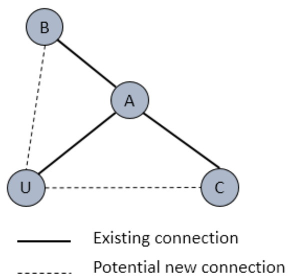


Figure 6. Recommendation step 1.

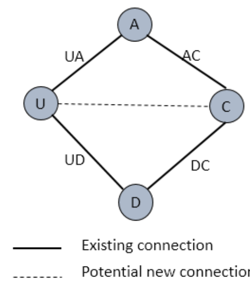


Figure 7. Recommendation step 2.

The group level analysis has not been possible to compute either by python or by software due to the large size of the data set and the computer memory limitations. In order to achieve the group level analysis a python script has been written to obtain the subgraphs of each university until dimension two. In other words, smaller networks for each university have been extracted from the main network. Each of the smaller networks contains the collaborators of each university as well as the collaborators of the collaborators. Although these networks are smaller the number of triangles is still too large for the available computer to manage it memory wise. Therefore, the group level analysis has been performed through network visualization. In short, a given subnetwork has been visualized with the purpose to identify communities. As mentioned above, communities are groups of nodes that are fully connected to one another.

There are a few challenges for integrating social networks with GIS (Andris, 2016). The different model nature of node-edge in social networks and layers in GIS could be handled by giving coordinates to the nodes and then creating line features connecting them. This has been attempted but the results of the conversion do not allow for a clear visualization with GIS. Other challenges could be taken care of but, perhaps, the most complicated issue is that social networks do not have any spatial constraints while GIS is tightly connected to the territory through coordinates. In order to manage these issues the nodes of the network have been geolocated and the results of the element level analysis have been added as attributes. Then, the centralities of all the nodes falling within a certain Spanish province have been used to measure the relative impact of innovation in each province, be it impact according to connectivity, influence, or relationships with important institutions.

Considering the distribution of the centrality values (Table 7), and as a solution to the heterogeneity of the results, a natural breaks (jenks) classification of the data has been computed with python obtaining two separate datasets: one for the flatter side of the curve, and one for the steeper side of the curve. Simply computing the median or the average values for the whole distribution, of the institutions in each province, would generate very large standard deviations because the highest and lowest values are very far apart and the flatter side of the curve represents a much larger number of institutions than the steeper side. Should the median be used for the whole distribution it would be skewed towards the flatter side of the curve. By "cutting" the distribution in two parts we reduce these errors. Therefore, for each type of centrality two maps are generated. One for the flatter side of the curve and one for the steeper side. In this manner, both the institutions with lower values (but more common) and those with the higher values (but rarer) are taken into account and through the visualization of these maps patterns can be identified. The results of the collaboration recommendations computed for each university by SNA have also been integrated in maps by geolocating each recommended institution. In this manner, it is possible to identify patterns for each university as well as for the whole Spanish innovation system.

6. RESULTS

A large dataset of metadata has been collected from the various universities. Once the data collection concluded a preliminary observation of said data provides insight on the matter of study. Table 3 presents a summary of the collected data from the Scopus scientific database and the Spanish Patent Office. In the case of Scopus the number of documents where collaborations are present, that is, manuscripts with two or more authors as well as those with grants are filtered at this stage. Later on, grants are merged simply as collaborations. For the case of the Spanish Patent Office, the documents with collaborations and those where a university participates as an applicant are also presented. Only the latter are included for the study. The average, median, standard deviation, coefficient of variation, the maximum number of collaborations and the minimum number of collaborations are also computed. The large standard deviation of collaborations in Scopus documents is due to the maximum of 511 authors. In this case, the median presents a more realistic perspective with four authors per manuscript. It is significant to note that the *Universidad a Distancia de Madrid* and the *Universidad Internacional de Andalucía* do not appear in Scopus. The *Universidad Menéndez Pelayo* does appear but only with 3 documents and all of them are signed by a single author. Therefore, these universities are not represented in the network.

	Scopus	**Spanish Patent Office**
# docs	34,360	28,546
# docs w. col.	34,275	772
# docs w. grant	1,527	
# docs col.-grant	1,525	
# docs col.-univ.		243
Avg. auth./doc	5.13	2.28
Med. auth./doc	4.00	2.00
St. Dev. auth./doc	13.53	0.86
Coef. Var.	2.64	0.35
Max. # auth.	511	15
Min. # auth.	2	2
Avg. appl./doc w. univ.		2.34
Med. appl./doc w. univ.		2.00
St. Dev. appl./doc w. univ.		0.75
Coef. Var. w. univ.		0.32
Max. # appl. w. univ.		7
Min. # appl. w. univ.		2

Table 3. Collected data summary.

The network generated by the downloaded dataset is presented with two different layout visualizations in Figure 8 and Figure 9 and summarized in table 3. The Fruchterman-Reingold Layout is considered a standard and it depicts the most interconnected nodes towards the center of the network.

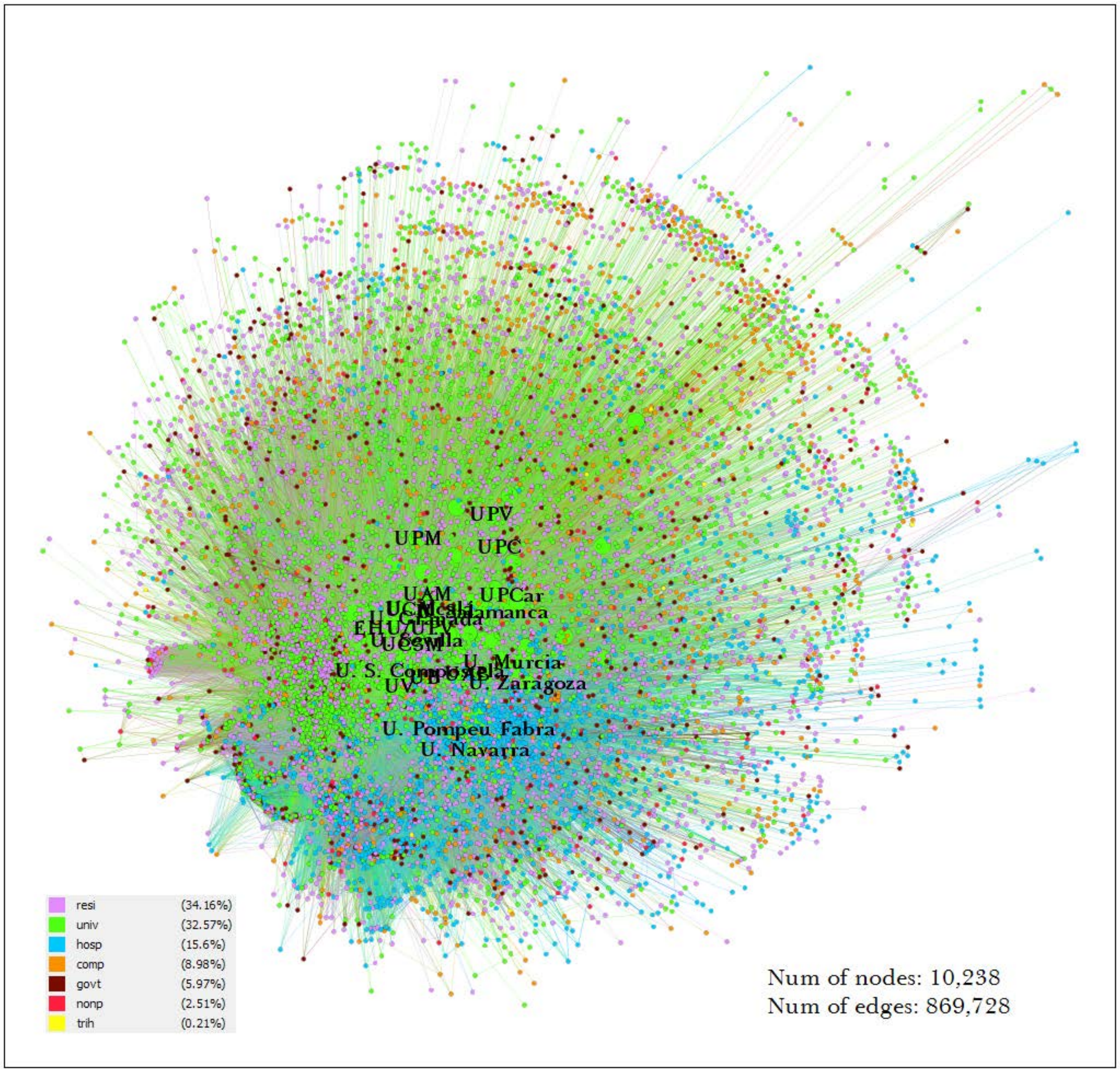


Figure 8. Full Network. Fruchterman-Reingold Layout.

The OpenOrd layout is intended to facilitate the identification of communities. A few communities can be seen on the left side of the network. Nonetheless the size of data complicates the interpretation of the network, which is also depicted by the high clustering coefficient. That is, there is a large number of triangles in the network. In spite of the dataset size the diameter of the network is seven, which confirms the "small-world" principle of complex networks (Zhukov, 2015).

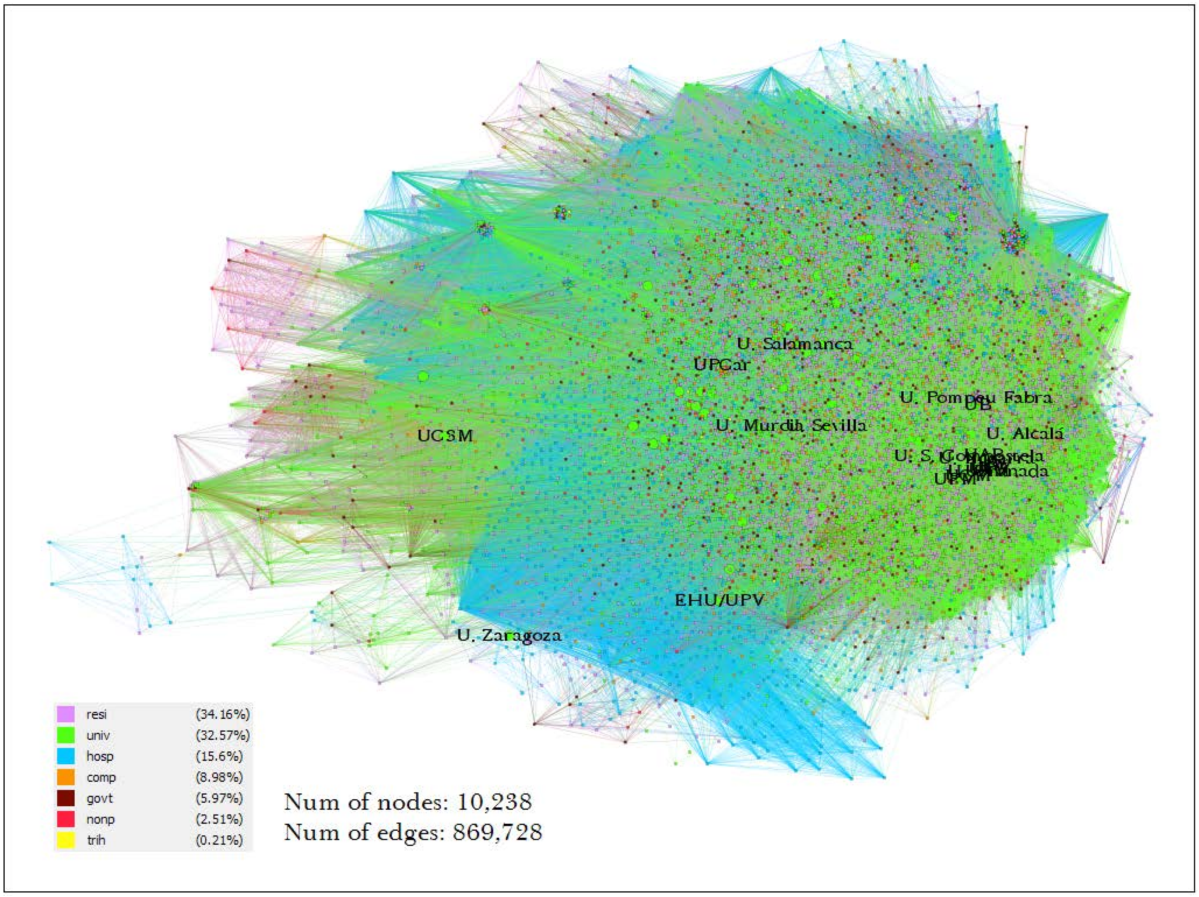


Figure 9. Full Network. OpenOrd Layout.

Concept	***Value***
# Nodes	10,238
# Edges	869,728
Diameter	7
Avg. Shortest Path	2.745
Clustering Coeff.	0.8
Univ %	35.57
Resi %	34.16
Hosp %	15.6
Comp %	8.98
Govt %	5.97
Trih %	0.21
Nonp %	2.51

Table 4. Characterization of the full network.

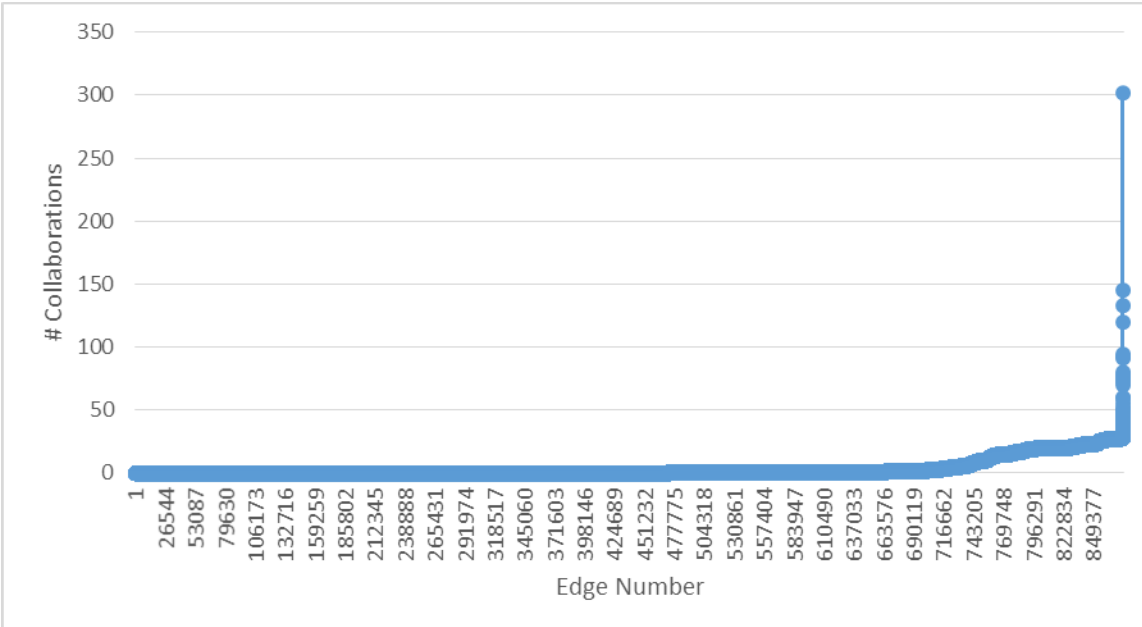


Figure 10. Collaborations distribution.

Figure 10 displays the distribution of collaborations for the whole network. The distribution has a long flat tale, which shows that many edges have very few collaborations and very few edges have many collaborations. Specifically, four edges have more than 100 collaborations, 169 edges have more than 30 collaborations, 145,429 have between 6 and 30 collaborations and 724,126 edges have 5 collaborations or less.

6.1. GENERAL MAPS

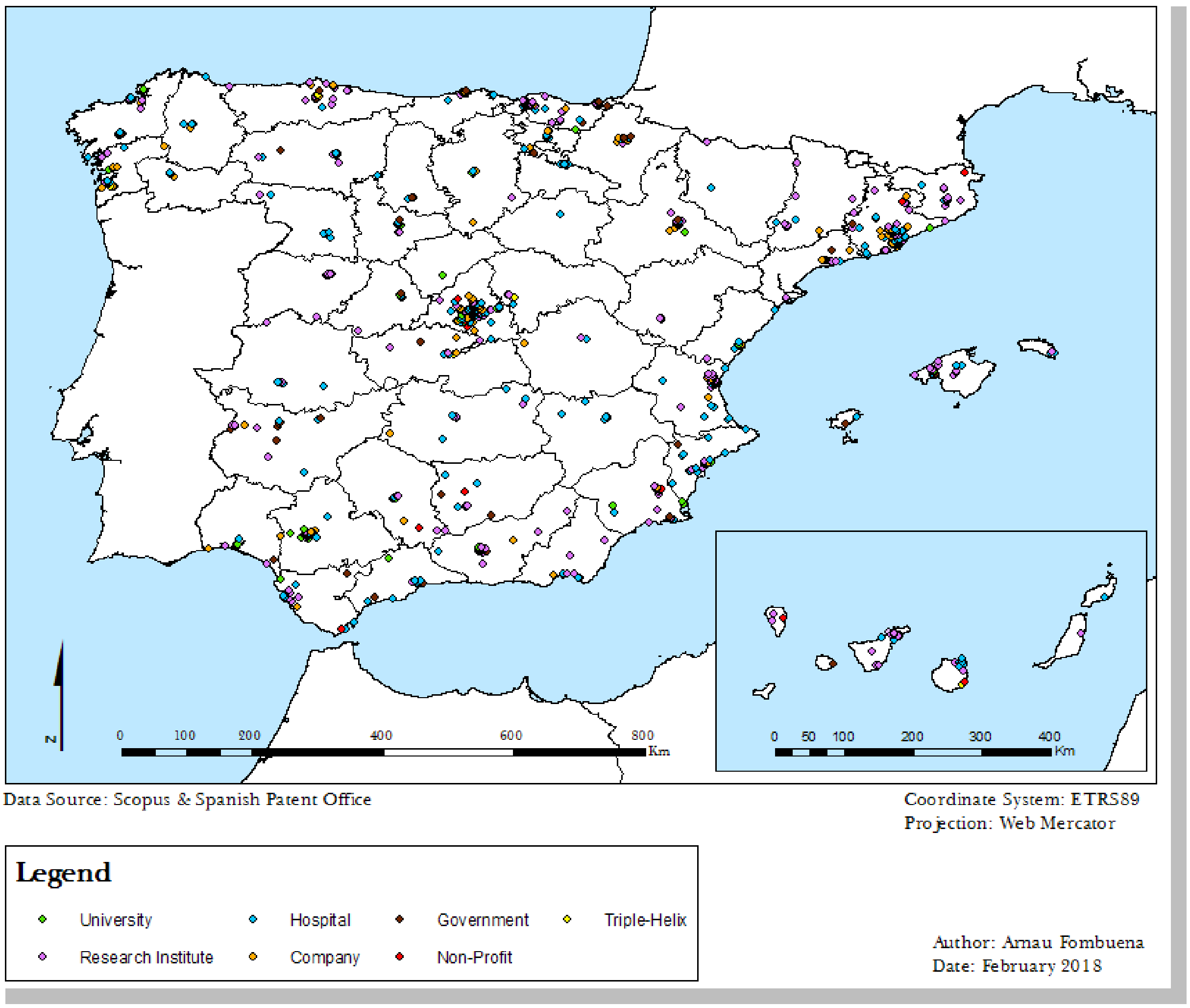


Figure 11. Spatial distribution of institutions by type in Spain.

Figure 11 displays the institutions participating in the innovation network in Spain symbolized by their type. Said institutions are concentrated in the two big cities of the country, Madrid and Barcelona, but also on the coasts with significant concentrations in Cantabria, Asturias and the Basque Country as well as the Valencian region. The central part of the country is less populated. No one type of institution seems to be more dominant than another except perhaps in the interior of the country where hospitals are more easily identifiable.

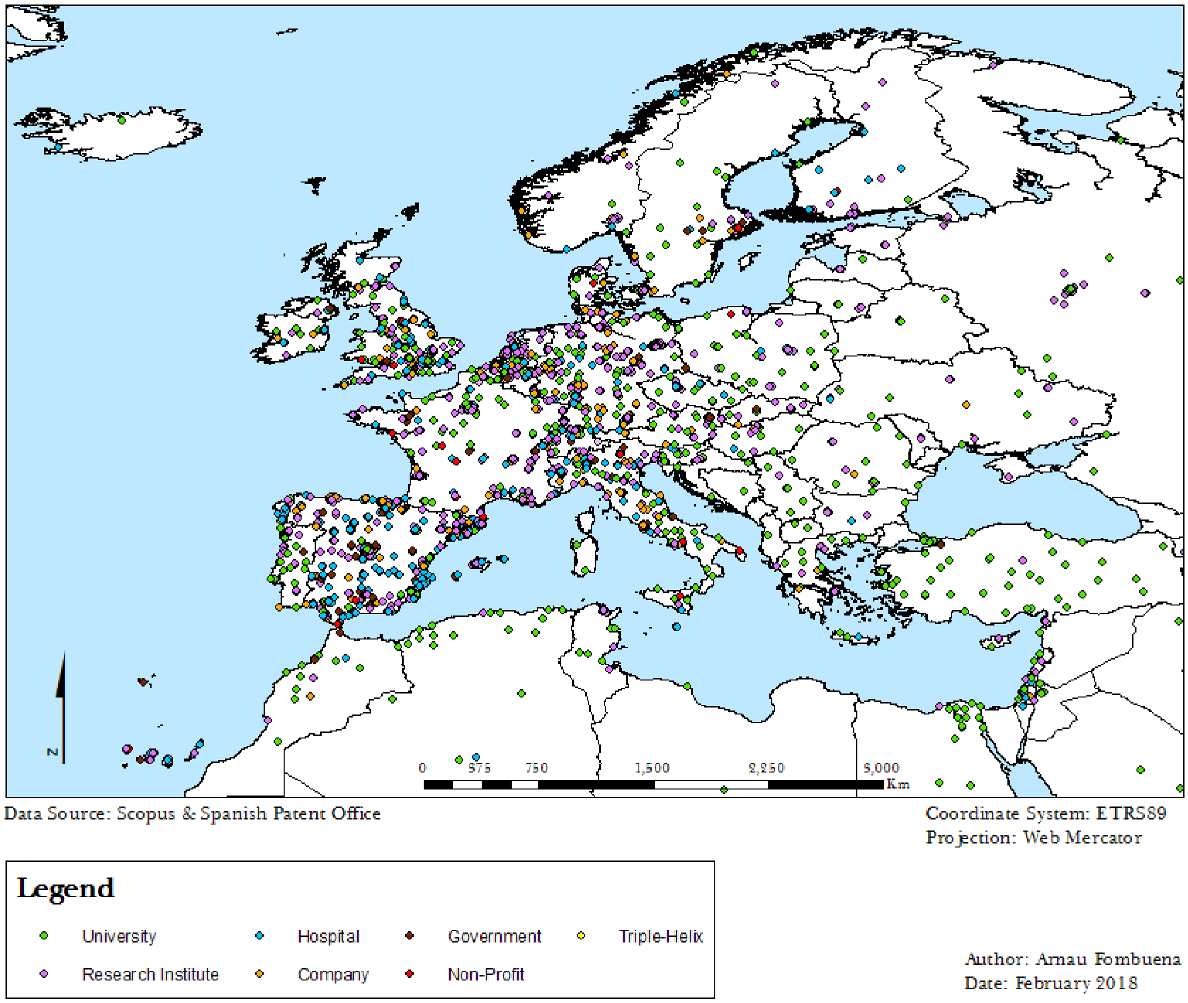


Figure 12. Spatial distribution of institutions by type in Europe.

Figure 12 displays the institutions participating in the innovation network in Europe symbolized by their type. Many of the institutions of the Spanish innovation network are located in what is commonly known as the "Blue Banana" of Europe (Figure 13) where about 110 million people live and where most of the European industry has traditionally thrived. In that area the typology of institutions is heterogeneous. The area of the central European boomerang, is where the potential of development is highest. In that area, most of the institutions are universities or research institutions with little to no presence of other types. The institutions located in the former Soviet Union countries also present the same limitations with only universities and research institutes. There is also another corridor formed from the south of Spain to the south of Italy following the Mediterranean coast with a high volume of institutions of all types.

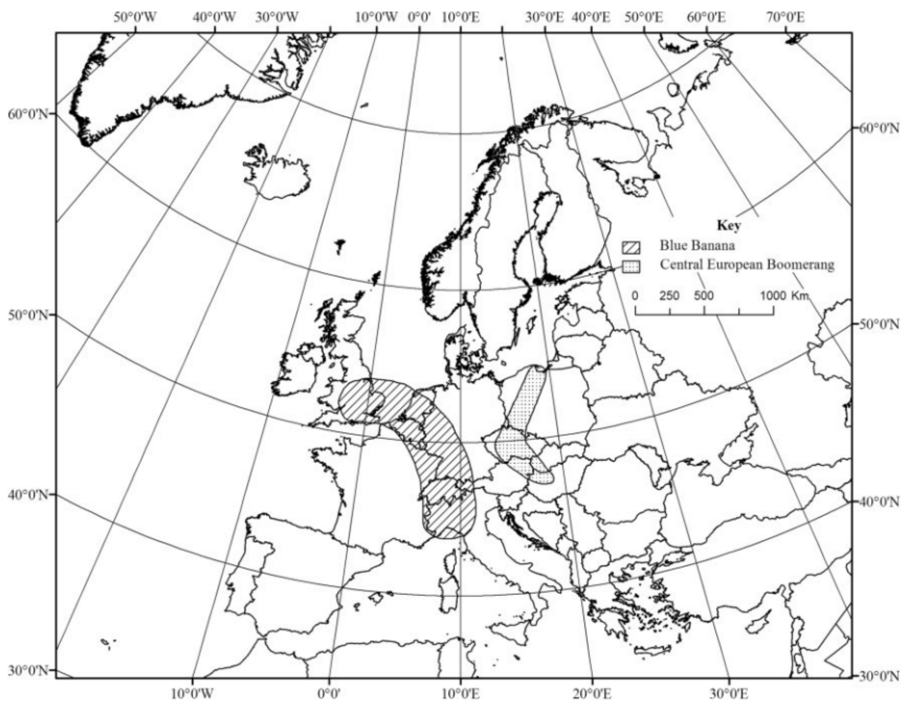


Figure 13. Blue Banana and Central European Boomerang. Source: Tóth, Kincses and Nagy, 2014.

Figure 14 displays the institutions participating in the innovation network around the world symbolized by their type. The institutions are mostly located in Europe and North America, where the type of institutions is heterogeneous. The institutions located in Asia are predominantly universities with a few companies and research institutes in China, South Korea and India. In South America Chile has a diverse set of institutions dispersed along its length and Argentina has a majority of research institutions also rather well distributed. In Brazil the universities represent the majority and they are mostly concentrated in the south-east along the coast between Porto Alegre and Rio de Janeiro. In Africa there is a concentration of heterogeneous institutions that seem to link the Canary Islands with the south of Italy, closing the Mediterranean corridor mentioned above. Central Africa does not present many institutions. There are two corridors in Africa, one along the east from South Africa to Ethiopia and a second one from Senegal to Angola along the west coast. Australia also shows a concentration of institutions on its east coast, where most of its population resides.

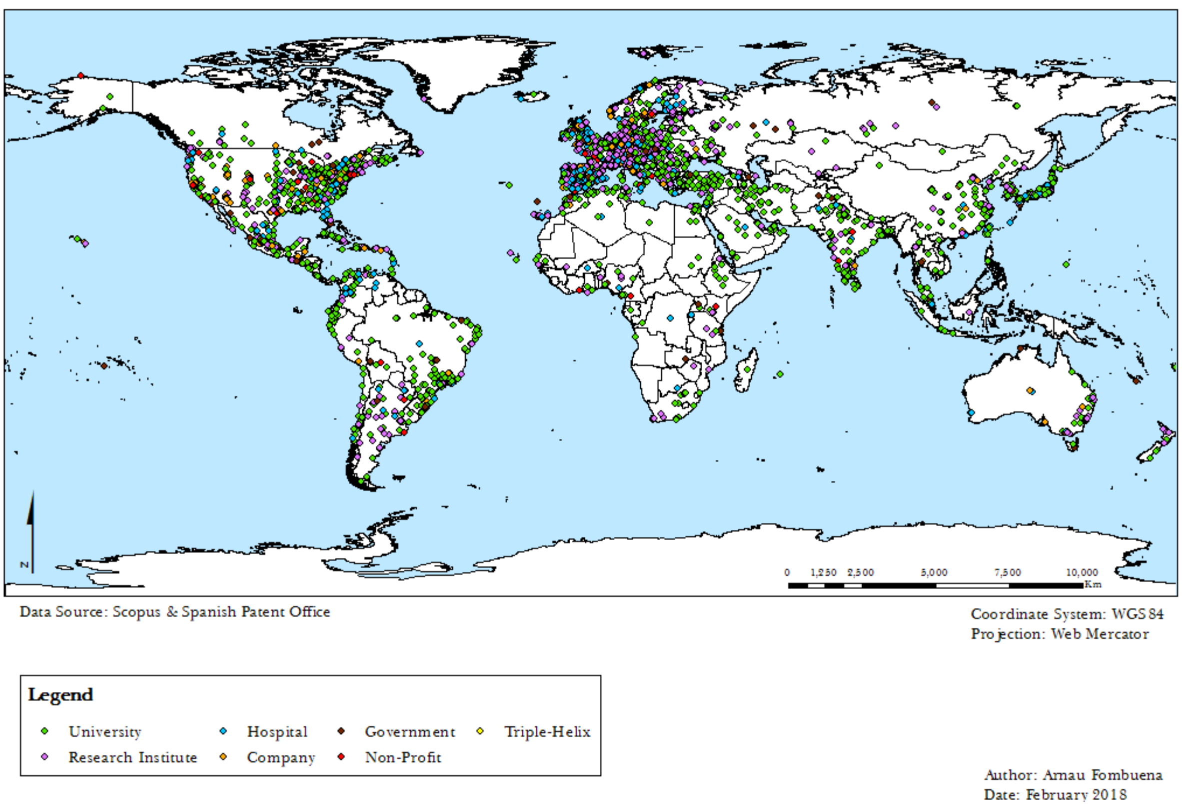


Figure 14. Spatial distribution of institutions by type around the world.

6.2. SUBNETWORKS

All Subgraphs are displayed using the Fruchterman-Reingold layout. A selection of universities are presented in this section but all 73 subnetworks are displayed in the Annex I.

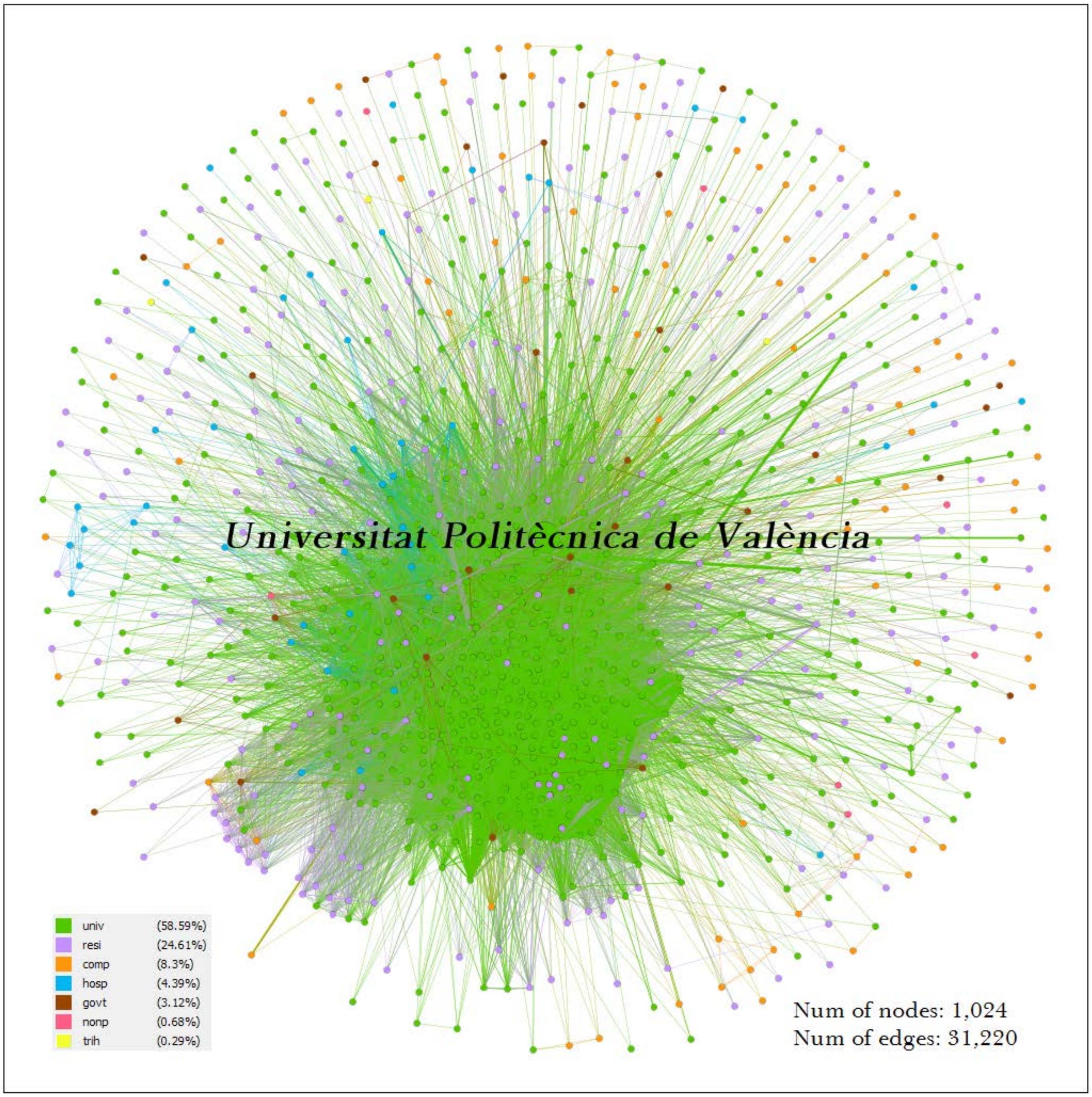


Figure 15. Subgraph of the *Universitat de Politècnica de València.*

The *Univeristat Politècnica de València*, as well as other Spanish polytechnic universities (Table 5), does have a rather high percentage of collaborators that are companies compared to other Spanish universities. There are three communities clearly identifiable (Figure 15). One on the left of the graph formed, mostly by universities, and two on the lower left formed mostly by research institutes although in one of them companies are also present (Figure 16). A small community formed by four companies connected to the *Universitat Politècnica de València* is also identifiable on the lower-right side of the network (Figure 17).

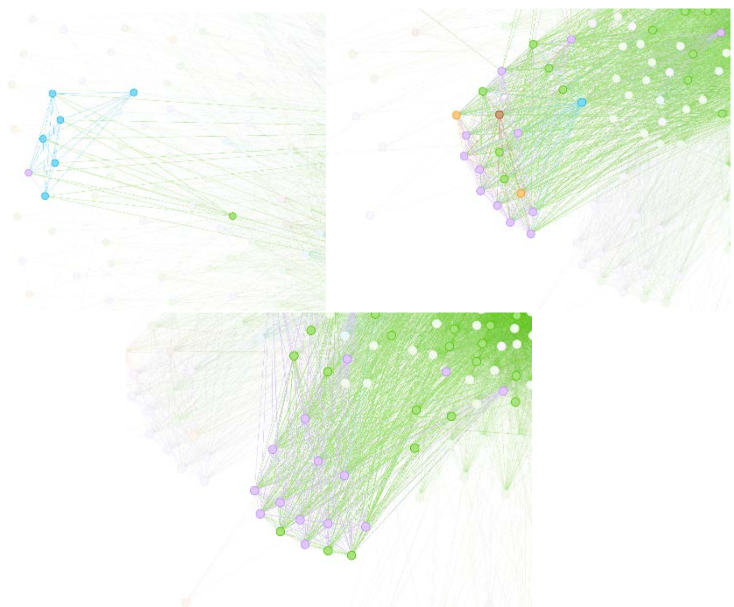


Figure 16. Subgraph of the *Universitat de Politècnica de València.* Detail of communities.

Figure 17. Subgraph of the *Universitat de Politècnica de València.* Detail of community.

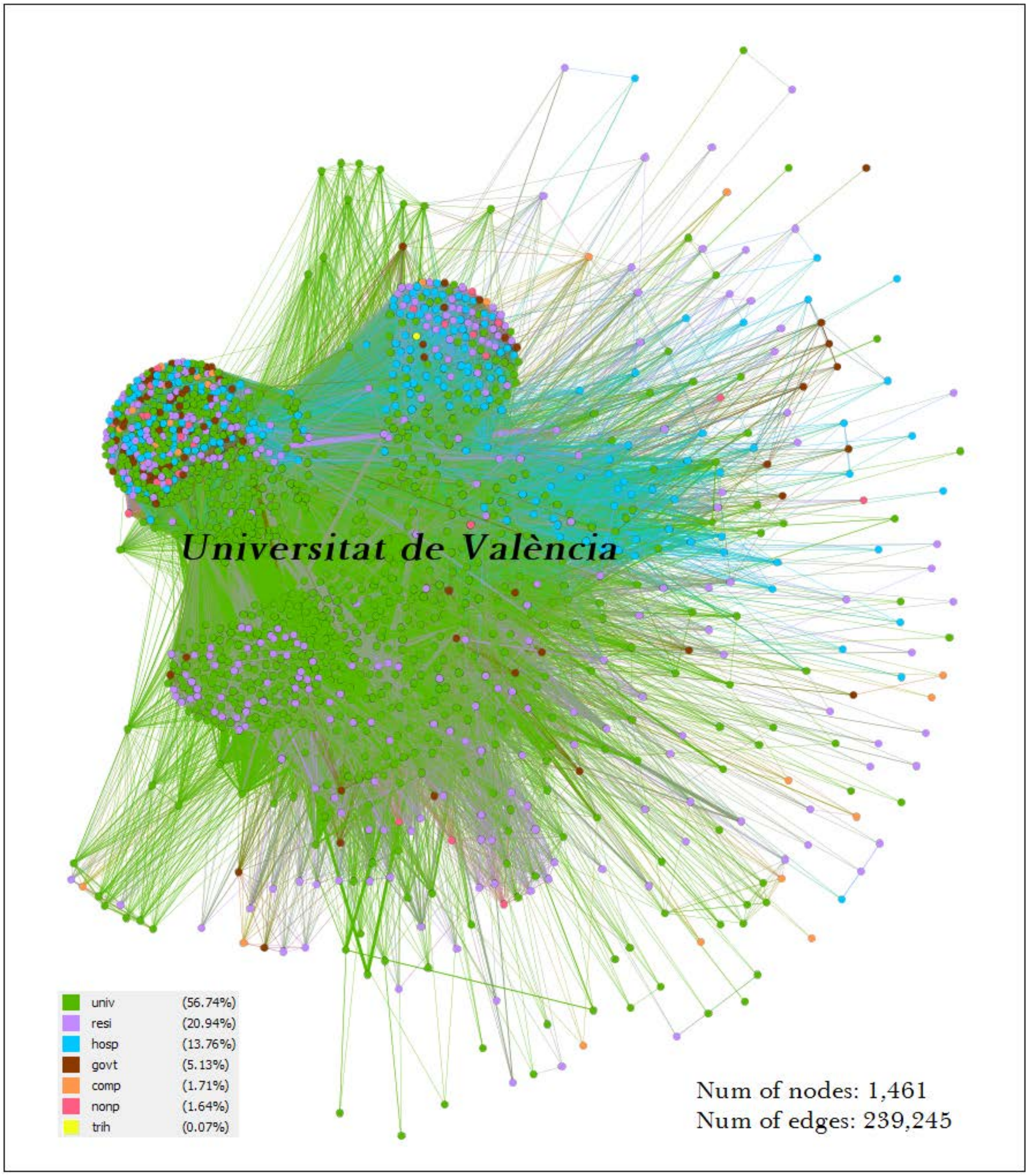


Figure 18. Subgraph of the *Universitat de València.*

The *Univesitat de València* has a large number of connections relative to the number of collaborators. For instance, it has 269 nodes less than the *Universidad Complutense de Madrid* but 131,416 connections more (x2.218). That is, the activity of the *Universitat de València* is well over double of that of the *Universidad Complutense de Madrid*.

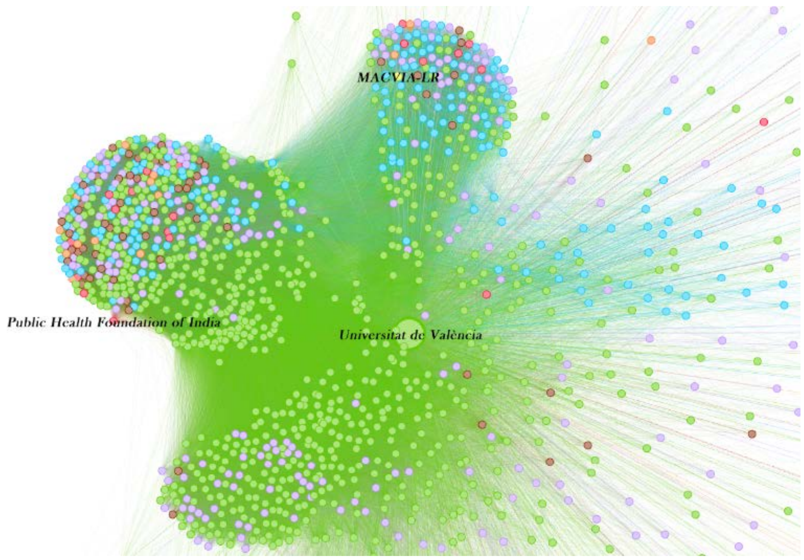


Figure 19. Subgraph of the *Universitat de València.* Detail of *Universitat de València*'s connections.

Three large clusters are observed in the subgraph of the *Universitat de València* (Figures 18-19). The cluster on the upper left corner is divided by the connection, or lack of connection, to the Public Health Foundation of India (Figure 21). Although the three clusters are connected through the *Universitat de València*, said university is not essential for these clusters to connect because a set of universities and hospitals are also connected to either two or three of the clusters (Figure 20).

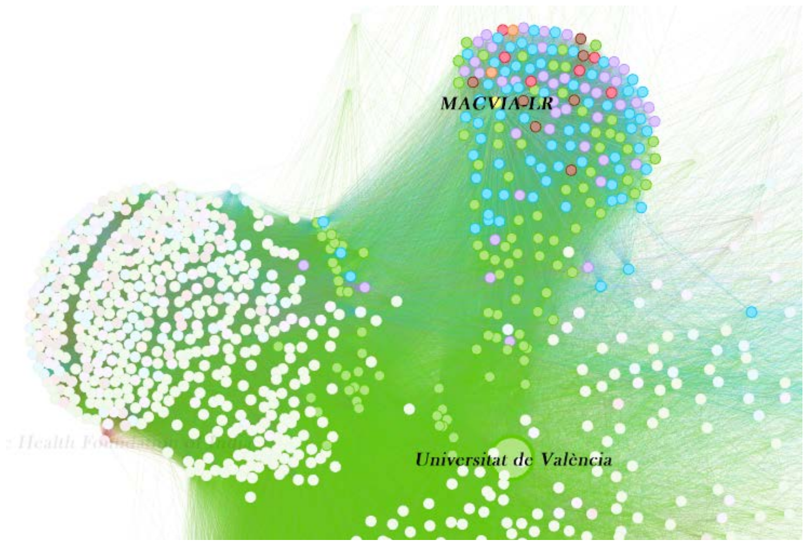


Figure 20. Subgraph of the *Universitat de València.* Detail of MACVIA-LR's connections.

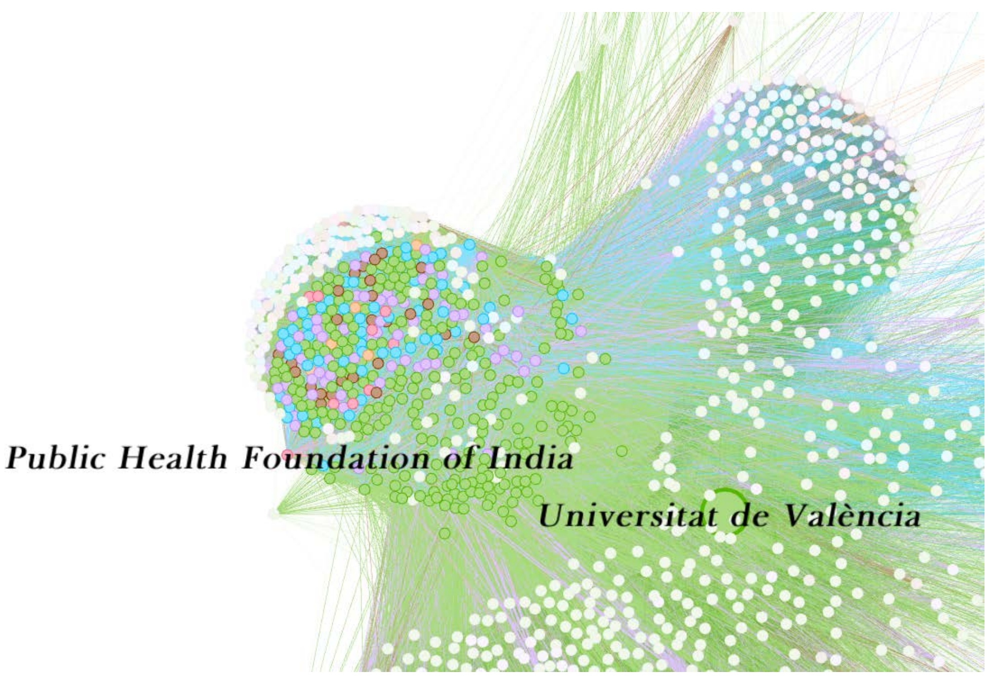


Figure 21. Subgraph of the *Universitat de València.* Detail of the Public Health Foundation of India.

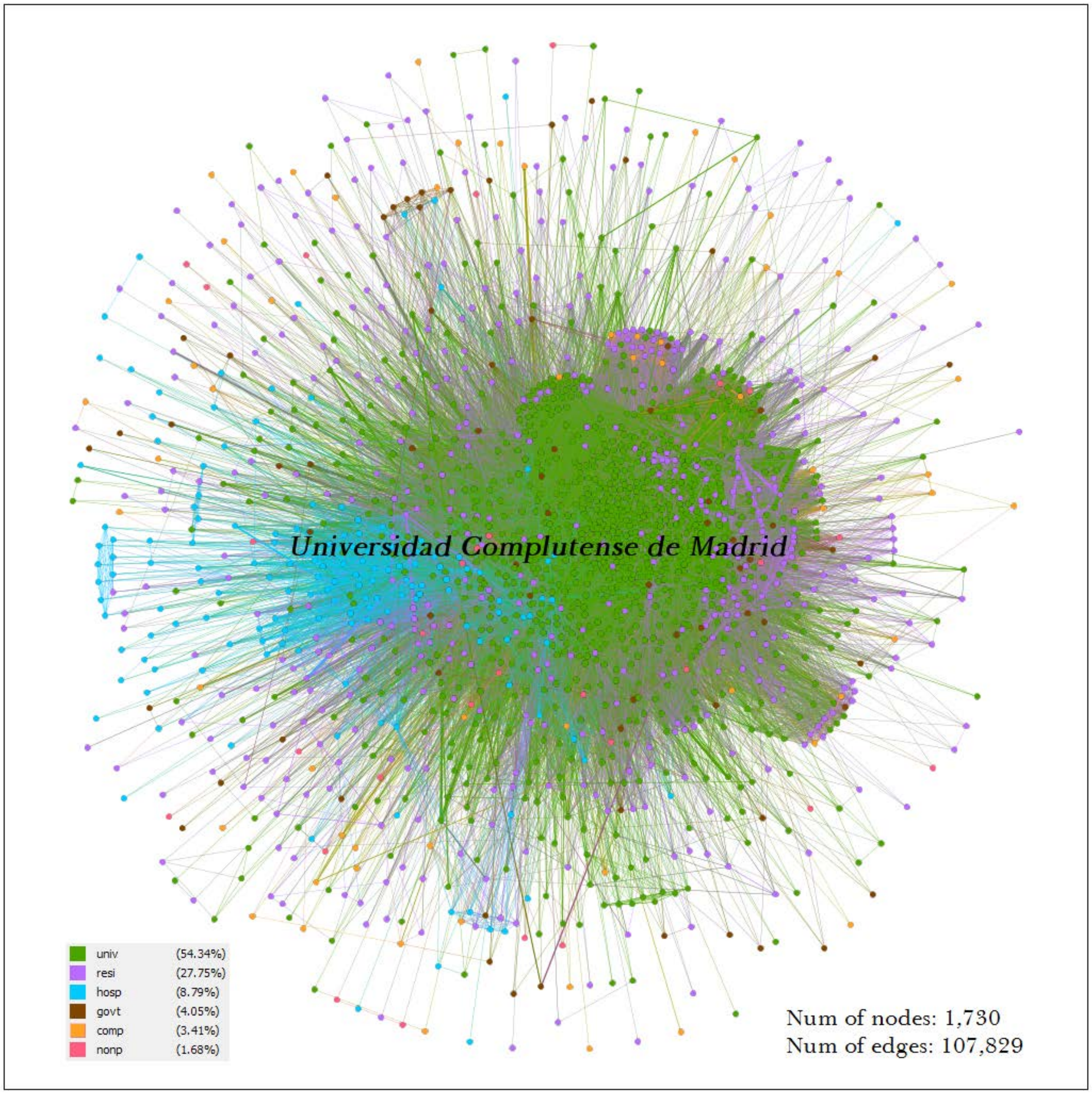


Figure 22. Subgraph of the *Universidad Complutense de Madrid.*

Several communities are formed around the *Universidad Complutense de Madrid*. A few of them are very clearly identified on Figure 22. For instance, on the left side of the network there is a very clear community formed mostly by hospitals next to a smaller one with a majority of hospitals as well (Figure 23). Also at the bottom there are two communities, one formed of hospitals, research institutes, a company and a government institution and the other one formed fully by universities (Figure 24). Towards the lower right side another rather large community is formed by research institutes and universities with a couple of companies and a government institution. A community of similar characteristics is identified towards the top-center of the graph (Figure 25).

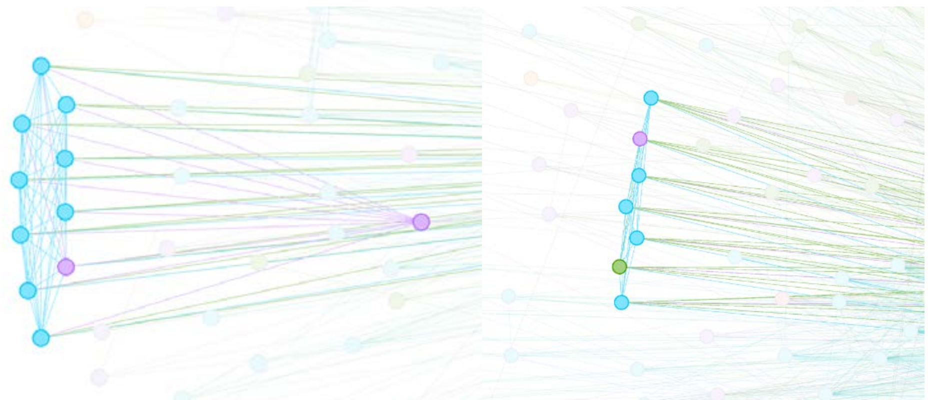


Figure 23. Subgraph of the *Universidad Complutense de Madrid.* Details of communities with a majority of hospitals.

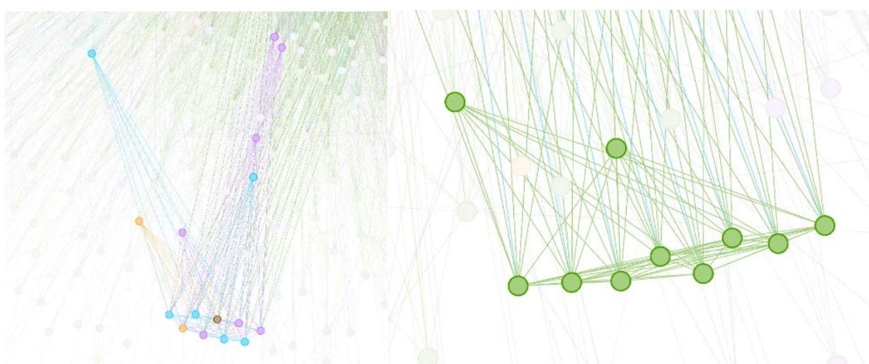


Figure 24. Subgraph of the *Universidad Complutense de Madrid.* Details of communities located at the bottom of the graph.

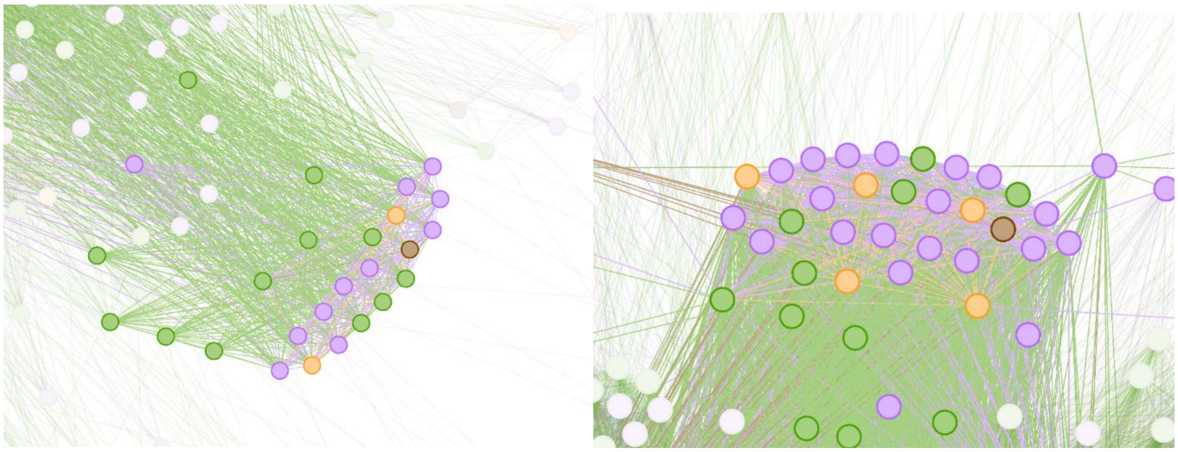


Figure 25. Subgraph of the *Universidad Complutense de Madrid.* Large communities detail.

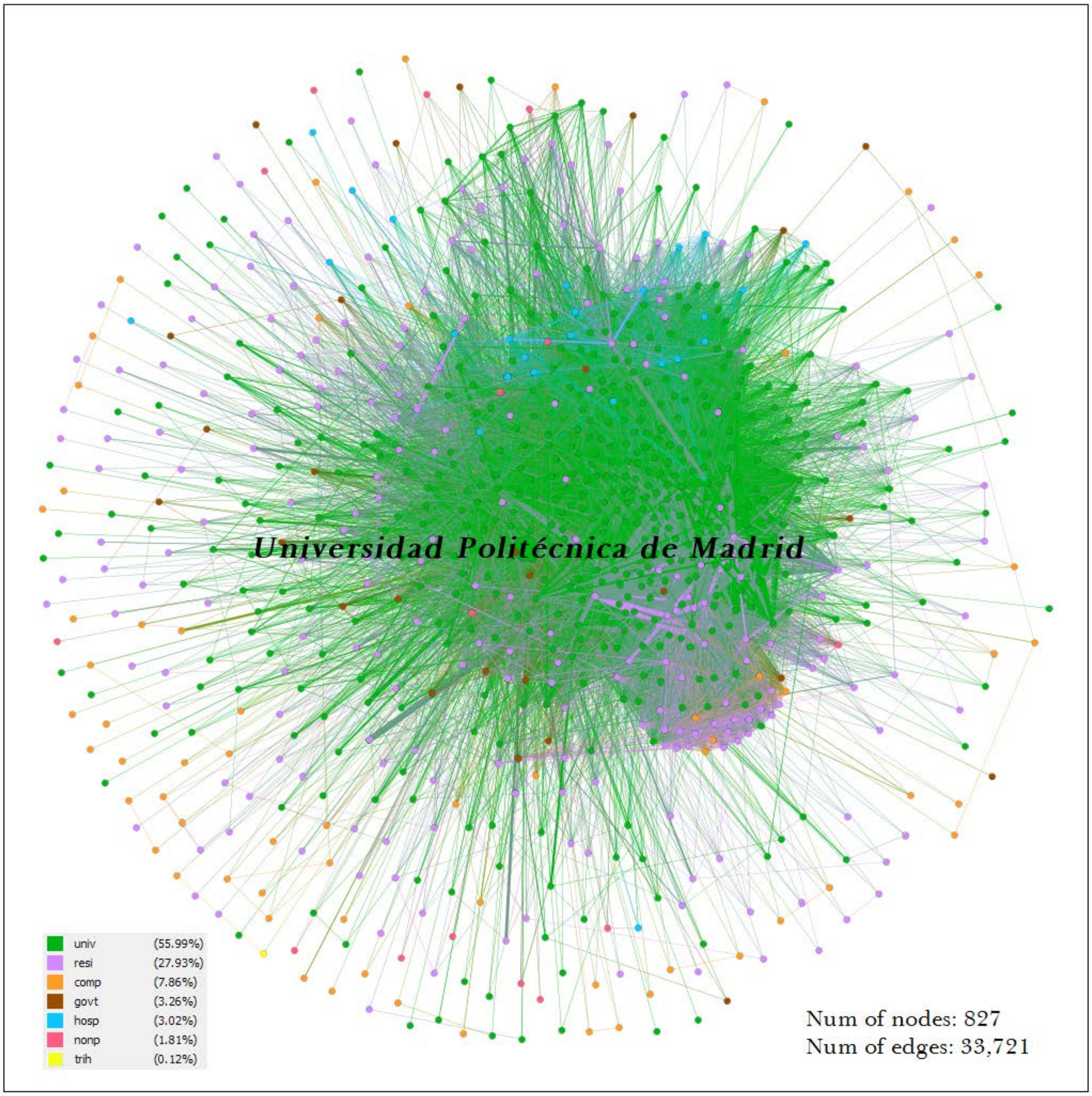


Figure 26. Subgraph generated by the *Universidad Politécnica de Madrid*.

In the subgraph of the *Universidad Politécnica de Madrid* two communities are identifiable. One at the top-right and one at the bottom-right side (Figure 26). The first one is composed mostly of universities with a hospital and a government institution. The second one, is dominated by research institutes and a few companies (Figure 27). Compared to the *Universitat Politècnica de València* it does have, approximately, 200 collaborators less. Nonetheless, the number of connections of the *Universitat Politécnica de Madrid* is larger with over 2500 connections more.

Figure 27. Subgraph generated by the *Universidad Politécnica de Madrid*. Details of communities.

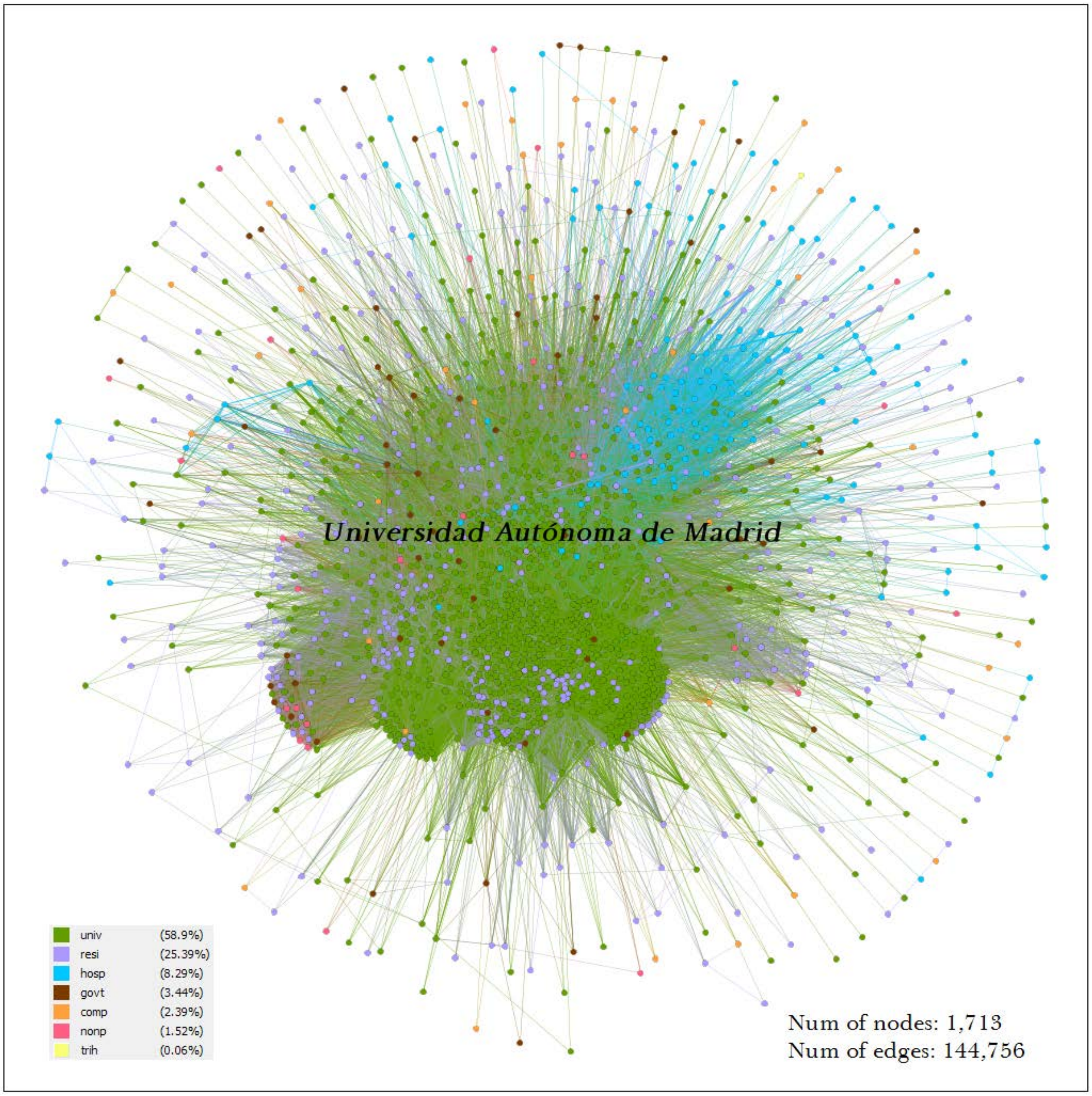


Figure 28. Subgraph generated by the *Universidad Autónoma de Madrid*.

The *Universidad Autónoma de Madrid* has approximately the same number of collaborators as the *Universidad Complutense de Madrid*. However, similarly to the *Universitat de València* its number of connections is more intensive than that of the *Universidad Complutense de Madrid* or that of the *Universitat Pompeu Fabra*. There are two large communities at the low-left side of the graph (Figure 29). Also, on the low-right side of the graph there is a cluster of nodes. The outer side of the cluster does form a community with many of the other nodes in the cluster connected to the community but not to one another (Figure 30).

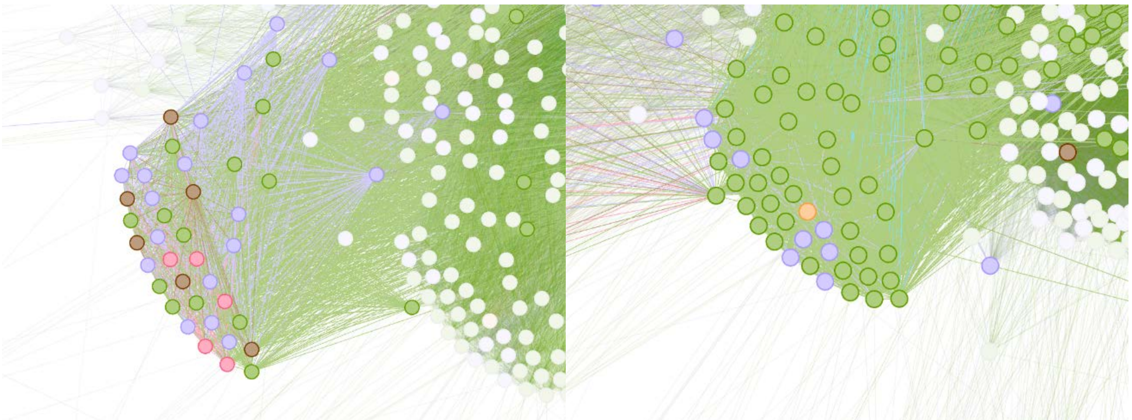


Figure 29. Subgraph generated by the *Universidad Autónoma de Madrid*. Details of communities.

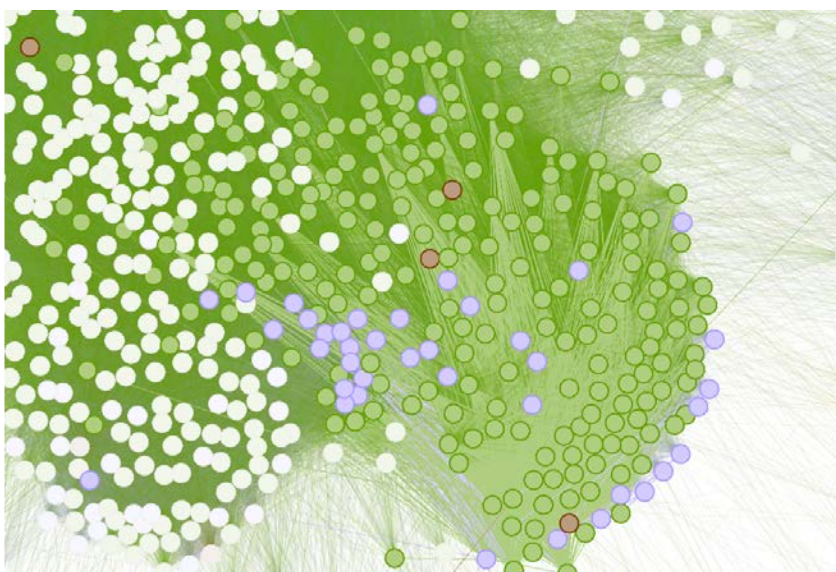


Figure 30. Subgraph generated by the *Universidad Autónoma de Madrid*. Details of the cluster.

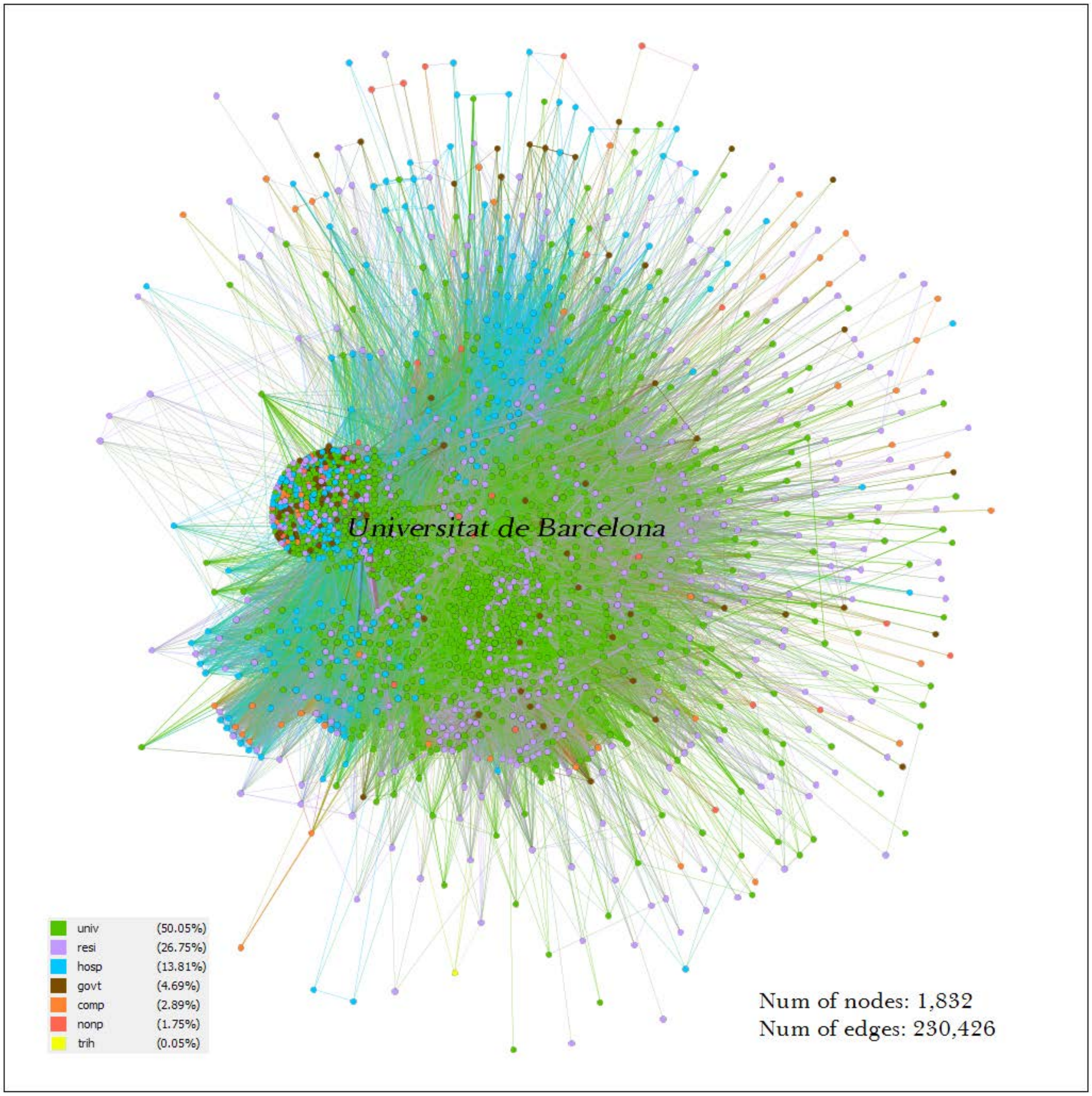


Figure 31. Subgraph generated by the *Universitat de Barcelona*.

The network of the *Universitat de Barcelona* is characterized by a large number of connections compared to its number of collaborators (Figure 31) although the proportion is less extreme than that of the *Universitat de València*. Another aspect that characterizes this network is the large cluster located on the left side. Similarly to the *Universitat de València* (Figure 21) the cluster is divided in two smaller clusters by the connection, or lack of connection, with the Public Health Foundation of India (Figure 32). There are also communities in the lower part of the graph with the presence of hospitals and companies, hospitals and research institutes, or universities and research institutes (Figure 33).

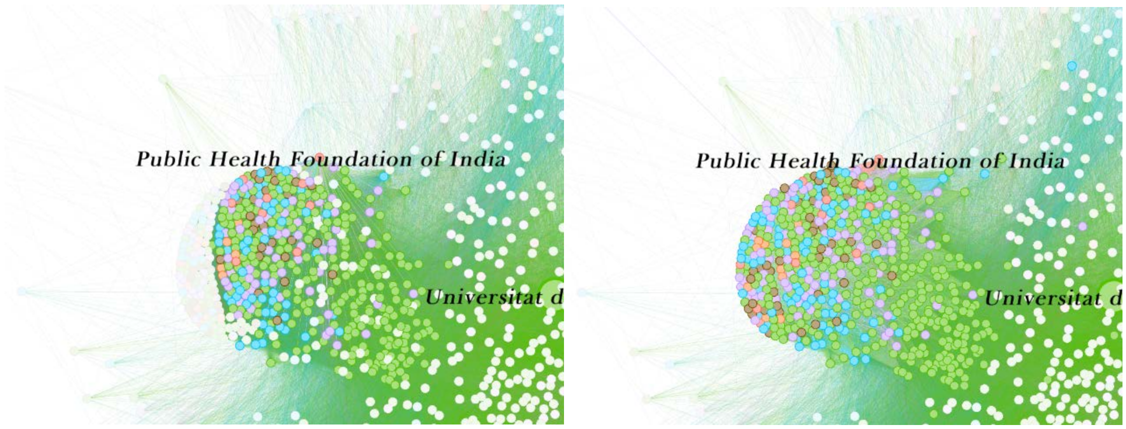


Figure 32. Subgraph of the *Universitat de Barcelona.* Detail of the Public Health Foundation of India.

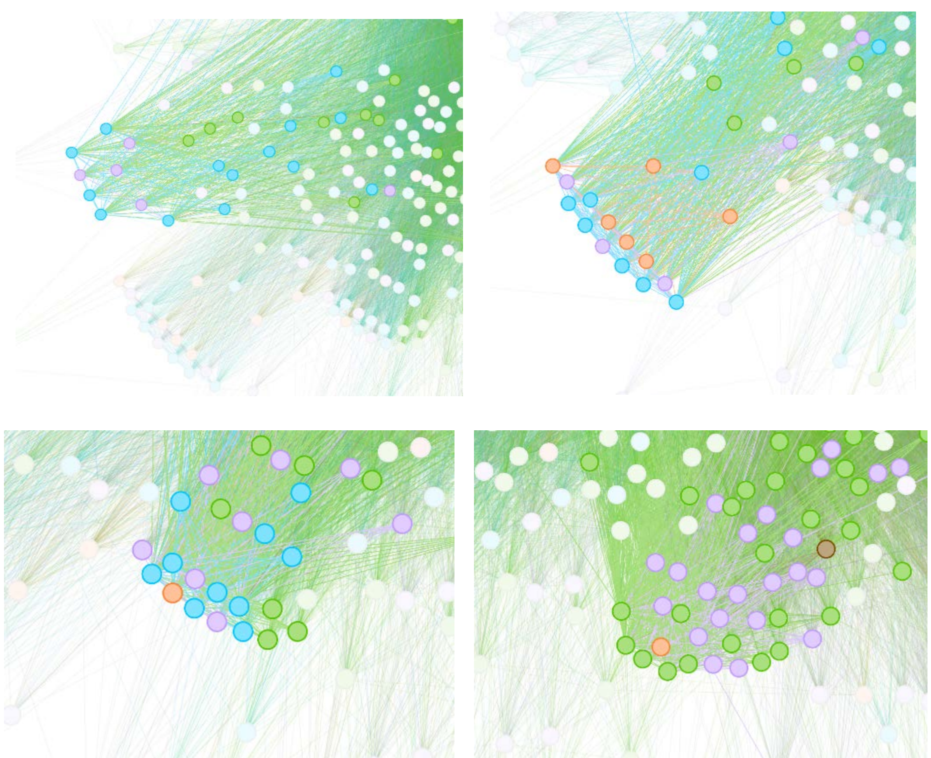


Figure 33. Subgraph of the *Universitat de Barcelona.* Detail of communities.

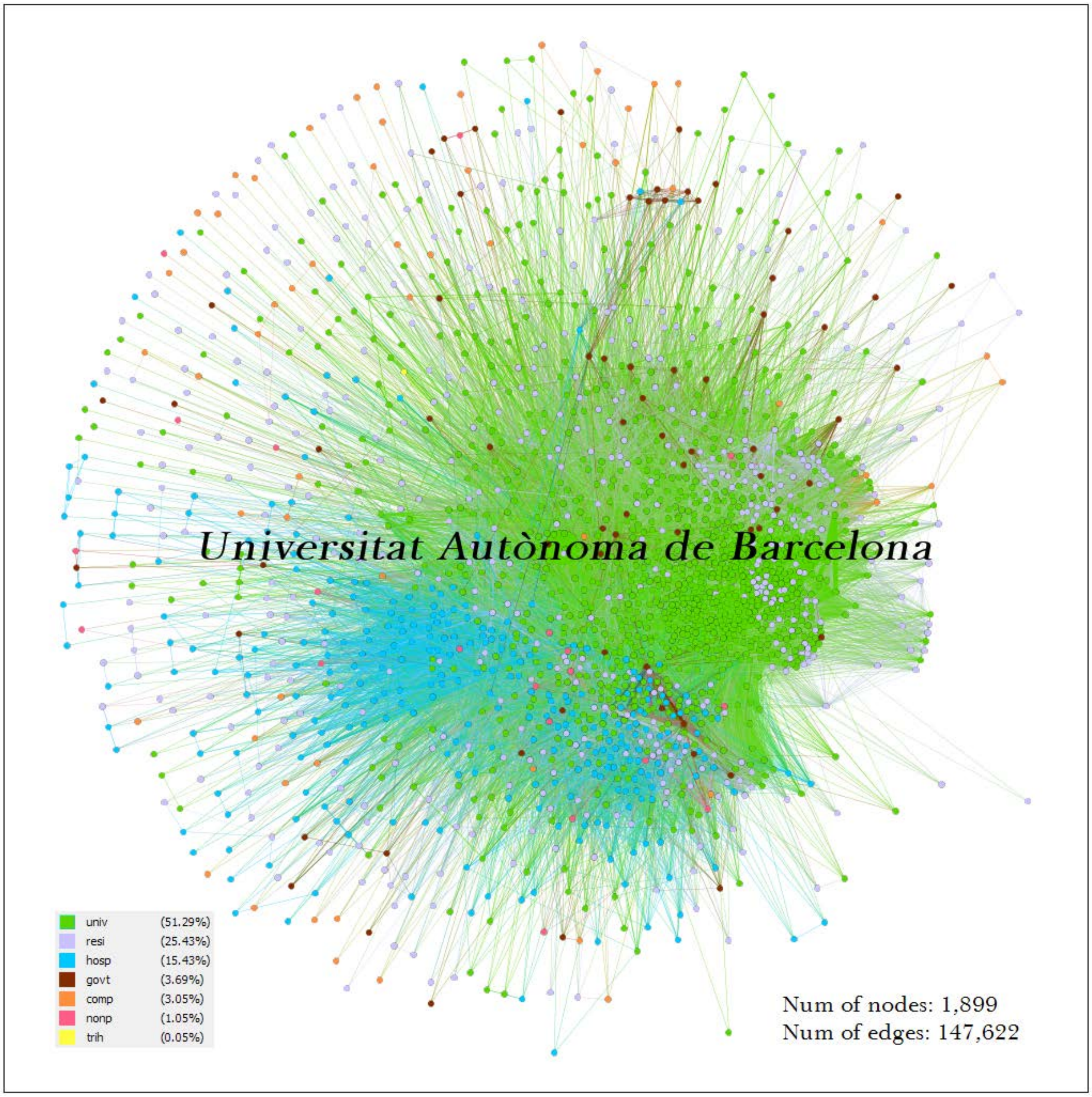


Figure 34. Subgraph generated by the *Universitat Autònoma de Barcelona*.

The *Universitat Autònoma de Barcelona* has the largest number of collaborators among Spanish universities. The nodes of its network are divided in two large clusters of universities and hospitals with only few communities clearly visible (Figures 34-35).

Figure 35. Subgraph of the *Universitat Autònoma de Barcelona.* Detail of communities.

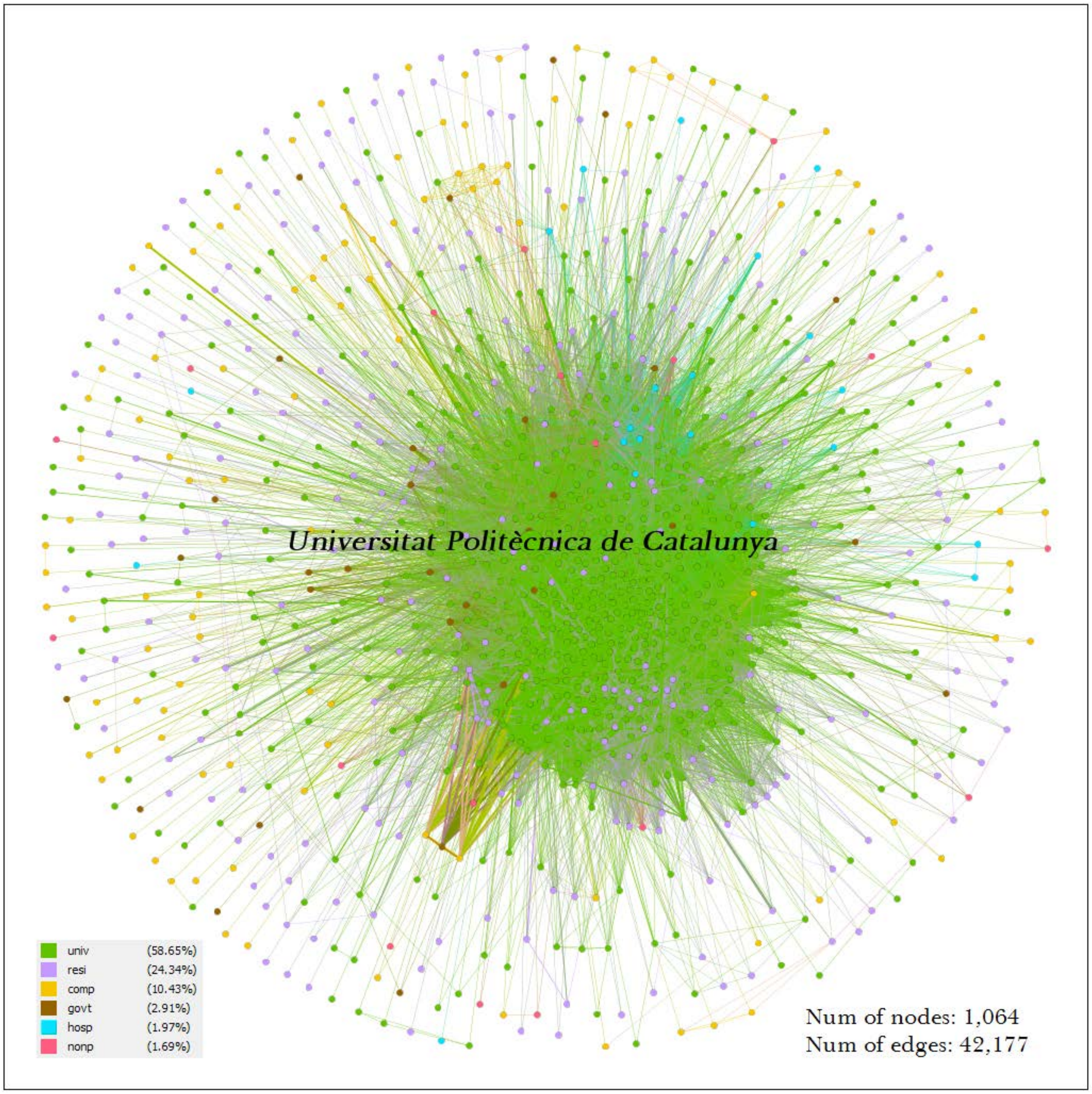


Figure 36. Subgraph of the *Universitat Politècnica de Catalunya.*

The network of the *Universitat Politécnica de Catalunya* has the largest number of collaborators among Spanish polytechnic universities as well as the largest number of connections. The percentage of participation of companies in this network is among the highest in Spain and is the highest among the polytechnic universities. However, few communities are present and those present are relatively small (Figures 36-37).

Figure 37. Subgraph of the *Universitat Politècnica de Catalunya.* Detail of communities.

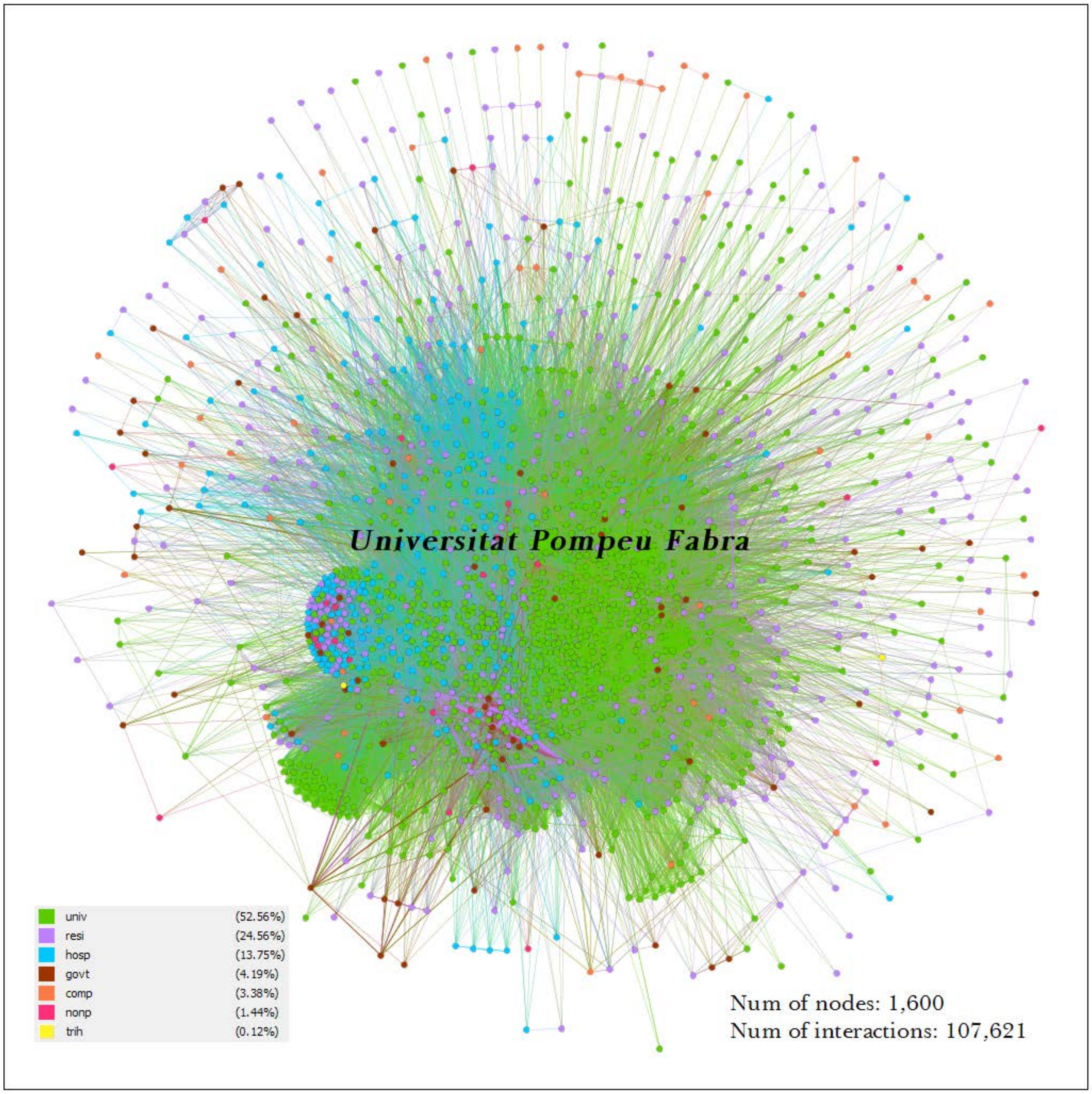


Figure 38. Subgraph of the *Universitat Pompeu Fabra*.

The network of the *Universitat Pompeu Fabra* displays two large communities in its lower-left side (Figure 38). There is a TH agent, MACVIA-LR, which does function as a connection between universities, hospitals, research institutes, non-profit institutions, and some companies (Figure 39). Technically, the MACVIA-LR is a project connected to the European Innovation Partnership on Active and Healthy Ageing and not really an institution. However, it does function as a TH agent promoting the collaboration between different types of institutions. Nonetheless, the Paris Municipal Department of Social Action Childhood is connected to one more community and has a betweenness centrality of 0.000047, which is larger than that of MACVIA-LR with its 0.00002 betweenness centrality (Figures 40-41).

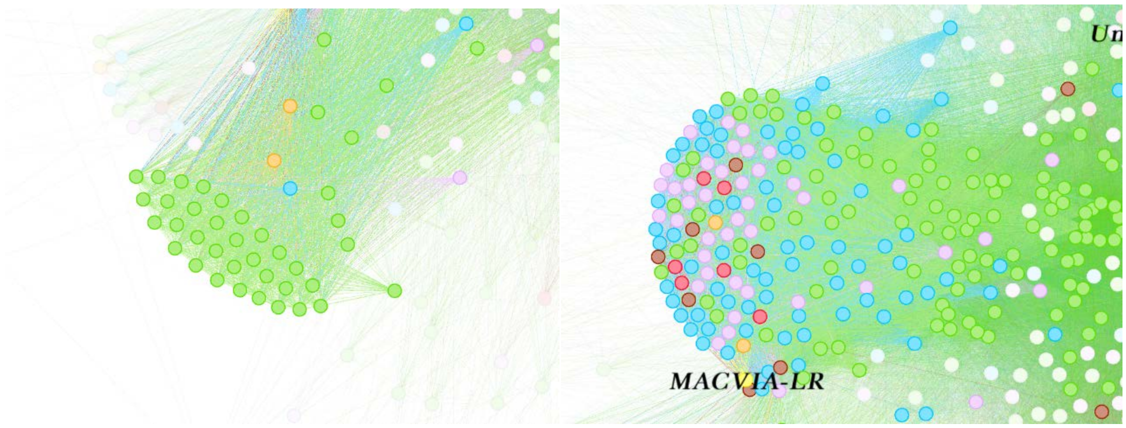


Figure 39. Subgraph of the *Universitat Pompeu Fabra*. Significant communities.

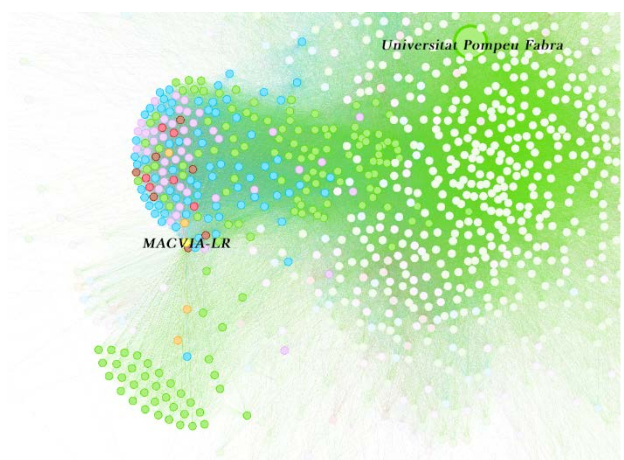


Figure 40. Communities connected to MACVIA-LR.

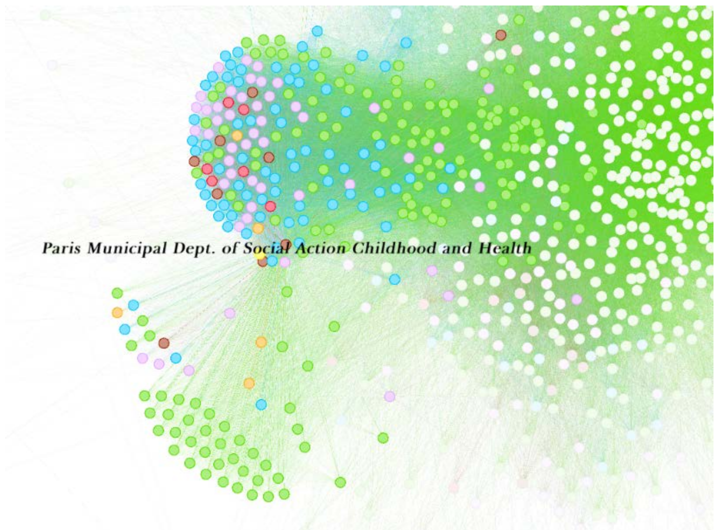


Figure 41. Communities connected to Paris Municipal Department of Social Action Childhood and Health.

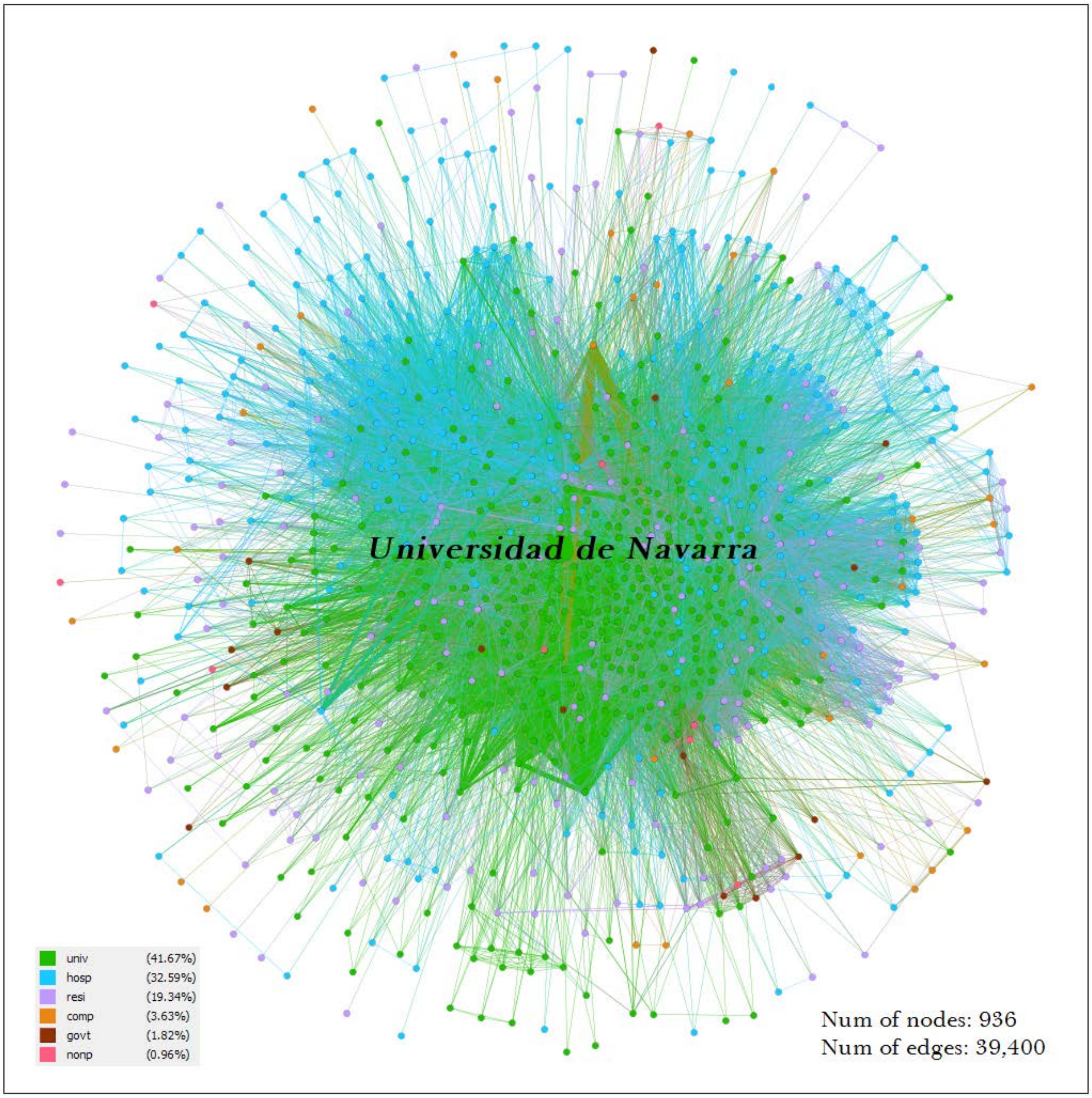


Figure 42. Subgraph of the *Universidad de Navarra.*

In the subnetwork of the *Universidad de Navarra* several communities are easily identifiable in the upper-right corner as well as at the bottom. Those communities in the upper-right corner are highly dominated by health-related institutions with a much lower number of research institutions and companies (Figure 42). The Rabin Medical Center Israel is particularly well connected as it is connected to both communities as well as the *Universidad de Navarra* (Figures 43-44). The communities at the bottom, one is fully composed of universities while the other one is more heterogeneous including a mix of universities, research institutes, non-profit institutions and government institutions (Figure 45). That community is, ideally, closer to the ideal TH interaction although the lack of companies is a drawback.

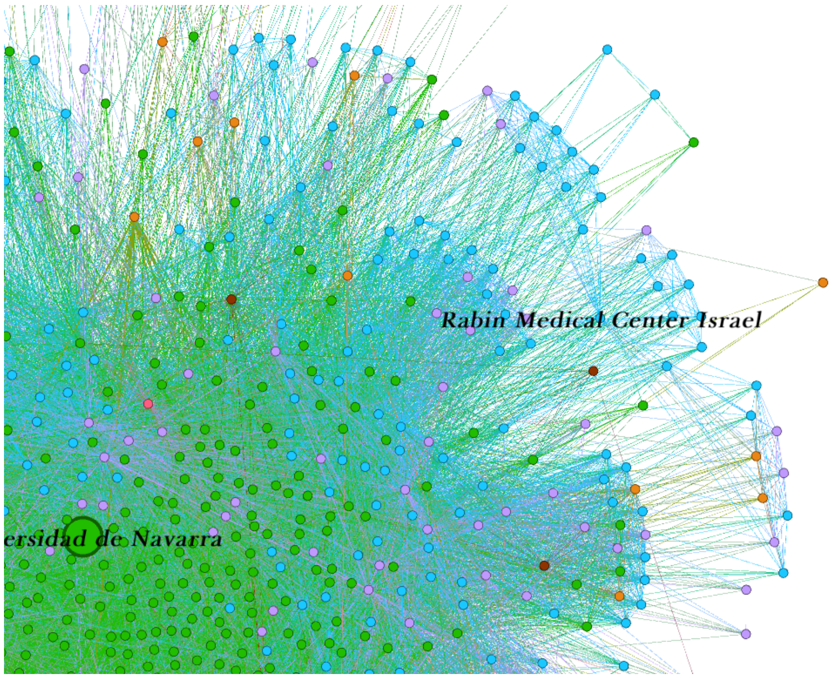


Figure 43. Detail of the subnetwork of the *Universidad de Navarra*.

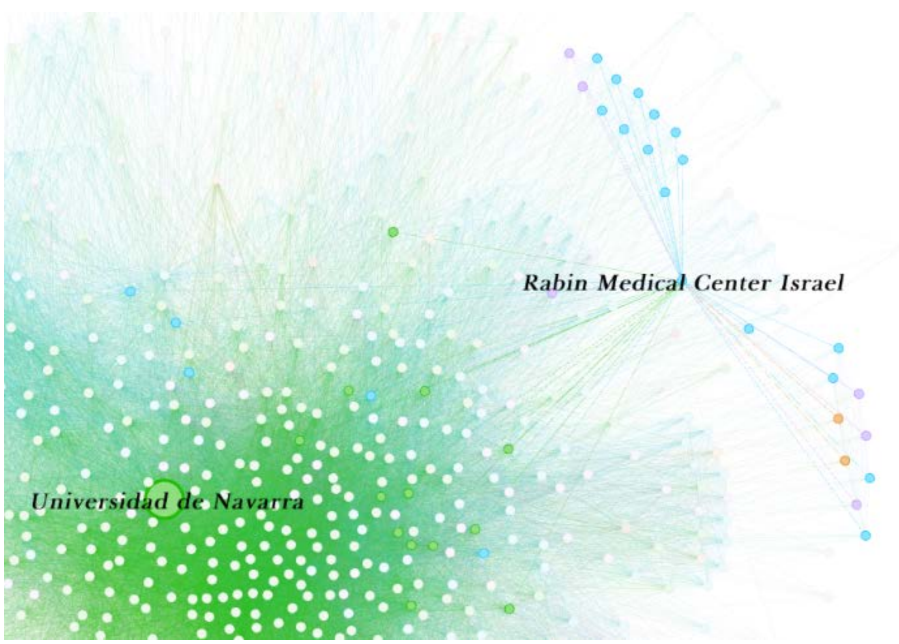


Figure 44. Detail of the subnetwork of the *Universidad de Navarra*.

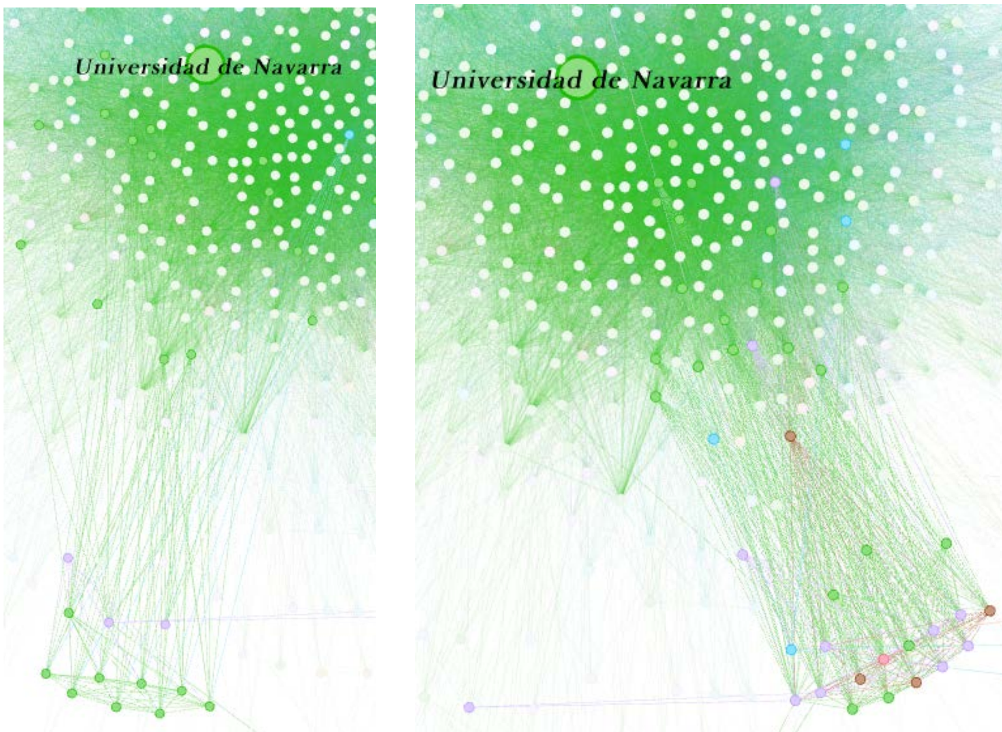


Figure 45. Detail of the subnetwork of the *Unviersidad de Navarra.* Communities.

Table 5 depicts for each university subnetwork the number of nodes and edges, the proportion of edges per node and the percentage of appearance of each type of institution. The variation of number of edges per node is very large with some universities, such as the *Universidad de Cantabria* or the *Universitat de Barcelona*, presenting a large number of edges per node and others such as the *Universidad San Jorge* or the *Universidad Loyola de Andalucía*, presenting less than ten edges per node. This is more clearly visible in table 6 with a big separation between maximum and minimum values. Figure 46 shows the networks are dominated by universities followed by research institutes and hospitals with other types of institutions following at a distance.

University	# Node	# Edges	edge/ node	univ %	resi %	comp %	hosp %	govt %	trih %	nonp %
U. Almería	164	1894	11.55	60.37	28.05	1.22	6.1	3.66	0	0.61
U. Cádiz	305	5336	17.50	64.26	22.3	3.61	6.23	2.62	0	0.98
U. Córdoba	408	8586	21.04	56.62	22.53	1.72	14.46	3.92	0	0.74
U. L. Andalucía	61	499	8.18	67.21	24.59	1.64	3.28	3.28	0	0
U. Granada	1391	108635	78.10	59.96	23.65	2.08	9.2	4.1	0	1.01
U. Huelva	281	7209	25.65	70.46	18.86	1.42	2.85	4.98	0	1.42
U. Jaén	218	3615	16.58	66.51	17.43	2.29	7.8	4.59	0	1.38
U. Málaga	151	2423	16.05	64.9	22.52	1.99	4.64	4.64	0	1.32
U. P. Olavide	224	4048	18.07	69.2	20.54	0.45	5.8	2.23	0	1.79
U. Sevilla	742	34777	46.87	62.13	25.34	2.29	6.06	2.96	0	1.21
U. San Jorge	36	154	4.28	55.56	11.11	0	16.67	16.67	0	0
U. Zaragoza	29	195	6.72	55.17	3.45	0	41.38	0	0	0
U. Oviedo	1069	90565	84.72	64.73	22.73	2.25	6.55	2.99	0.09	0.65
U. P. G. Canaria	408	9613	23.56	63.24	15.44	2.45	11.27	5.88	0.25	1.47
U. la Laguna	1109	67083	60.49	56.54	28.31	1.62	5.77	6.49	0	1.26
U. Cantabria	640	65617	102.53	76.41	13.28	0.94	7.66	0.94	0	0.78
U. C-La Mancha	463	10766	23.25	54.64	22.46	3.46	13.17	4.97	0.86	0.43
U. Cat. Ávila	17	84	4.94	94.12	5.88	0	0	0	0	0
U. Burgos	121	2068	17.09	69.42	18.18	3.31	3.31	4.13	0	1.65
U. León	225	3180	14.13	57.33	18.67	3.11	16.44	4	0	0.44
U. P. Salamanca	15	35	2.33	93.33	0	0	6.67	0	0	0
U. Salamanca	691	27029	39.12	59.33	22	3.62	10.27	4.2	0	0.58
IE University	11	29	2.64	81.82	9.09	0	0	9.09	0	0
U.E.M.Cervante	11	31	2.82	81.82	18.18	0	0	0	0	0
U. Valladolid	339	9309	27.46	68.44	19.47	1.47	7.67	2.26	0	0.59
U. A. Oliba CEU	7	15	2.14	85.71	14.29	0	0	0	0	0
U. A. Barcelona	1899	147622	77.74	51.29	25.43	3.05	15.43	3.69	0.05	1.05
U. Barcelona	1832	230426	125.78	50.05	26.75	2.89	13.81	4.69	0.05	1.75

Table 5. Subnetworks characteristics. Continues next page.

U. I. Catalunya	198	3165	15.98	45.96	17.68	1.01	28.79	3.54	0	3.03
U. O. Catalunya	90	1131	12.57	56.67	28.89	1.11	12.22	0	0	1.11
U. P. Catalunya	1064	42177	39.64	58.65	24.34	10.43	1.97	0	0	1.69
U. P. Fabra	1600	107621	67.26	52.56	24.56	3.38	13.75	4.19	0.12	1.44
U. Ramon Llull	206	6604	32.06	73.3	14.56	2.43	4.37	3.4	0	1.94
U. Vic	147	2618	17.81	55.1	23.13	2.72	13.61	3.4	0	2.04
U. Girona	452	11417	25.26	58.19	25.22	2.88	7.52	4.65	0	1.55
U. Lleida	326	6702	20.56	49.39	34.66	1.84	10.12	3.37	0	0.61
U. R. i Virgili	830	28173	33.94	57.57	28.07	4.1	4.94	3.73	0.12	1.45
U. Alcalá	724	30766	42.49	59.25	23.07	2.35	10.36	3.31	0.14	1.52
U. A.X El Sabio	18	66	3.67	50	22.22	5.56	22.22	0	0	0
U. A. Nebrija	33	203	6.15	93.94	3.03	3.03	0	0	0	0
U. A. Madrid	1713	144756	84.50	58.9	25.39	2.39	8.29	3.44	0.06	1.52
U. C. José Cela	50	412	8.24	50	20	0	30	0	0	0
U. Carlos III	654	31581	48.29	64.68	22.78	4.43	3.82	3.06	0	1.22
U. CEU S. Pablo	20	121	6.05	50	40	0	0	10	0	0
U. C Madrid	1730	107829	62.33	54.34	27.75	3.41	8.79	4.05	0	1.68
U. E. Madrid	81	1304	16.10	49.38	18.52	0	27.16	2.47	0	2.47
U. Fr. Vitoria	28	162	5.79	67.86	28.57	0	3.57	0	0	0
U. P. Madrid	827	33721	40.78	55.99	27.93	7.86	3.02	3.26	0.12	1.81
U. P. Comillas	17	67	3.94	70.59	23.53	5.88	0	0	0	0
U.R. Juan Carlos	547	12.917	0.02	57.95	24.13	2.38	9.69	4.02	0.18	1.65
U. Navarra	936	39400	42.09	41.67	19.34	3.63	32.59	1.82	0	0.96
U. P. Navarra	250	3902	15.61	65.2	25.6	2.8	3.2	2.8	0	0.4
U. Alacant	522	17800	34.10	56.7	19.75	2.54	16.12	3.26	0	1.63
U. M. H. Elche	329	7714	23.45	47.72	17.02	1.52	27.05	6.08	0	0.61
U. Jaume I	31	153	4.94	48.39	25.81	6.45	3.23	12.9	3.23	0
U Cat. Val. SVM	46	207	4.50	54.35	13.04	4.35	23.91	4.35	0	0
U. C. H. CEU	91	827	9.09	49.45	16.48	3.3	21.98	7.69	0	1.1
U. P. València	1024	31220	30.49	58.59	24.61	8.3	4.39	3.12	0.29	0.68
U. València	1461	239245	163.75	56.74	20.94	1.71	13.76	5.13	0.07	1.64

Table 5. Subnetworks characteristics. Continues next page.

U. Extremadura	842	148211	176.02	55.46	19.71	2.02	12.95	8.19	0	1.66
U. Coruña	415	13166	31.73	62.41	13.25	3.61	18.8	1.45	0	0.48
U.S. Compostela	806	48014	59.57	64.14	22.08	2.23	7.94	2.85	0.12	0.62
U. Vigo	342	6782	19.83	61.7	28.07	3.22	3.51	2.34	0.29	0.88
U. Illes Balears	420	17335	41.27	69.05	20.48	2.38	2.62	4.76	0	0.71
U. I. La Rioja	42	301	7.17	95.24	2.38	0	2.38	0	0	0
U. La Rioja	117	1624	13.88	70.94	17.09	2.56	3.42	5.13	0	0.85
U. Deusto	88	882	10.02	46.59	35.23	3.41	10.23	2.27	0	2.27
Euskal Herriko U	506	19913	39.35	63.83	23.52	1.19	8.5	2.37	0	0.59
Mondragon U	22	39	1.77	54.55	13.64	27.27	0	4.55	0	0
U.C.S. A. Murcia	17	89	5.24	100	0	0	0	0	0	0
U. Murcia	688	28377	41.25	61.92	24.51	2.33	7.56	5.38	0.15	1.16
U. P.Cartagena	209	3060	14.64	63.64	24.88	7.66	0.96	1.91	0	0.96
UNED	318	10.77	0.03	68.87	18.24	3.77	4.72	3.46	0	0.94

Table 5. Subnetworks characteristics.

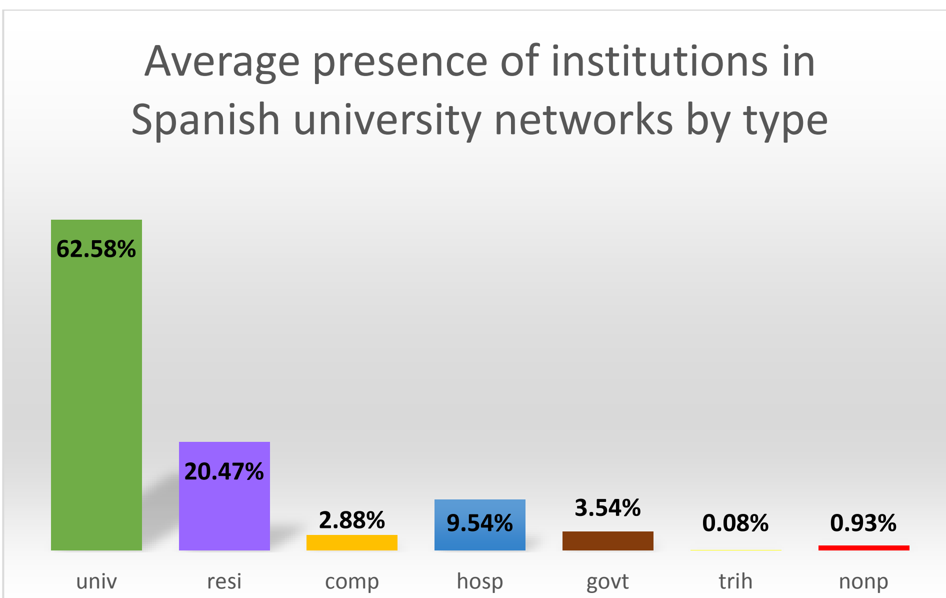


Figure 46. Average presence of institutions in Spanish university networks by type.

	Average	***Maximum***	***Minimum***
# Nodes	462.25	1899.00	7.00
# Edges	27804.43	239245.00	10.77
edges/node	31.02	176.02	0.02
univ	62.58%	100.00%	41.67%
resi	20.47%	40.00%	0.00%
comp	2.88%	27.27%	0.00%
hosp	9.54%	41.38%	0.00%
govt	3.54%	16.67%	0.00%
trih	0.08%	3.03%	0.00%
nonp	0.93%	3.03%	0.00%

Table 6. Subnetworks summary.

6.3. CENTRALITIES

The centralities for each Spanish university have been computed. The degree centrality represents the relationship intensity of a university, with high values denoting a high number of connections relative to the potential of the total number of connections. The betweenness centrality denotes innovation influence, with higher values denoting more influence. The eigenvector centrality denotes the relationship intensity of a university's connections with important institutions, with higher values representing more relative connections. Table 7 presents the three centralities for each Spanish university.

Figures 47 to 49 depict the distributions of the degree centrality, the betweenness centrality and the eigenvector centrality for the Spanish universities. These distributions show a picture similar to the collaborations distribution (Figure 10) with a large number of institutions with very low centralities and a few institutions with high centralities.

Region	University	Deg. Cent.	Bet. Cent.	Eigen Cent.
Andalucía	U. de Almería	0.015834	0.003411	0.002282
	U. de Cádiz	0.029532	0.00809	0.003984
	U. de Córdoba	0.039538	0.009932	0.005746
	U. Loyola de Andalucía	0.005829	0.000338	0.001169
	U. de Granada	0.13503	0.038719	0.024161
	U. de Huelva	0.0272	0.004364	0.004654
	U. de Jaén	0.02108	0.005302	0.00337
	U. de Málaga	0.014572	0.001226	0.002275
	U. Pablo de Olavide	0.021663	0.004316	0.003963
	U. de Sevilla	0.071984	0.012826	0.01261
Aragón	U. San Jorge	0.0034	0.000453	0.00045
	U. de Zaragoza	0.00272	0.000312	0.000489
Asturias	U. de Oviedo	0.10375	0.021534	0.020808
Canarias	U. de las Palmas de Gran Canaria	0.039538	0.010651	0.00633
	U. de la Laguna	0.107636	0.026384	0.016892
Cantabria	U. de Cantabria	0.062075	0.001655	0.017104
C.-La Mancha	U. Castilla-La Mancha	0.044881	0.018763	0.006916
C. y León	U. Católica de Ávila	0.0015543	0.000023	0.000396
	U. de Burgos	0.011657	0.00153	0.002643
	U. de León	0.02176	0.005453	0.002961
	U. Pontificia de Salamanca	0.00136	0.000018	0.0095
	U. de Salamanca	0.067029	0.018908	0.010313
	IE University	0.000971	0.000202	0.000293
	U. Europea Miguel de Cervantes	0.000971	0.000002	0.00011
	U. de Valladolid	0.032835	0.004861	0.00649
Cataluña	U. Abat Oliba CEU	0.000583	0.000194	0.000222
	U. Autònoma de Barcelona	0.184379	0.053507	0.029426
	U. de Barcelona	0.177871	0.030373	0.051159
	U. Internacional de Catalunya	0.019137	0.003922	0.003338
	U. Oberta de Catalunya	0.008646	0.000418	0.001771
	U. Politècnica de Catalunya	0.103264	0.051844	0.01524
	U. Pompeu Fabra	0.155333	0.038364	0.024987
	U. Ramon Llull	0.019915	0.003124	0.005409
	U. de Vic	0.014183	0.000923	0.003404
	U. de Girona	0.043812	0.013792	0.007778
	U. de Lleida	0.031572	0.00688	0.005169
	U. Rovira i Virgili	0.080532	0.02894	0.012565
C. Madrid	U. de Alcalá	0.070235	0.015681	0.010821
	U. Alfonso X El Sabio	0.001651	0.000025	0.00026
	U. Antonio de Nebrija	0.003109	0.0001	0.000611
	U. Autónoma de Madrid	0.166311	0.04583	0.027552
	U. Camilo José Cela	0.00476	0.000526	0.000789
	U. Carlos III de Madrid	0.063435	0.013874	0.01177
	U. CEU San Pablo	0.001846	0.00001	0.00039
	U. Complutense de Madrid	0.167962	0.047994	0.023421

Table 7. 2015 Centralities for Spanish Universities. Continues next page.

Region	University	Deg. Cent.	Bet. Cent.	Eigen Cent.
	U. Europea de Madrid	0.007772	0.000247	0.001438
	U. Francisco de Vitoria	0.002623	0.000016	0.000445
	U. Politécnica de Madrid	0.080241	0.026436	0.012767
	U. Pontificia de Comillas	0.001554	0.000034	0.000164
	U. Rey Juan Carlos	0.053041	0.016845	0.007231
C. F. Navarra	U. de Navarra	0.09083	0.021829	0.013497
	U. Pública de Navarra	0.024189	0.007003	0.003725
C. Valenciana	U. d'Alacant	0.053526	0.015138	0.008011
	U. Miguel Hernández de Elche	0.031863	0.006523	0.004216
	U. Jaume I	0.002914	0.000443	0.000566
	U. Católica de Valencia S. Vicente Mártir	0.004371	0.000954	0.000609
	U. Cardenal Herrera CEU	0.008743	0.001878	0.00134
	U. Politècnica de València	0.099378	0.053078	0.012617
	U. de València	0.141927	0.013252	0.051565
Extremadura	U. de Extremadura	0.081698	0.013255	0.041801
Galicia	U. da Coruña	0.040218	0.009372	0.006979
	U. de Santiago de Compostela	0.078201	0.015239	0.015064
	U. de Vigo	0.033126	0.01044	0.004998
Illes Balears	U. de les Illes Balears	0.040703	0.008912	0.007896
La Rioja	U. Internacional de La Rioja	0.003983	0.000399	0.000893
	U. de La Rioja	0.011269	0.001882	0.002215
País Vasco	U. de Deusto	0.008452	0.001613	0.001381
	Euskal Herriko Unibertsitatea	0.049252	0.008203	0.009595
	Mondragon Unibersitatea	0.00204	0.001304	0.000076
R. Murcia	U. Católica San Antonio de Murcia	0.001554	0.000004	0.000421
	U. de Murcia	0.066738	0.01814	0.011374
	U. Politécnica de Cartagena	0.020206	0.007001	0.003357
Nacional	U. Nacional de Educación a Distancia	0.030795	0.005374	0.005558

Table 7. 2015 Centralities for Spanish Universities.

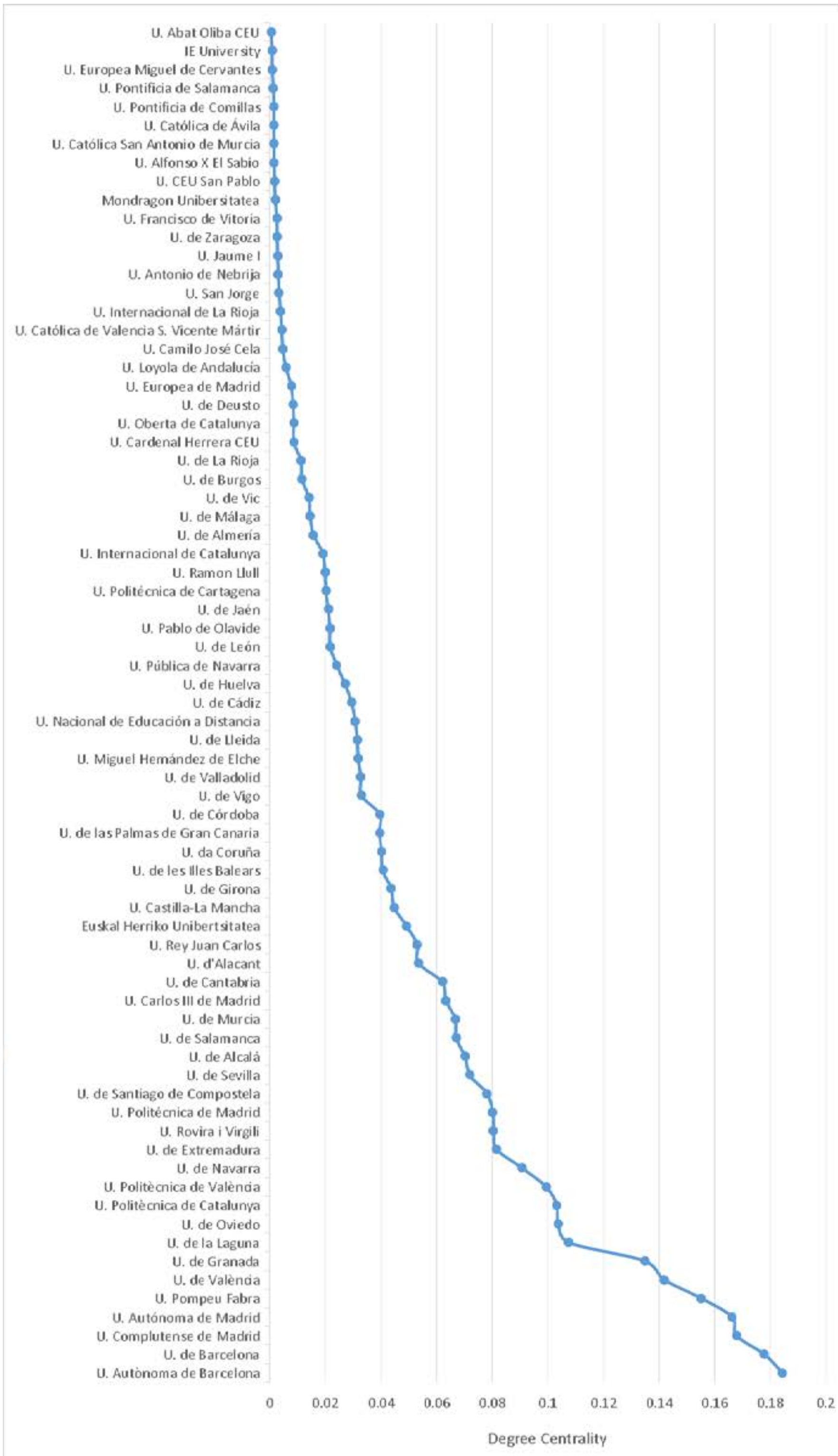


Figure 47. Degree Centrality Distribution of Spanish Universities.

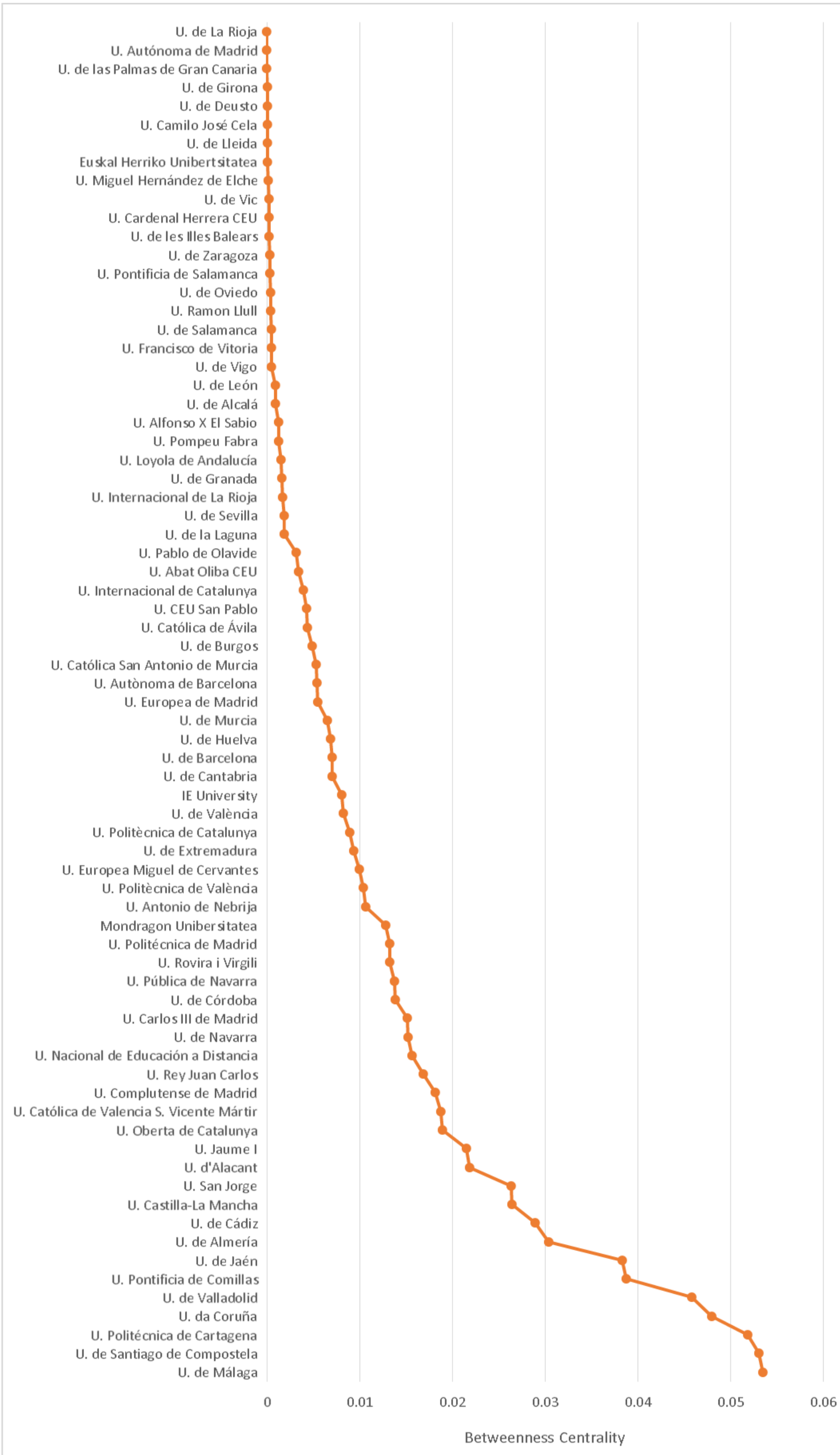


Figure 48. Betweenness Centrality Distribution of Spanish Universities.

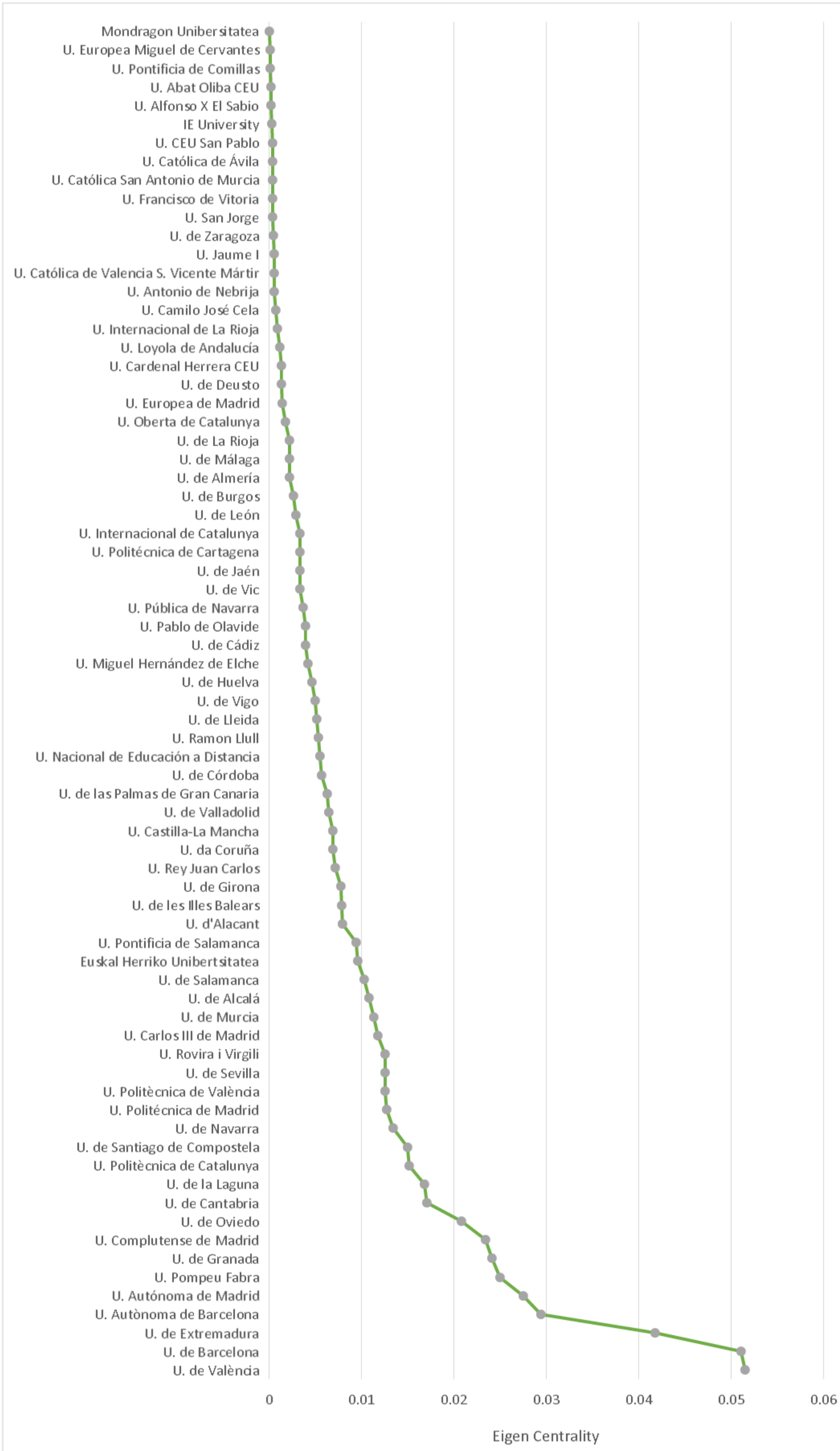


Figure 49. Eigen Centrality Distribution of Spanish Universities.

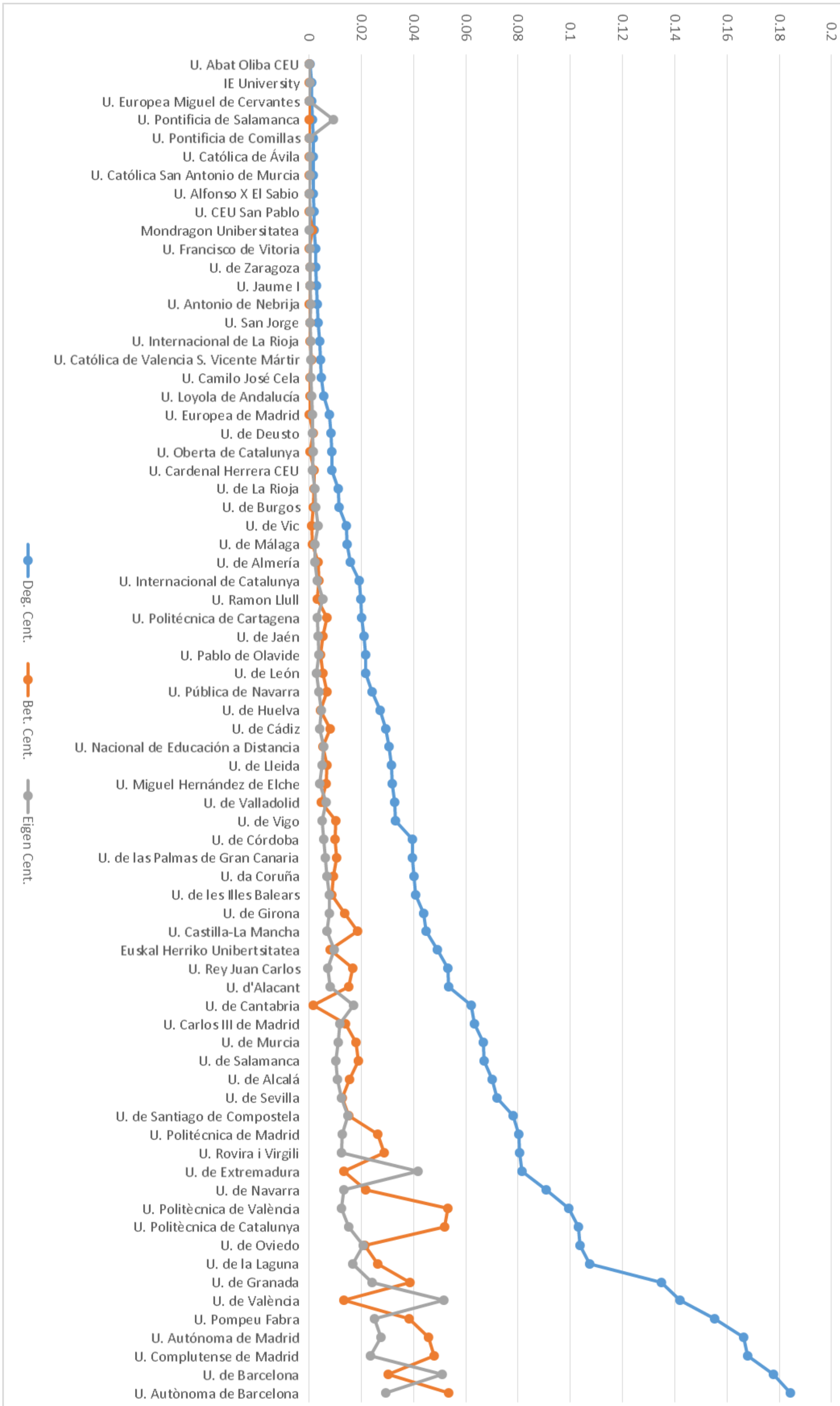


Figure 50. Centralities Distributions of Spanish Universities.

Figure 50 shows all three centralities together ordered by the degree centrality. There are a few peaks worthy of note. For instance, the *Universidad Pontificia de Salamanca* has a high eigenvector centrality compared to its degree and betweenness centralities. The *Universitat de Barcelona*, the *Universitat de València*, the *Universidad de Extremadura*, and the *Universidad de Cantabria* have their betweenness and eigenvector centralities forming peaks in opposite directions. These universities have a much higher eigenvector centrality than betweenness centrality, which depicts that they are well connected to important institutions but their influence does not correspond with such connections. The opposite situation is true for another set of universities that includes among others the *Universitat Autònoma de Barcelona*, *The Universidad Complutense de Madrid*, the *Universidad Autónoma de Madrid*, the *Universitat Pompeu Fabra*, the *Universitat Politècnica de València*, the *Universitat Politècnica de Catalunya,* and the *Universidad Plitécnica de Madrid*. This second group of universities are very influential in the Spanish innovation network but are not necessarily connected to important institutions.

6.4. RANKINGS VERSUS CENTRALITIES

Tables 8 to 10 show the ranking of Spanish universities at national level according to the most popular international rankings: the Times Higher Education ranking, the QS ranking and the AWRU ranking (also known as Shanghai ranking).
Table 11 compares the three aforementioned rakings with the ranking that would result of using the degree centrality as the only measure. Table 12 does the same as table 11 but using the betweenness centrality and table 13 as well but with the eigenvector centrality.

TWUR	***University***
1	U. Pompeu Fabra
2	U. Barcelona
3	U. Autònma Barcelona
4	U. Autónoma Madrid
5	U. Valencia
6	U. Navarra

Table 8. 2015 Times World University Ranking for Spanish Universities.

QS Rank	University
1	U. Barcelona
2	U. Autónoma Madrid
3	U. Autònoma Barcelona
4	U. Complutense de Madrid
5	U. Navarra
6	U. Pompeu Fabra
7	U. Polit. Catalunya
8	U Carlos III Madrid
9	U. Polit. València
10	U. Polit. Madrid
11	U. Granada
12	U. Zaragoza
13	U. Sevilla
14	U. València
15	U. Salamanca
16	U. Santiago Compostela
17	U. Alcalá
18	U. Murcia

Table 9. 2015 QS sRanking for Spanish Universities.

AWRU Rank	University
1	U. Barcelona
2 to 5	U. Autònoma Barcelona
2 to 5	U. Autònoma Madrid
2 to 5	U. Complutense Madrid
2 to 5	U. Pompeu Fabra
6 to 8	U. Polit. València
6 to 8	U. Granada
6 to 8	U. València
9 to 13	U. Polit. Catalunya
9 to 13	U. Santiago Compostela
9 to 13	U. Sevilla
9 to 13	U. País Vasco
9 to 13	U. Zaragoza

Table 10. 2015 AWRU Ranking for Spanish Universities.

Rank	University	Degree Centrality	TWRU Rank	QS Rank	AWRU Rank
1	U. Autònoma de Barcelona	0.184379	3	3	2 to 5
2	U. de Barcelona	0.177871	2	1	1
3	U. Complutense de Madrid	0.167962	-	4	2 to 5
4	U. Autónoma de Madrid	0.166311	4	2	2 to 5
5	U. Pompeu Fabra	0.155333	1	6	2 to 5
6	U. de València	0.141927	5	14	6 to 8
7	U. de Granada	0.13503	6	11	6 to 8
8	U. Politècnica de Catalunya	0.103264	-	7	9 to 13
9	U. Politècnica de València	0.099378	-	9	6 to 8
10	U. de Navarra	0.09083	-	5	-
11	U. Politécnica de Madrid	0.080241	-	10	-
12	U. de Santiago de Compostela	0.078201	-	16	9 to 13
13	U. de Sevilla	0.071984	-	13	9 to 13
14	U. de Alcalá	0.070235	-	17	-
15	U. de Salamanca	0.067029	-	15	-
16	U. de Murcia	0.066738	-	18	-
17	U. Carlos III de Madrid	0.063435	-	8	-
18	U. de Zaragoza	0.00272	-	12	9 to 13

Table 11. 2015 University Ranking comparison according to the degree centrality.

Rank	University	Betweenness Centrality	TWRU Rank	QS Rank	AWRU Rank
1	U. Autònoma de Barcelona	0.053507	3	3	2 to 5
2	U. Politècnica de València	0.053078	-	9	6 to 8
3	U. Politècnica de Catalunya	0.051844	-	7	9 to 13
4	U. Complutense de Madrid	0.047994	-	4	2 to 5
5	U. Autónoma de Madrid	0.04583	4	2	2 to 5
6	U. de Granada	0.038719	6	11	6 to 8
7	U. Pompeu Fabra	0.038364	1	6	2 to 5
8	U. de Barcelona	0.030373	2	1	1
9	U. Politécnica de Madrid	0.026436	-	10	-
10	U. de Navarra	0.021829	-	5	-
11	U. de Salamanca	0.018908	-	15	-
12	U. de Murcia	0.01814	-	18	-
13	U. de Alcalá	0.015681	-	17	-
14	U. de Santiago de Compostela	0.015239	-	16	9 to 13
15	U. Carlos III de Madrid	0.013874		8	-
16	U. de València	0.013252	5	14	6 to 8
17	U. de Sevilla	0.012826	-	13	9 to 13
18	U. de Zaragoza	0.000312	-	12	9 to 13

Table 12. 2015 University Ranking comparison according to the betweenness centrality.

Rank	University	Eigen Centrality	TWRU Rank	QS Rank	AWRU Rank
1	U. de València	0.051565	5	14	6 to 8
2	U. de Barcelona	0.051159	2	1	1
3	U. Autònoma de Barcelona	0.029426	3	3	2 to 5
4	U. Autónoma de Madrid	0.027552	4	2	2 to 5
5	U. Pompeu Fabra	0.024987	1	6	2 to 5
6	U. de Granada	0.024161	6	11	6 to 8
7	U. Complutense de Madrid	0.023421	-	4	2 to 5
8	U. Politècnica de Catalunya	0.01524	-	7	9 to 13
9	U. de Santiago de Compostela	0.015064	-	16	9 to 13
10	U. de Navarra	0.013497	-	5	-
11	U. Politécnica de Madrid	0.012767	-	10	-
12	U. Politècnica de València	0.012617	-	9	6 to 8
13	U. de Sevilla	0.012609	-	13	9 to 13
14	U. Carlos III de Madrid	0.01177	-	8	-
15	U. de Murcia	0.011374	-	18	-
16	U. de Salamanca	0.010313	-	15	-
17	U. de Alcalá	0.010821	-	17	-
18	U. de Zaragoza	0.000489	-	12	9 to 13

Table 13. 2015 University Ranking comparison according to the degree centrality.

In table 11 the top universities slightly switch their positions but they remain approximately in the same position. In table 12 there is a significant change of position, for instance, the *Universitat Politècnica de València* and the *Universitat Politècnica de Catalunya* jump from ranks 9 and 7 to ranks 2 and 3 respectively. The *Universidad de Granada* also improves its position by 5 ranks. However, the *Universitat Autònoma de Barcelona* does remain in the top ranks. In table 13 the *Universitat Autònoma de Barcelona* also keeps its rank while other universities change their ranks. In this case, it is the *Universitat de València* the one that improves its position the most jumping from a rank below 5 to the top rank.

6.5. PROVINCES CENTRALITIES

Figures 51 to 56 depict, through maps, the 2015 spatial distribution by Spanish provinces of the innovation relationship intensity, the innovation influence, and the innovation relationship intensity with important institutions. The values per province are shown in table 14. As mentioned above, the centralities have distributions characterized by a long flat tale and a steep value increase. Therefore, the distribution is represented considering both sides of the curve separately: on one side, the low end (flat tale), and on the other side the high end (steep increase).

The lower end of the innovation relationship intensity distribution (Figure 51) has its highs in the northern area of Spain although it is distributed along the northern and Mediterranean coasts. This spatial distribution is more accentuated in the higher end of the curve with the interior provinces of the country such as Cuenca, Teruel, Soria or Zamora having nearly no influence (Figure 52). It is also significant that the more intensive provinces swift slightly from Cantabria and Vizcaya in the northern coast to Granada and Málaga in the southern Mediterranean coast. The influence of provinces of Barcelona and its surroundings, Madrid, the Balearic Islands and the Canary Islands remain virtually the same in both the low and the high ends of the curve.

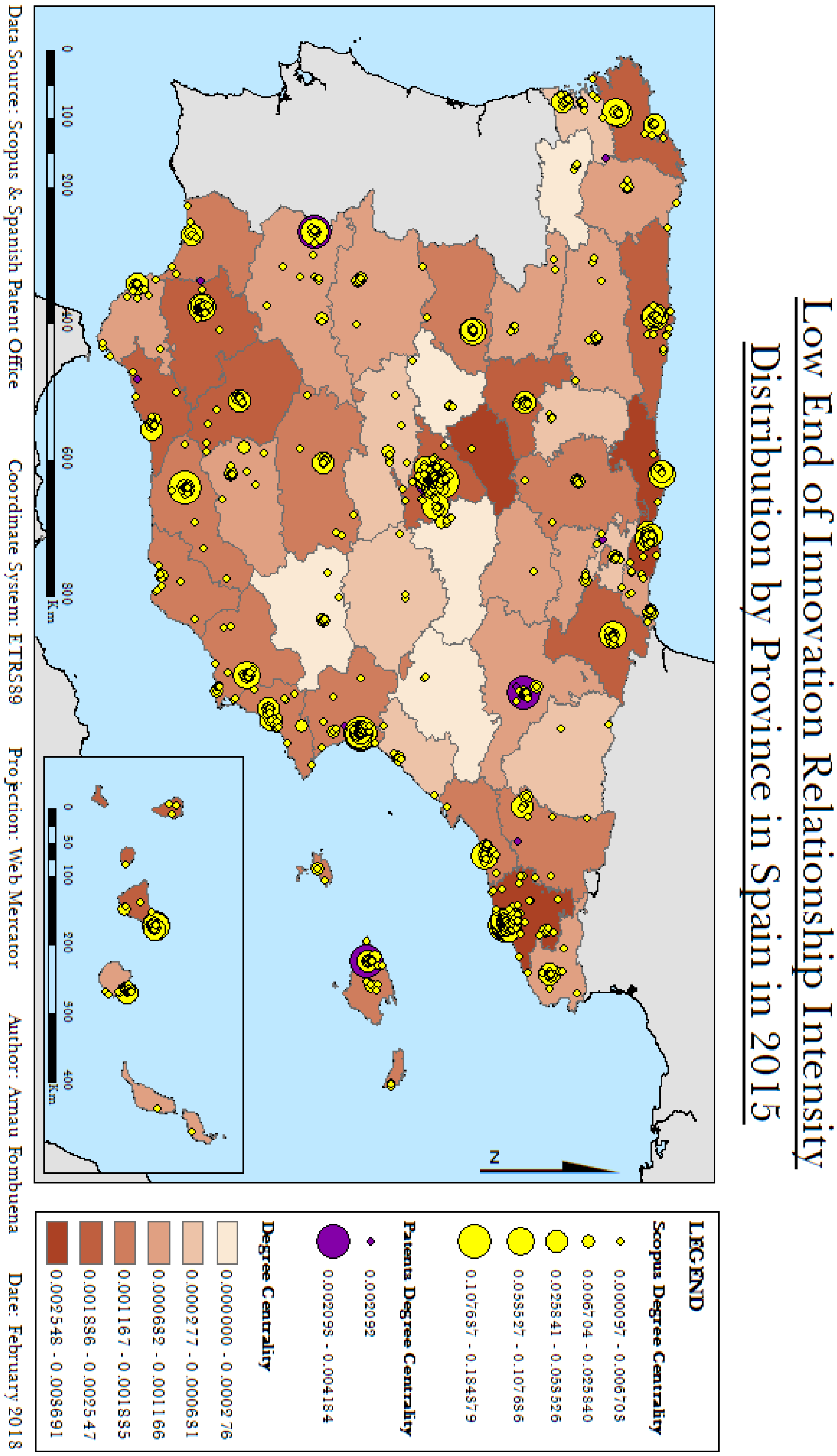


Figure 51. Low end of innovation relationship intensity distribution by province in Spain in 2015.

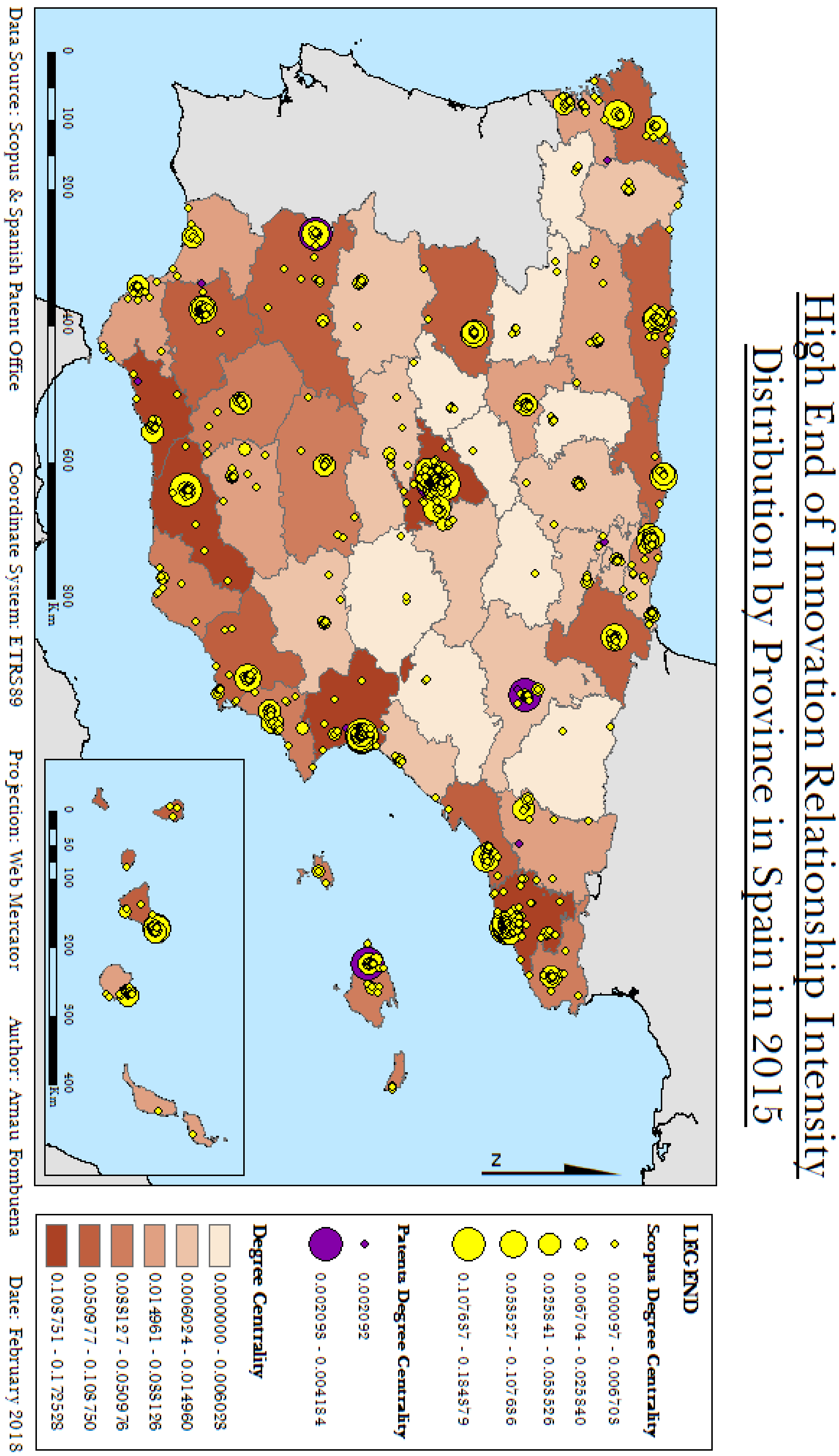


Figure 52. High end of innovation relationship intensity distribution by province in Spain in 2015.

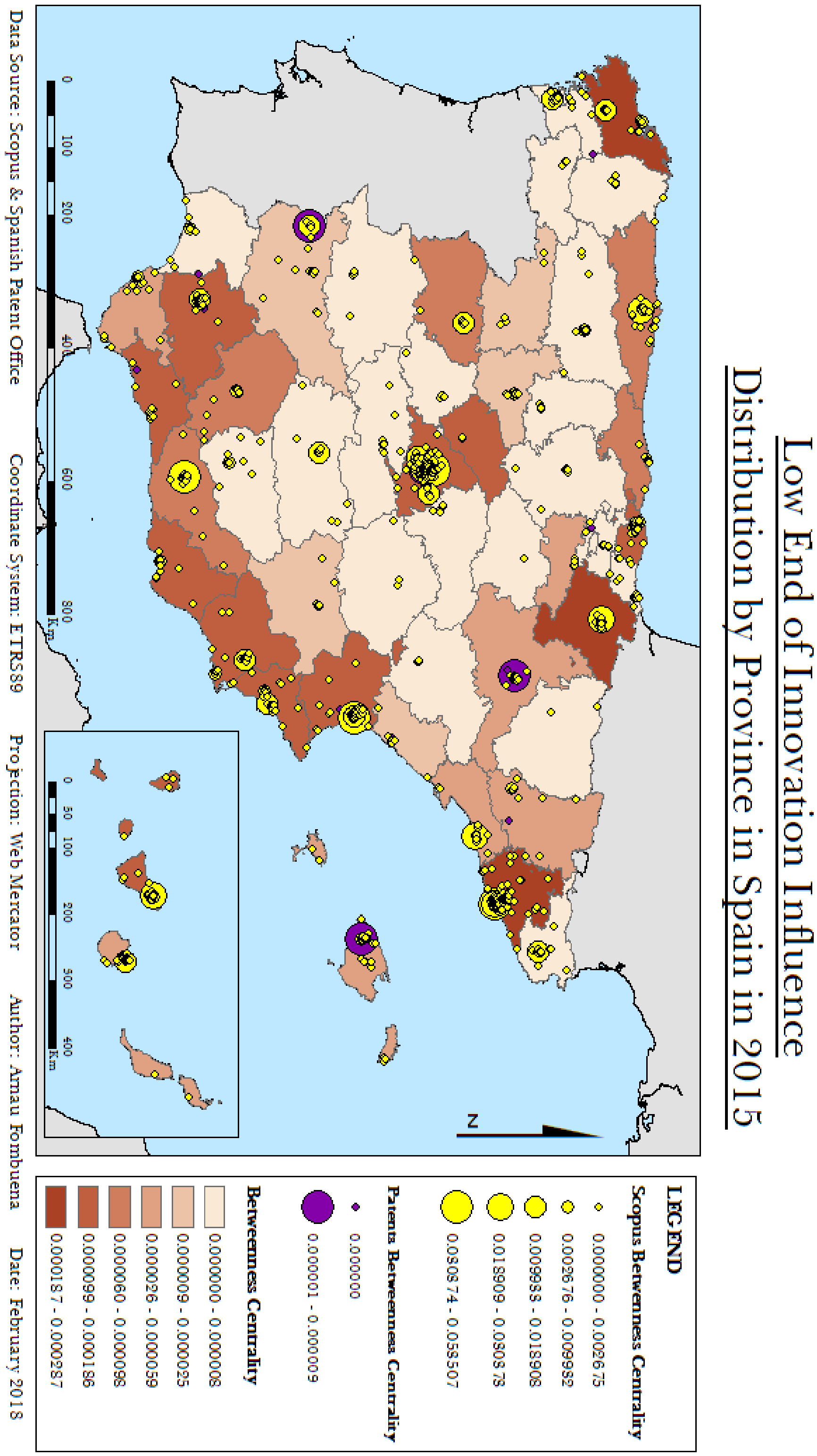


Figure 53. Low end of innovation influence distribution by province in Spain in 2015.

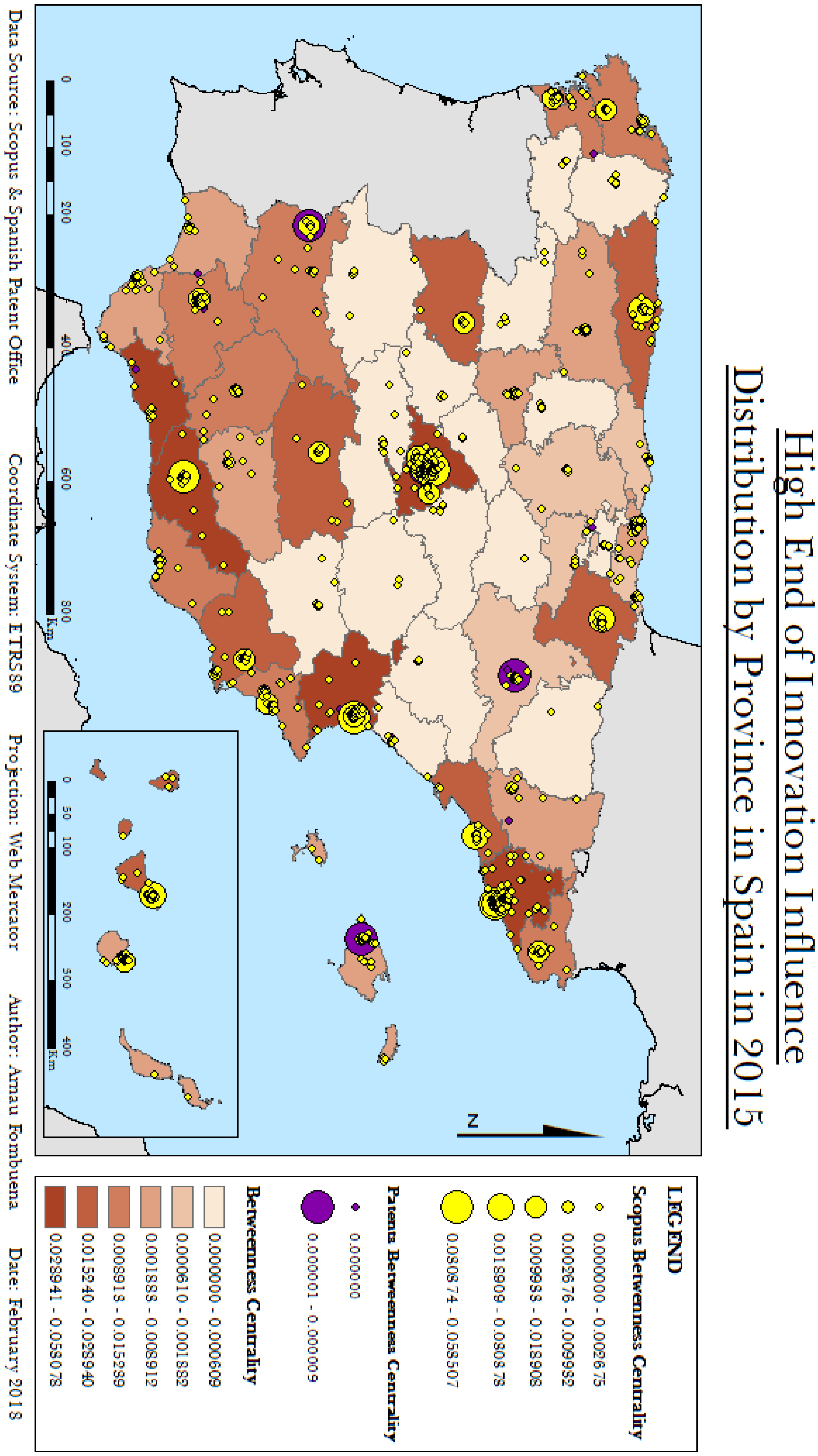


Figure 54. High end of innovation influence distribution by province in Spain in 2015.

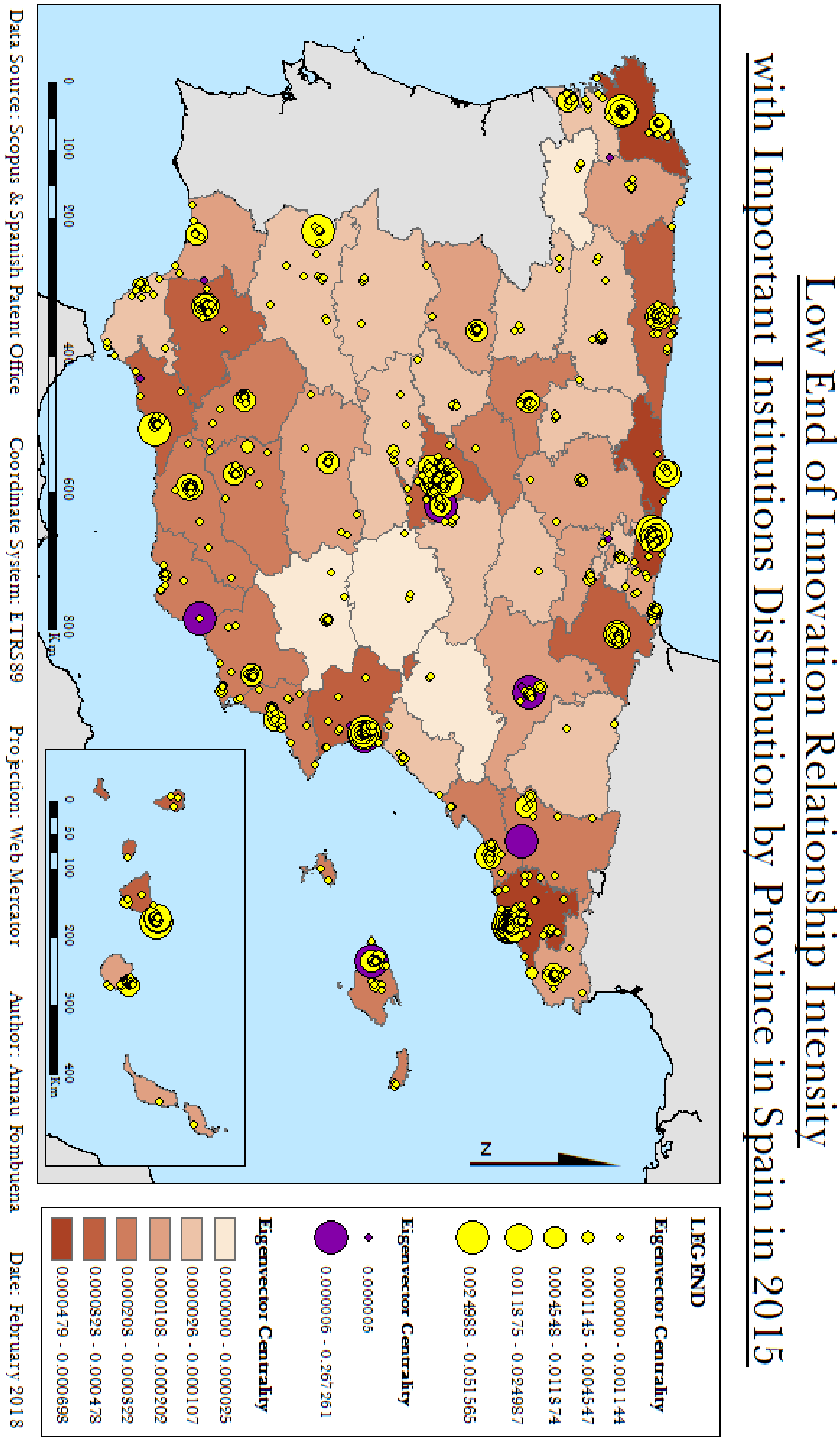


Figure 55. Low end of innovation relationship intensity with important institutions distribution by province in Spain in 2015.

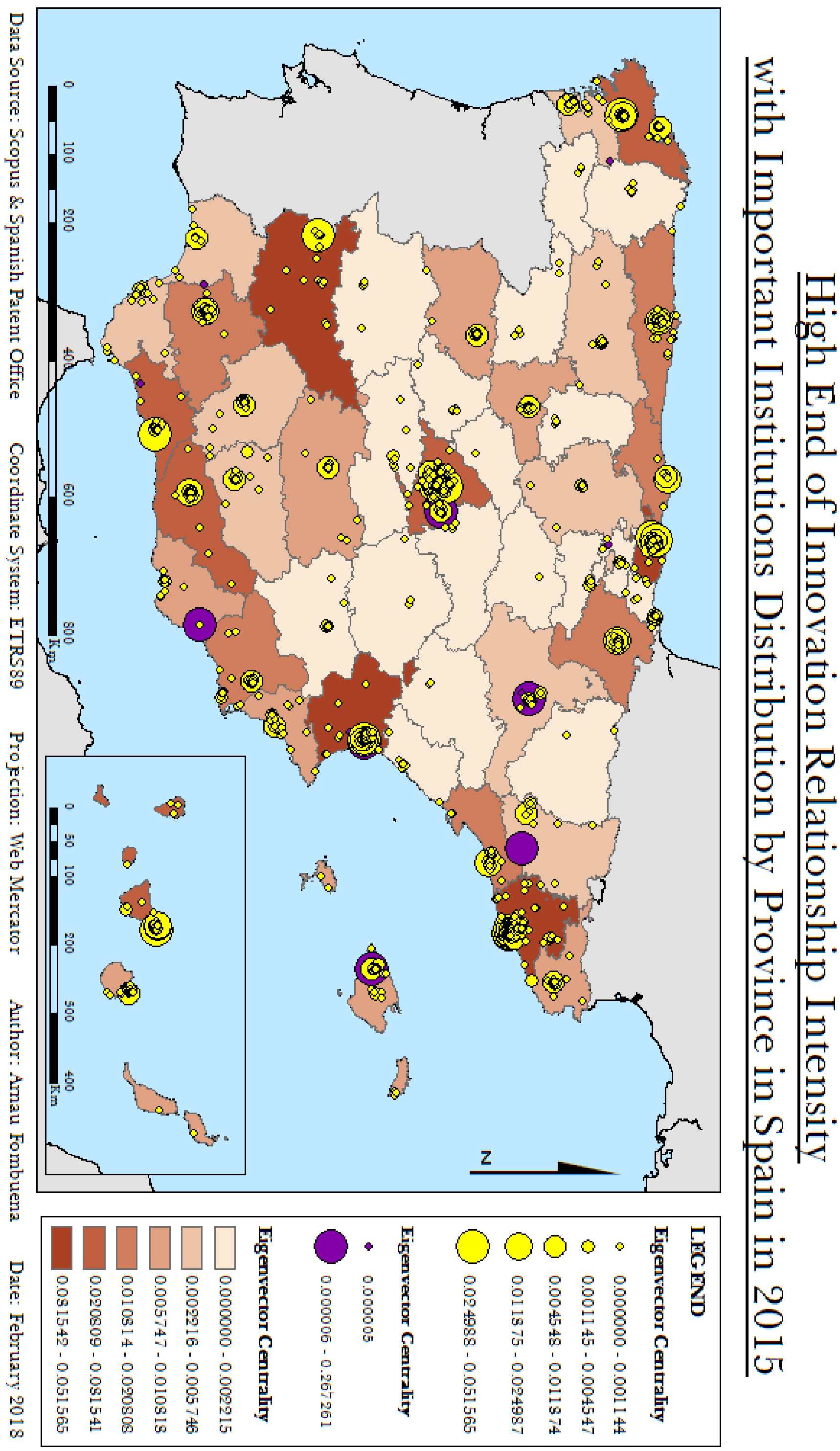


Figure 56. High end of innovation relationship intensity with important institutions distribution by province in Spain in 2015.

		Average Centrality low end			*Average Centrality high end*		
Province	***# Institutions***	***Deg. Cent.***	***Bet. Cent.***	***Eigen Cent.***	***Deg. Cent.***	***Bet. Cent.***	***Eigen. Cent.***
A Coruña	47	0.002044	0.000275	0.000669	0.070041	0.015239	0.031541
Albacete	40	0.000276	0.000011	0.000014	0.013212	0.000416	0.001426
Alicante	41	0.001452	0.000175	0.000269	0.042695	0.015138	0.008011
Almería	26	0.001452	0.000175	0.000269	0.042695	0.015138	0.008011
Araba	21	0.000629	0.000003	0.000107	0.008257	0.000609	0.001624
Asturias	47	0.00241	0.000098	0.000438	0.10375	0.021534	0.020808
Ávila	8	0.000243	0.000001	0.000057	0.001603	0.000023	0.000396
Badajoz	31	0.000946	0.000025	0.000083	0.081698	0.013255	0.041801
Barcelona	458	0.003152	0.000287	0.000657	0.172528	0.052675	0.041148
Bizcaya	57	0.002744	0.000138	0.000687	0.050976	0.008203	0.038253
Burgos	15	0.001592	0.000006	0.000162	0.010637	0.00153	0.002643
Cáceres	14	0.000822	0.000005	0.000086	0.00952	0.000113	0.000993
Cádiz	32	0.00094	0.000044	0.000103	0.029532	0.00809	0.003984
Cantabria	15	0.003691	0.000092	0.000626	0.062075	0.001655	0.017104
Castellón	22	0.000631	0.000012	0.00005	0.007723	0.000443	0.00065
Ceuta	0	0	0	0	0	0	0
Ciudad Real	25	0.00157	0.000008	0.000139	0.044881	0.018763	0.006916
Córdoba	29	0.001939	0.00009	0.000249	0.039538	0.009932	0.005746
Cuenca	5	0.00051	0	0.000025	0.004566	0.000039	0.000631
Guipuzkoa	57	0.000818	0.000007	0.000202	0.008218	0.001304	0.001817
Girona	26	0.000863	0.000008	0.000147	0.043812	0.013792	0.007778
Granada	54	0.001565	0.000064	0.00026	0.13503	0.038719	0.024161
Guadalajara	7	0.000243	0	0.000044	0.010394	0.000109	0.000704
Huelva	14	0.001382	0.000005	0.000148	0.0272	0.004364	0.004654
Huesca	2	0.000486	0	0.00005	0.000486	0	0.00005
Illes Balears	50	0.001759	0.000037	0.000257	0.040703	0.008912	0.007896
Jaén	23	0.000805	0	0.000282	0.021517	0.005302	0.005361
La Rioja	12	0.001069	0.000037	0.000196	0.011269	0.001882	0.002215

Table 14. Provinces average centralities. Continues next page.

		Average Centrality low			Average Centrality high		
Province	# Institutions	Deg. Cent.	Bet. Cent.	Province	Deg. Cent.	Bet. Cent.	Eigen. Cent.
Las Palmas	43	0.000796	0.000017	0.000137	0.039538	0.010651	0.00633
León	25	0.000785	0.000006	0.000078	0.02176	0.005453	0.002961
Lleida	23	0.00151	0.000044	0.000255	0.031572	0.00688	0.005169
Lugo	8	0.000988	0.000002	0.000142	0.007383	0.000028	0.000523
Madrid	697	0.002357	0.000186	0.000399	0.167136	0.046912	0.030349
Málaga	25	0.002357	0.000186	0.000399	0.167136	0.046912	0.030349
Meililla	.	0	0	0	0	0	0
Murcia	71	0.001835	0.000142	0.000309	0.066738	0.01814	0.011374
Navarra	42	0.002547	0.000218	0.000478	0.09083	0.021829	0.013497
Ourense	8	0.000236	0	0.00001	0.001069	0	0.000194
Palencia	6	0.000408	0	0.000061	0.005246	0.000052	0.000436
Pontevedra	31	0.000541	0.000003	0.000068	0.033126	0.01044	0.004998
Salamanca	42	0.001559	0.000073	0.000179	0.067029	0.018908	0.010313
S. C. Tenerife	72	0.002014	0.000071	0.000693	0.095007	0.026384	0.037392
Segovia	2	0.002817	0.000121	0.000322	0.002817	0.000121	0.000322
Sevilla	64	0.002254	0.000126	0.000356	0.071984	0.012826	0.01261
Soria	2	0.001166	0	0.000055	0.001166	0	0.000055
Tarragona	39	0.00171	0.000059	0.000303	0.080532	0.02894	0.012565
Teruel	6	0.000175	0	0.000006	0.003011	0	0.000284
Toledo	18	0.000611	0.000005	0.000081	0.01496	0.000256	0.001166
Valencia	137	0.001834	0.000149	0.000415	0.120653	0.053078	0.051565
Valladolid	14	0.002272	0.000023	0.000254	0.032835	0.004861	0.00649
Zamora	6	0.001049	0.000014	0.000092	0.006023	0.000194	0.000636
Zaragoza	42	0.000859	0.00004	0.000196	0.014151	0.001529	0.003295

Table 14. Provinces average centralities.

The spatial distribution of the low end of the innovation influence (Figure 53) is clearly distributed along the Mediterranean coast and the northern coast with the interior of the country having nearly no influence with the exception of Madrid and Segovia. The most influential provinces in this case are A Coruña, Navarra and Barcelona. The spatial distribution of the high end innovation influence (Figure 54) includes a larger number of provinces although, similarly to the low end distribution, the interior of the country remains largely insignificant in terms of innovation influence. In this second case, the higher values tend to switch once again from the north to the Mediterranean coast. For instance, Navarra lowers its influence, which, arguably, moves towards Valencia while the influence of A Coruña and Asturias seems to move towards Andalucía in general and Granada and Málaga specifically. Cantabria is an exception to the north to south trend since it increases its influence. Madrid also increases its influence while Barcelona, the Balearic Islands and the Canary Islands remain consistent in their respective levels of influence.

The spatial distribution of the low end of the innovation relationship intensity with important institutions (Figure 55) shows that most provinces have at least a small number of connections with important institutions of the Spanish innovation network. However, the trend is similar to the aforementioned distributions with the provinces along the coasts having higher values than the provinces located in the interior of the country. The high end of the innovation relationship intensity with important institutions (Figure 56) intensifies the differences between the interior provinces and the coasts. A few provinces also gain relevance. For instance, Valencia is a lot more significant in the high end of the curve. This is also true for the province of Badajoz that may be benefited by its low number of institutions. In this case the north towards south trend is not as clear as in other cases. The provinces of Barcelona, the Balearic Islands and the Canary Islands are once again the most consistent with little to no variation between the low and higher ends of the curve.

In the three cases, the 2015 distribution by Spanish provinces of the innovation relationship intensity, the innovation influence, and the innovation relationship intensity with important institutions; the general trend shows that the provinces located by the coasts are more and better connected, and more influential in the Spanish innovation network. The differentiation between the flat tale of the distribution and the high end depict a tendency of a larger number of institutions with low values in the northern coast and less institutions in the south and the Mediterranean coast. However, the latter tend the have higher values in all three cases. It is also significant to note that the provinces of Barcelona, the Balearic Islands and the Canary Islands have a consistent representation both in the flat tale and the high end of the curve.

6.6. RECOMMENDATIONS

The distribution of recommendations (Figure 57) resulting from the criteria presented in the specific case section shows that a large number of institutions do not have any recommendation while several universities have about 100 recommendations approximately and a few universities do have well over 1,000. It is worthy of note that both the *Universitat Politècnica de València* and the *Universitat Autònoma de Barcelona* fall in the category with no recommendations. However, the number of recommendations does not seem to be correlated with the results of the element based analysis of the innovation network. Although both universities have high betweenness centrality, which could suggest they are already highly influential and therefore do not need more connections, the *Universitat Politécnica de Catalunya* has nearly the same betweenness centrality value as the *Universitat Politécnica de València* and it does have also about 100 recommendations. Their eigenvector centralities are also rather low but, once again, so is that of the *Universitat Politécnica de Catalunya* or that of the *Universidad Politécnica de Madrid*. A similar situation is encountered if the degree centrality is considered instead with many of the universities in the 100 recommendations category having a rather high degree centrality, which is also high for both the *Universitat Politècnica de València* and the *Universitat Autònoma de Barcelona*. The potential correlation between centralities and the number of recommendations is therefore dismissed.

In terms of spatial distribution of the recommended institutions figures 58 to 65 present the distribution of a selection of universities. All the other maps depicting the spatial distribution of the recommended distributions is available in the Annex II.

The recommended institutions tend to be located outside of Spain. Instead, most recommendations tend to be located primarily in Europe followed closely by North America and, at a distance, by the Far East in Asia, specifically South Korea, Japan, and the eastern coast of China. The recommendations located in South America and Africa are less significant.

The typology of recommended institutions is strongly dominated by universities and research institutes. In the case of recommendations located in Europe the presence of hospitals, companies and non-profit organizations is also of note although as the distance from Europe increases their presence is strongly reduced with the notable exception of North America.

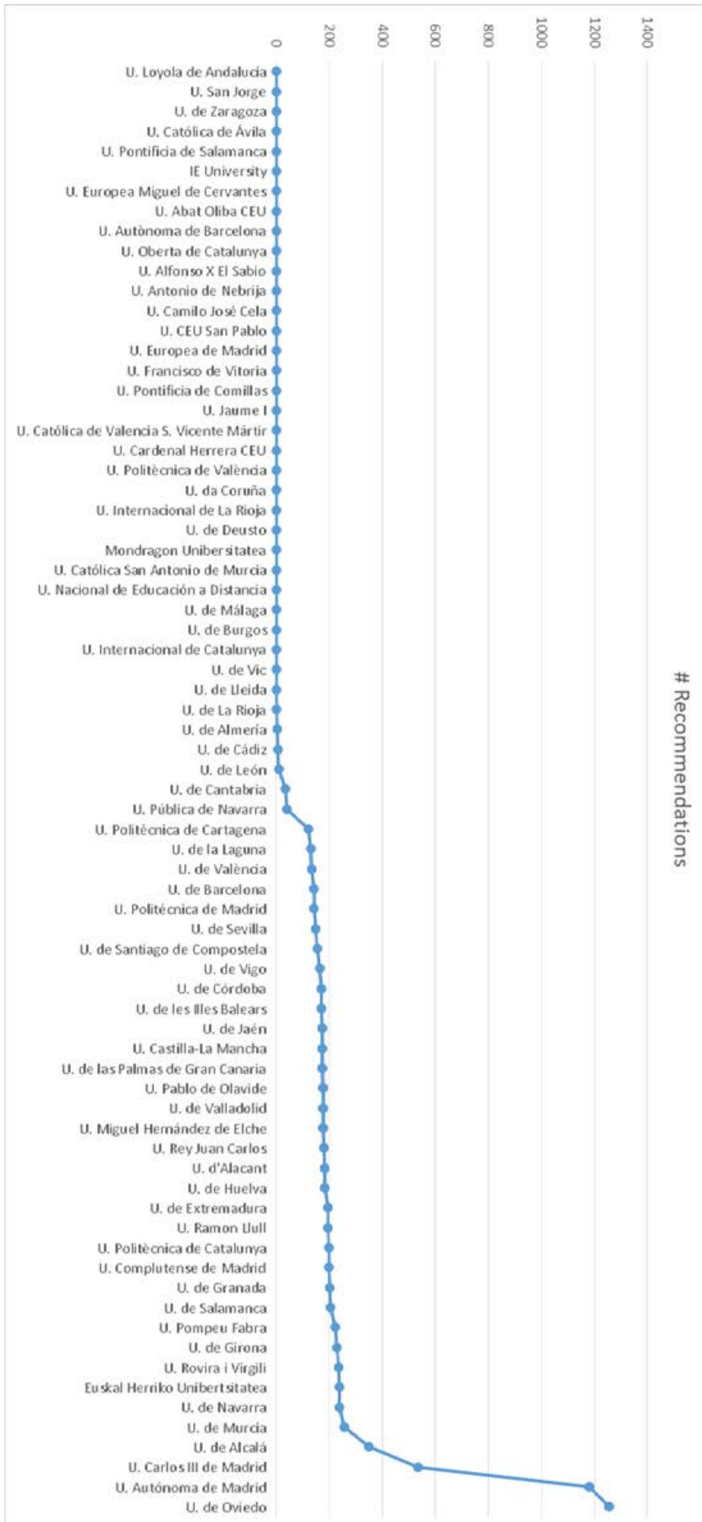


Figure 57. Distribution of the number of recommendations per university.

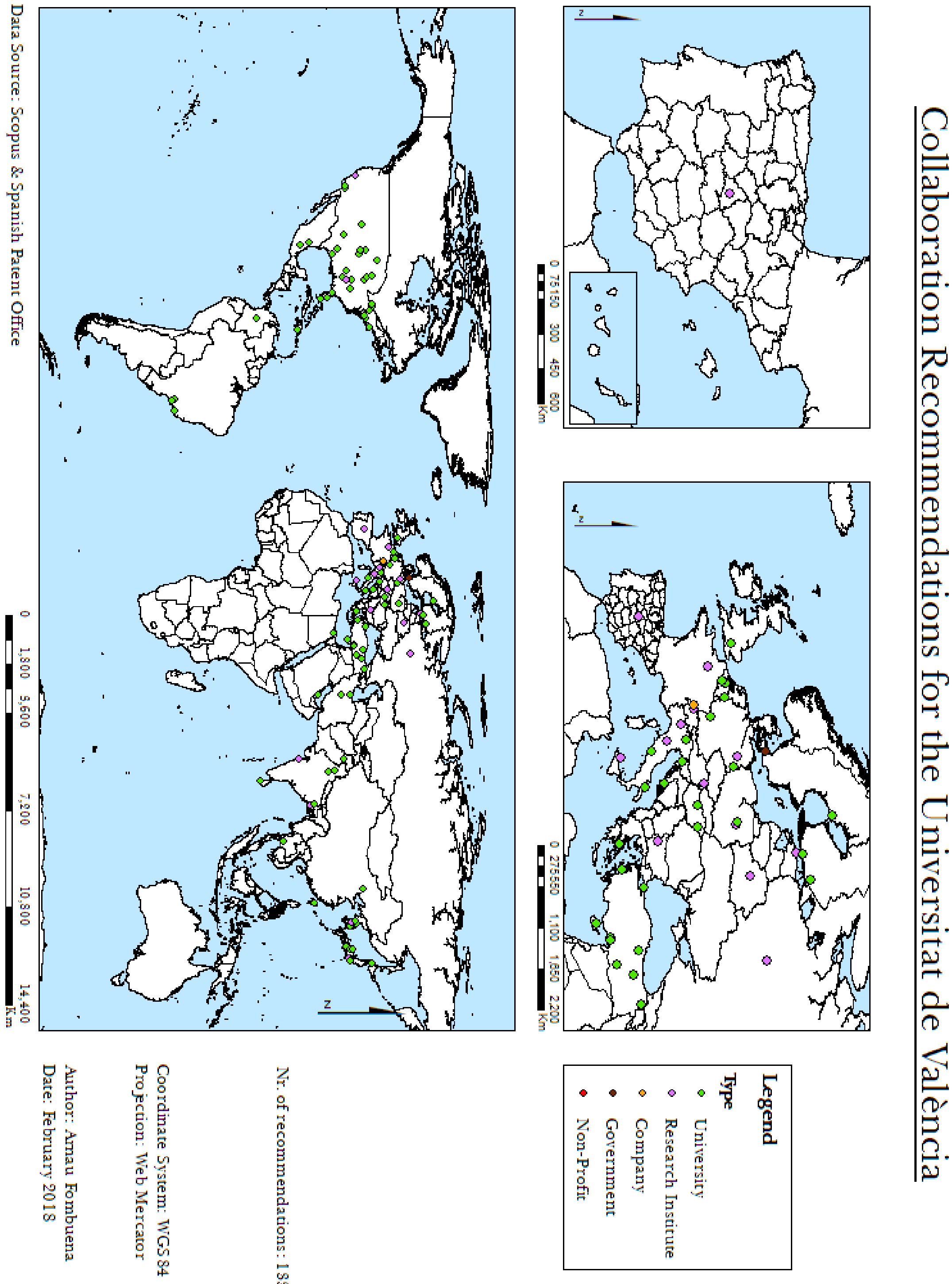


Figure 58. Collaboration recommendations for the *Universitat de València.*

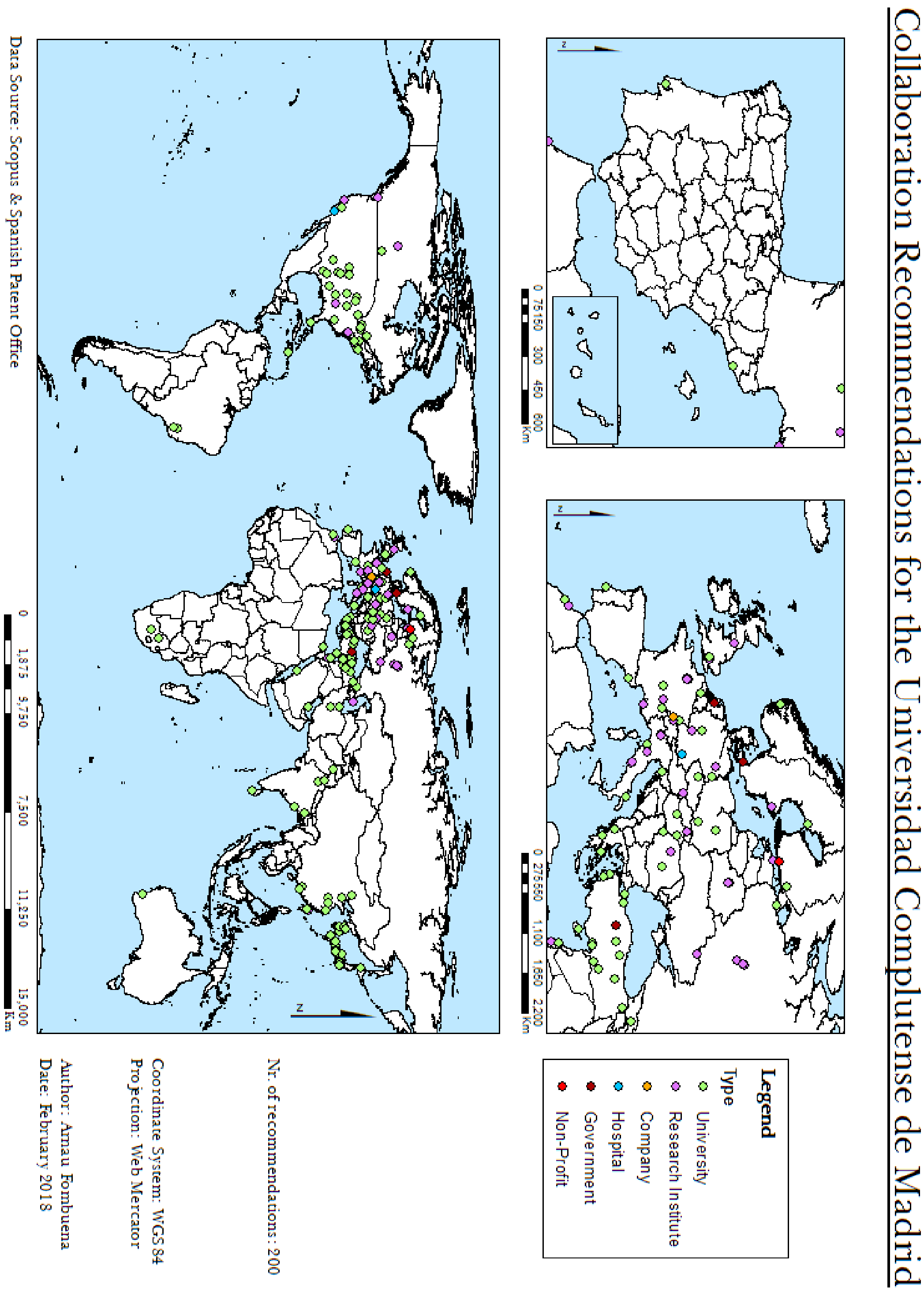


Figure 59. Collaboration recommendations for the *Universidad Complutense de Madrid*.

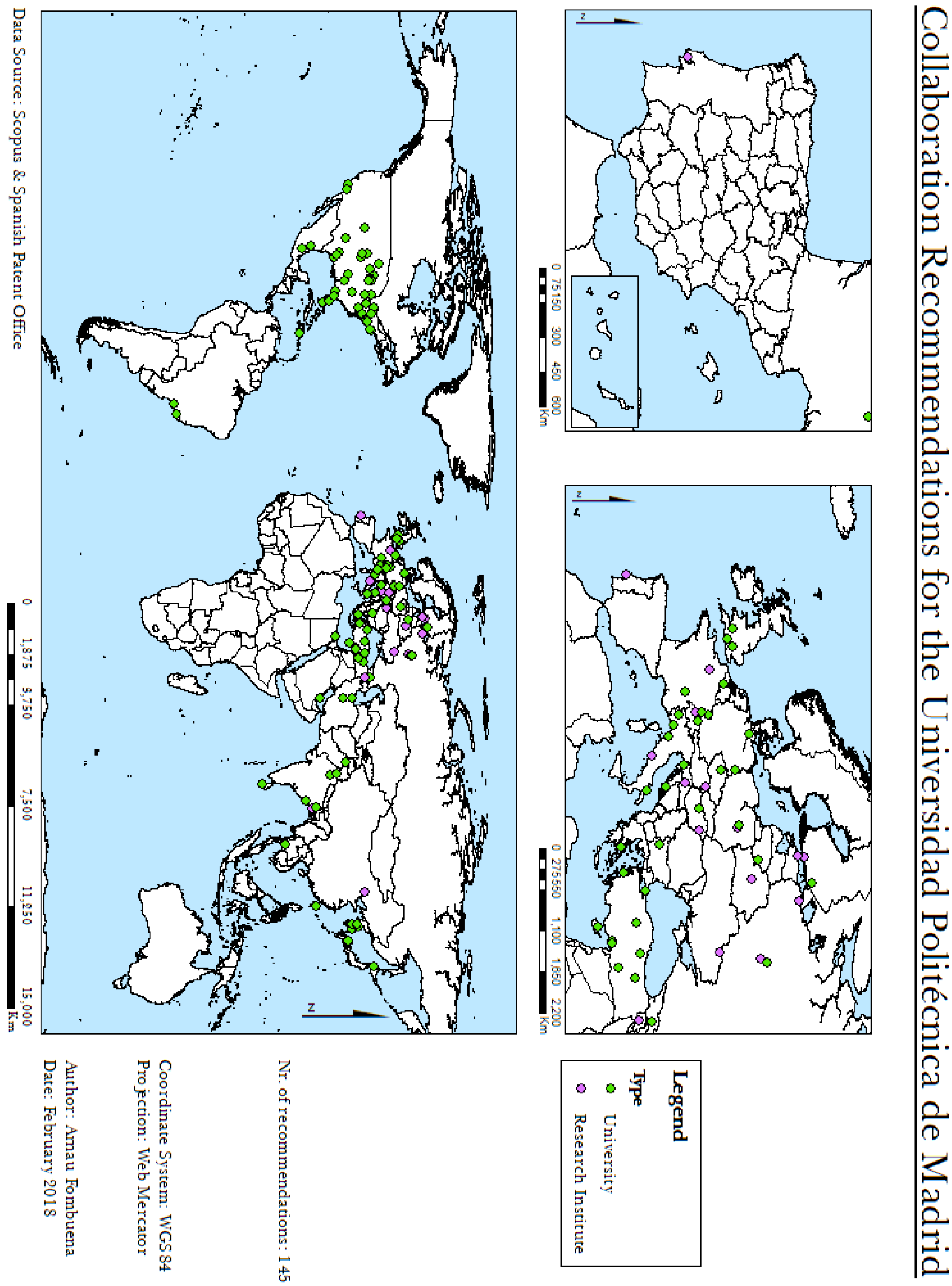


Figure 60. Collaboration recommendations for the *Universidad Politécnica de Madrid*.

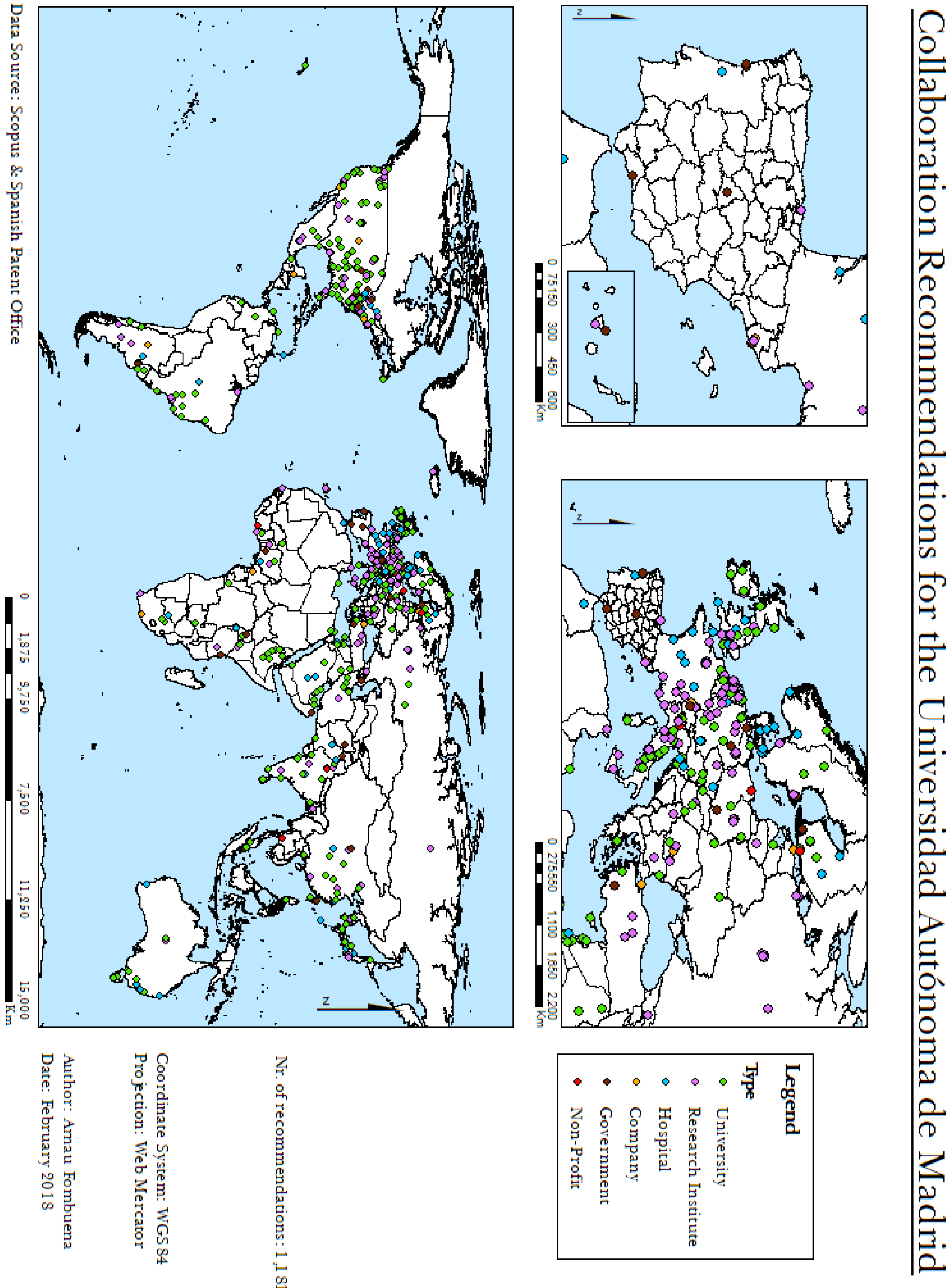


Figure 61. Collaboration recommendations for the *Universidad Autónoma de Madrid*.

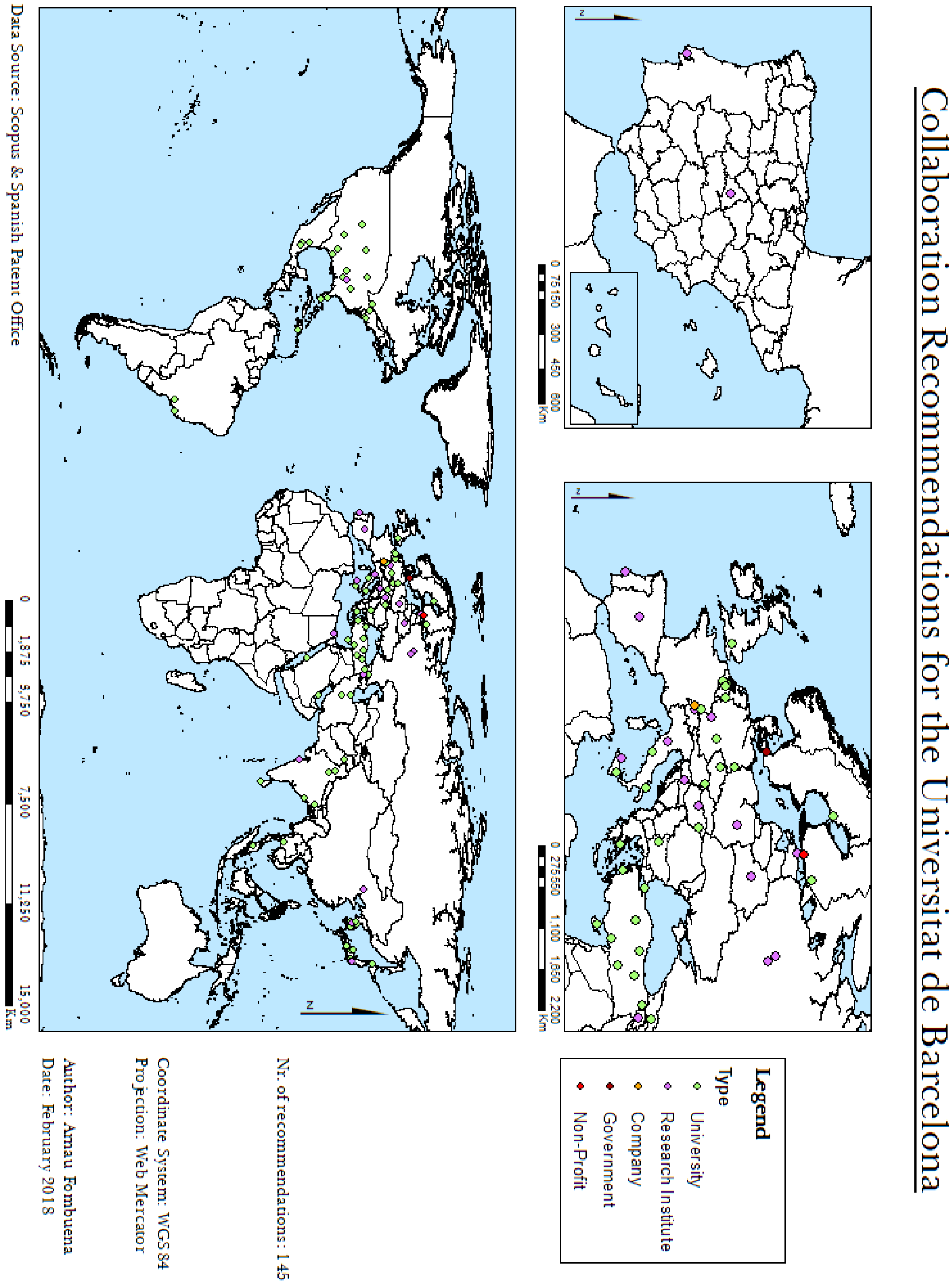


Figure 62. Collaboration recommendations for the *Universitat de Barcelona*.

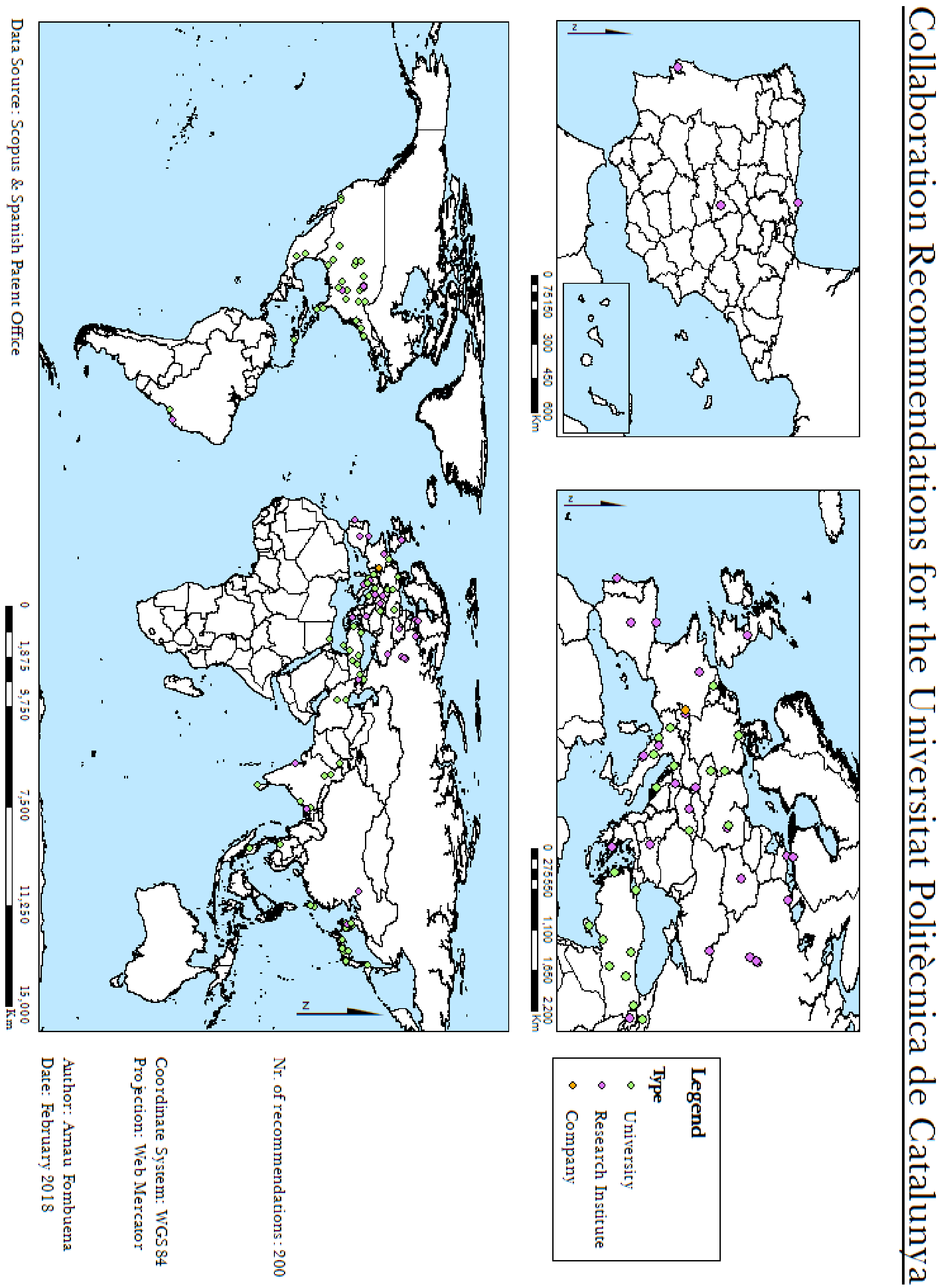


Figure 63. Collaboration recommendations for the *Universitat Politècnica de Catalunya*.

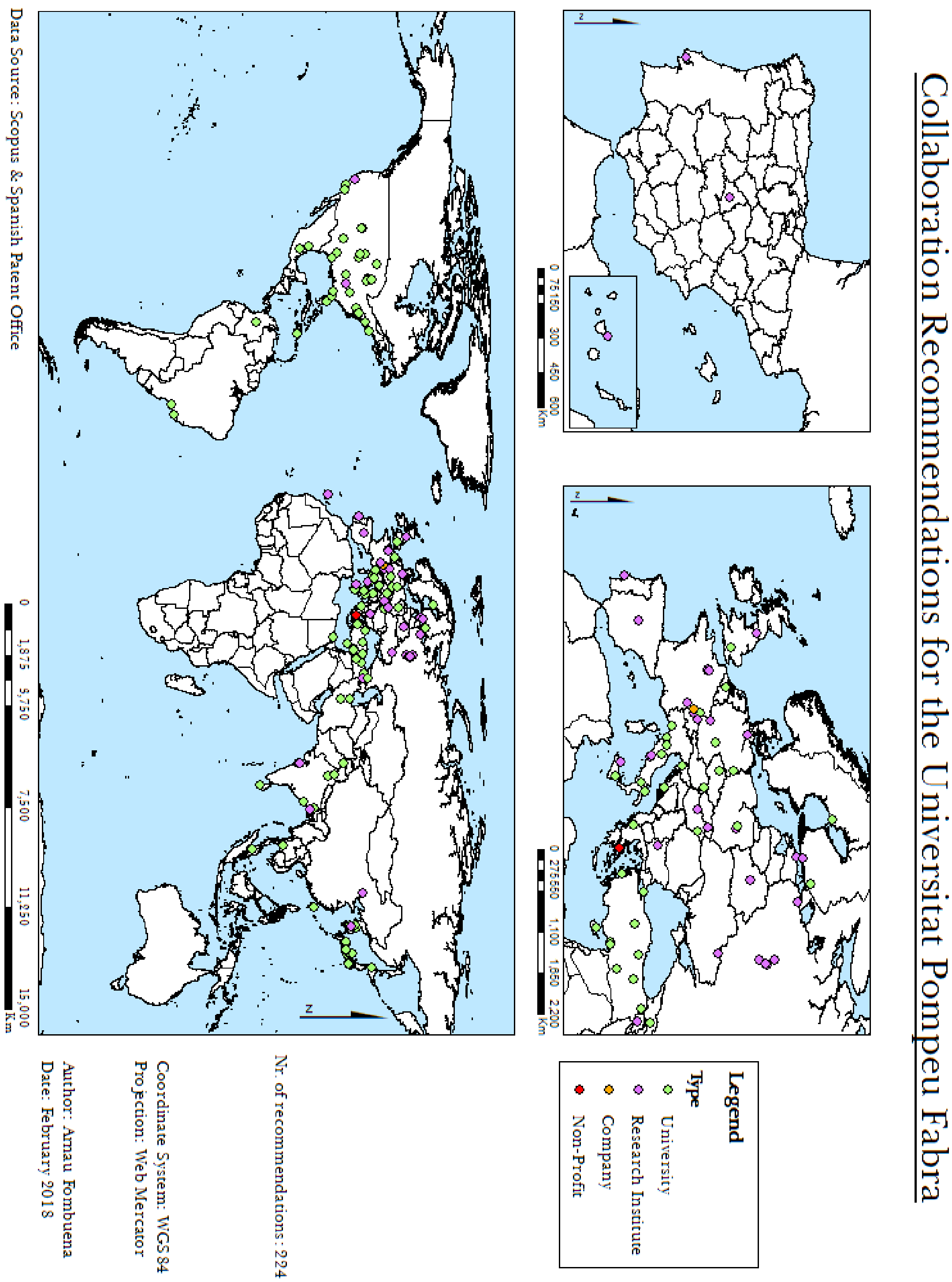


Figure 64. Collaboration recommendations for the *Universitat Pompeu Fabra*.

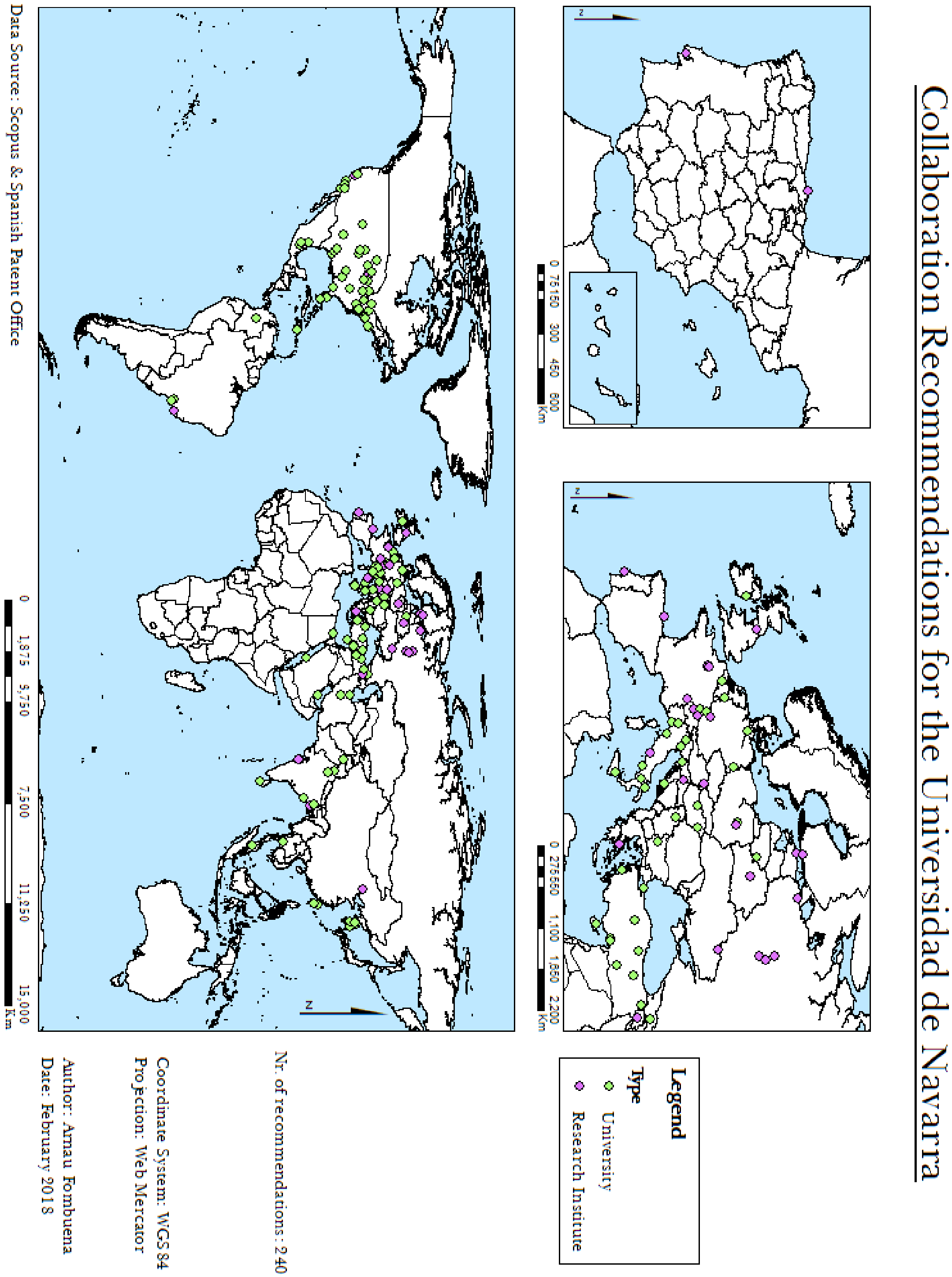


Figure 65. Collaboration recommendations for the *Universidad de Navarra*.

7. DISCUSSION

The dataset collected from both Scopus and the Spanish Patent Office is very large but a lot of the data that would be desirable for this kind of study is not easily accessible. For example, the list of institutions that have agreements with a given university as well as the type of agreement. Logically, this limits the inputs that may be used.

The first summary of the collected data shows that only a small portion of the published articles benefit from funding, be it public or private. Also, most of the patents are published by a single institution, often a company, even if there may be several applicants. Therefore, innovation synergies may be hardly measured by patent documents applicants alone.

The distributions of the number of collaborations per edge as well as the distributions and the number of collaborations per university tend to display a Power Law distribution, that is, a large number of edges or institutions with low values and a select few with high values. This is observed throughout the results. This type of distribution combined with the small diameter of the network and the high clustering coefficient depicts that the Spanish innovation network is a complex network. Because of the high clustering coefficient and the large volume of data, computing the group level analysis, that is, the identification of communities is extremely demanding in terms of computing capacity.

The dominant type of institutions in the network are universities and research institutions followed by hospitals. This could be expected. However, the low appearance of TH institutions (Technological Parks) may be due to the synergies happening within the institutions rather than connecting with outside institutions. Nonetheless, many Technological Parks function, in practice, as a company that builds companies and have economic goals in a similar manner.

In the maps of provinces there are a few provinces that have a rather small variation of centrality no matter the case. This leads to suggest these provinces are well balanced with many institutions having low values but also enough institutions of high significance. Therefore, resulting in an even distribution.

The patterns seen in the recommendation maps show that most recommendations are with institutions located outside of Spain. However, should new institutions located in Spain be added to the network, these recommendations could change. Also, the large variability of recommendations between universities denotes that a single criteria for all the universities listed by CRUE is not the best solution. Rather, a case by case approach according to the needs and desires of each university would certainly provide a more adjusted solution. Nonetheless, the method is not to be completely dismissed as it is clear that with a few tweaks in the criteria universities can find institutions in their neighborhood, in terms of connections, with the potential to improve their innovation impact. Although all centralities are important a high betweenness centrality denotes influence but it also means that the information is received sooner and more frequently. Hence, universities may be interested in focusing on this aspect first and then improving the other centralities. Perhaps the eigenvector centrality should be considered before the degree centrality because being connected to significant institutions may facilitate increasing the total number of partners.

The comparison of universities by centrality with the existing world rankings shows how SNA could be used to improve the assessment of universities.

Nonetheless, instead of using a simple indicator perhaps it would be more beneficial to include the results of SNA in a combined ranking such as the U-multirank that does not classify institutions with a simple integer denoting its rank.

8. CONCLUSIONS

The goal of this dissertation was the development of a model that integrates GIS and the triple-helix concept for innovation assessment from the perspective of universities and the territory. Then, through application of the model for the case of the assessment of innovation produced by the Spanish universities listed in CRUE in the year 2015, patterns of innovation linked to the territory have been found. The visualization of results through maps and networks combined with a series of tables provides valuable information that is easy to understand for decision-makers, as well as the public in general.

The Geospatial Helix Innovation Assessment model presented in this thesis does provide an innovative solution to better understand innovation networks and their effect on the territory. Its significance lies on the combination of SNA-GIS to depict the impact of the national innovation network on the territory. For instance, the use of SNA rather than the TH indicator resulting in megabits of information offers a perspective that is more practical and straightforward even for non-experts. Likewise, the focus of the analysis on the institutions rather than authors permits to the institutions themselves as well as policymakers, that use said institutions as knowledge and economy drivers, to accurately assess their significance as well as their influence on the territory. In the specific case studied, the assessment provides an easy-to-understand solution for decision makers in the different provinces. The decision makers can then identify what type of institutions are driving innovation and where they are located, what connections they have and how to improve their innovation results through the identification of significant partners. Furthermore, the funding for research and innovation could be better directed towards those institutions with the higher potential.

There are other projects such as the GEOUP4 (PoliScience, 2018) that through the geolocation of research attempt to depict the impact of the research produced in the Spanish polytechnic universities around the world. In the case studied in this dissertation, not only have the participating institutions been geolocated. They have also been identified by type and classified according to their centrality values. Furthermore, the centralities of all the institutions located in a certain province have been used to compute the level of connectivity and influence of said province. Deeper level of knowledge is also reached including detailed visualization of universities' networks as well as recommendations to improve their connectivity and influence. All this, is achieved through the application of the Geospatial Helix Innovation Assessment model, which provides a systematized method to analyze datasets of all sizes.

9. FUTURE RESEARCH

This thesis contributes to the fields of Geomatics Engineering, Information Communication Science, and Sociology of Innovation in the specific area of the Triple-Helix. Particularly, through merging these fields in a single combined model that takes into account the territory.

Future research derived from this thesis could be longitudinal studies to identify variations in the innovation network as well as the innovation outputs in provinces. Certainly, adding new inputs as the data becomes more accessible would also facilitate developing this line of research.

In a similar direction as this thesis, the computation of a more complex impact factor for journals that would include the influence of a journal in a specific territory and the analysis of its variations would be a line of research with many years to come.

A more complex line of research would focus on the integration of SN-GIS in a similar manner as GIS-BIM, perhaps with the collaboration of sociologists and information communication scientists. The main goal would be to find methods to reduce or eliminate the constraints produced by the different model nature of SN and GIS.

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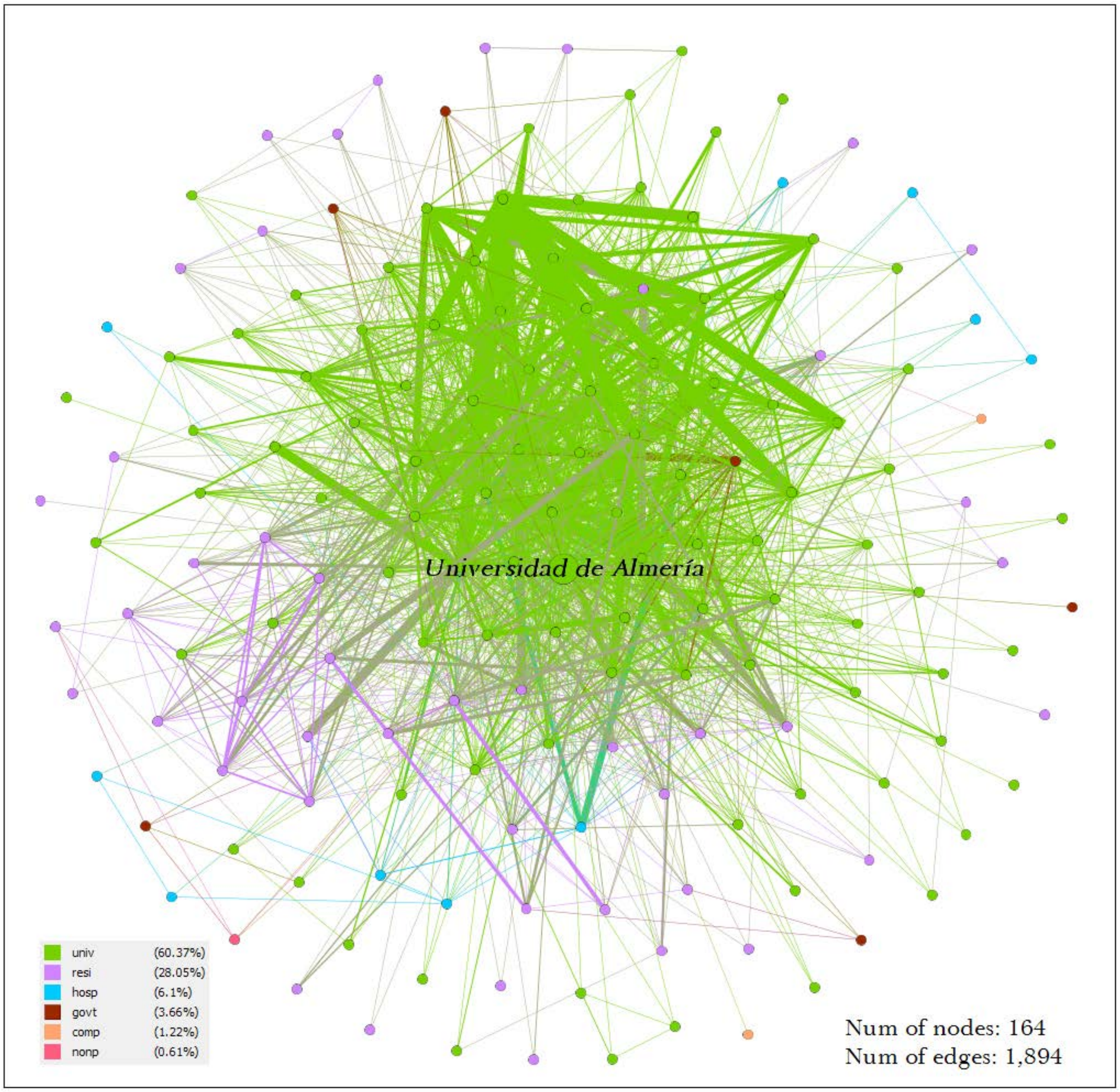
ANNEX I

UNIVERSITIES SUBNETWORKS

LIST OF FIGURES



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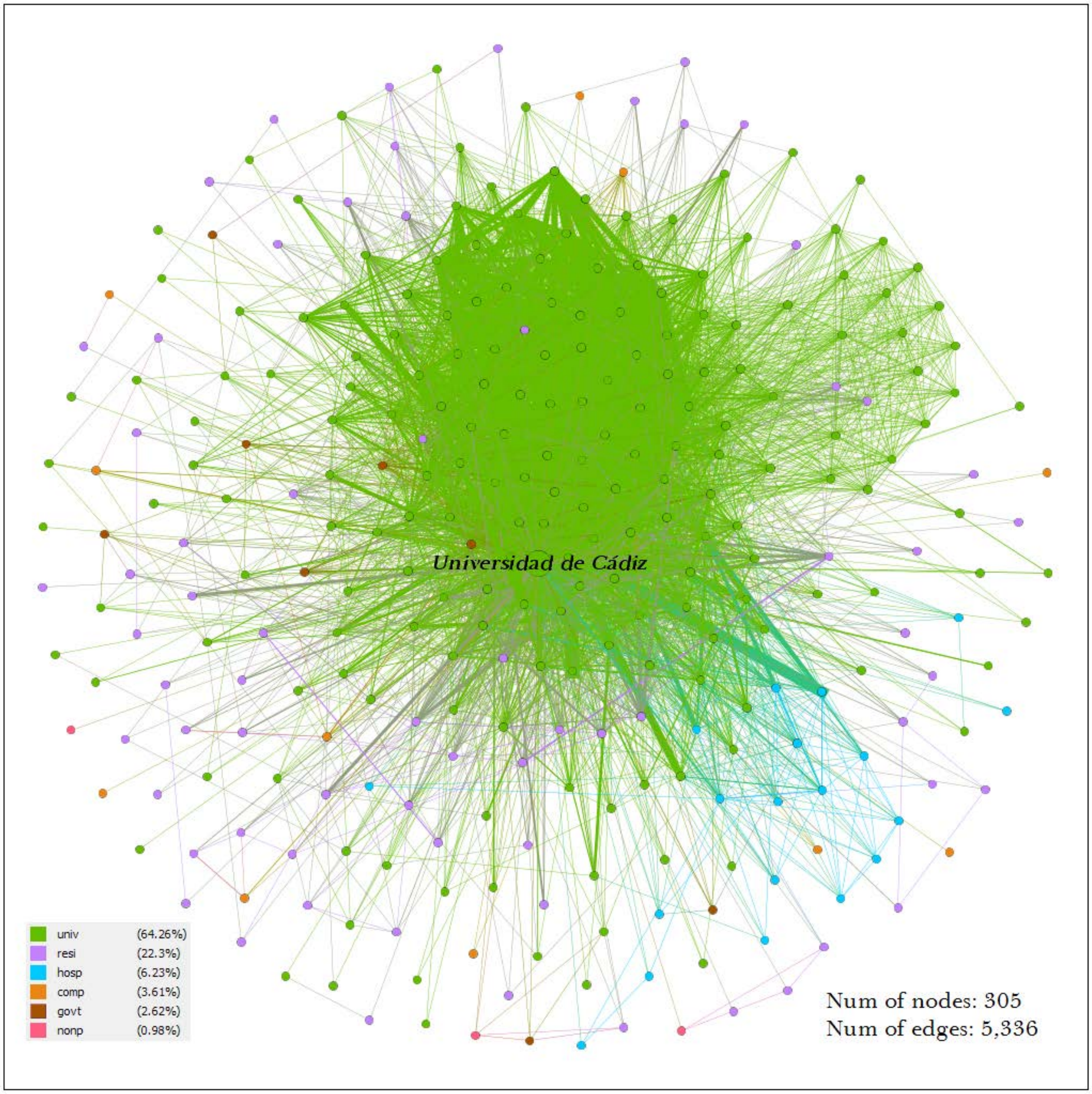

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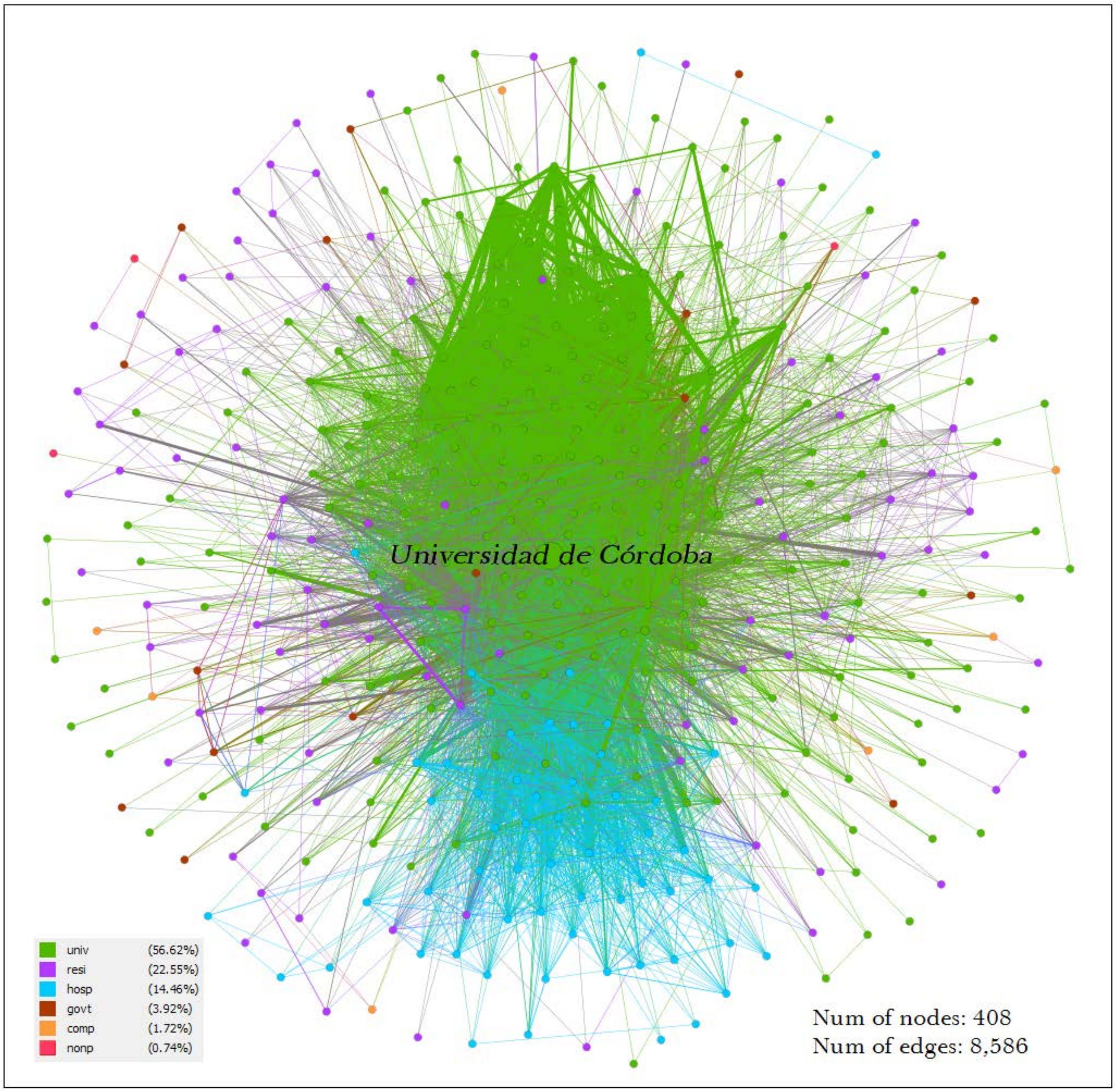

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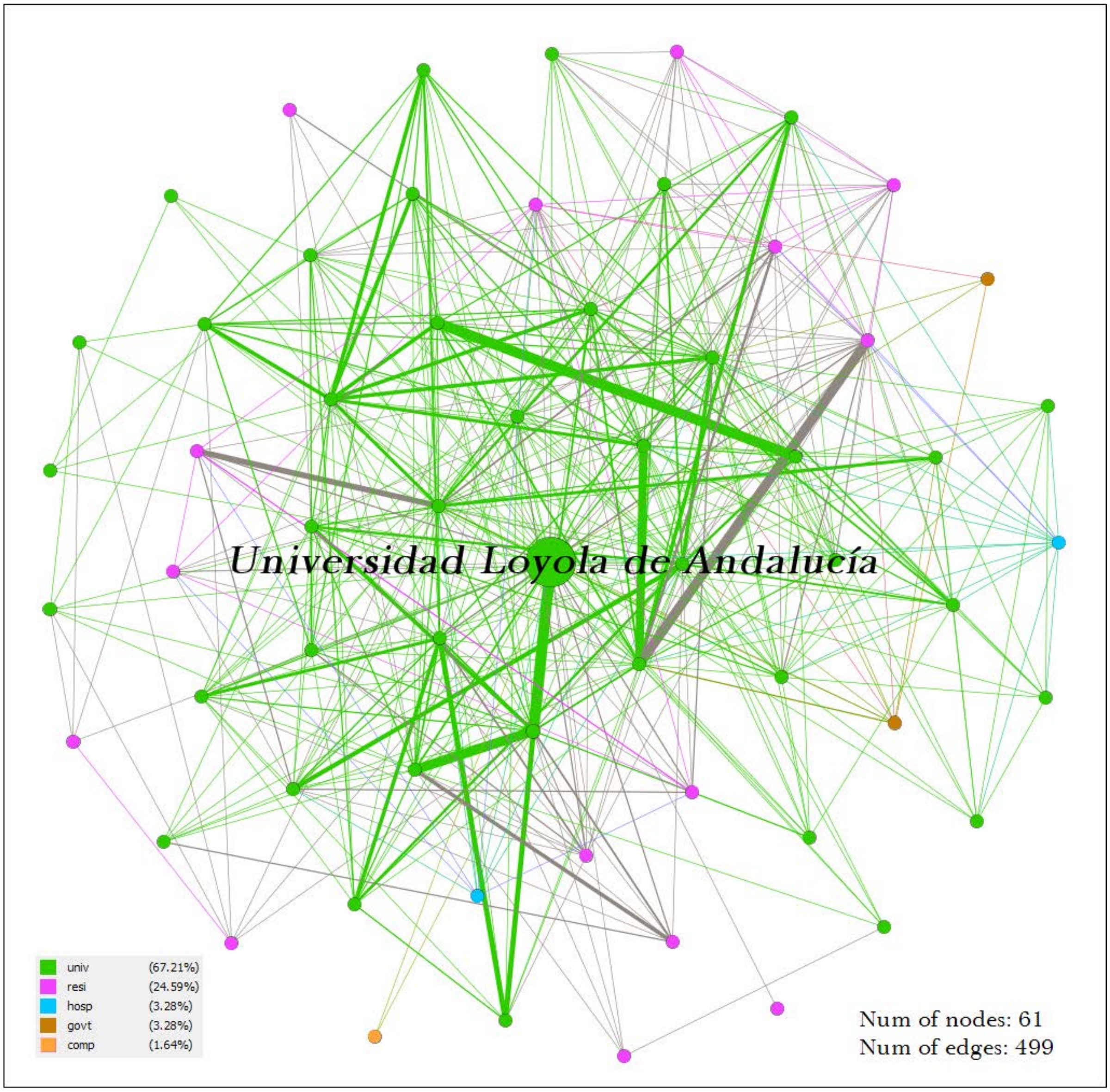

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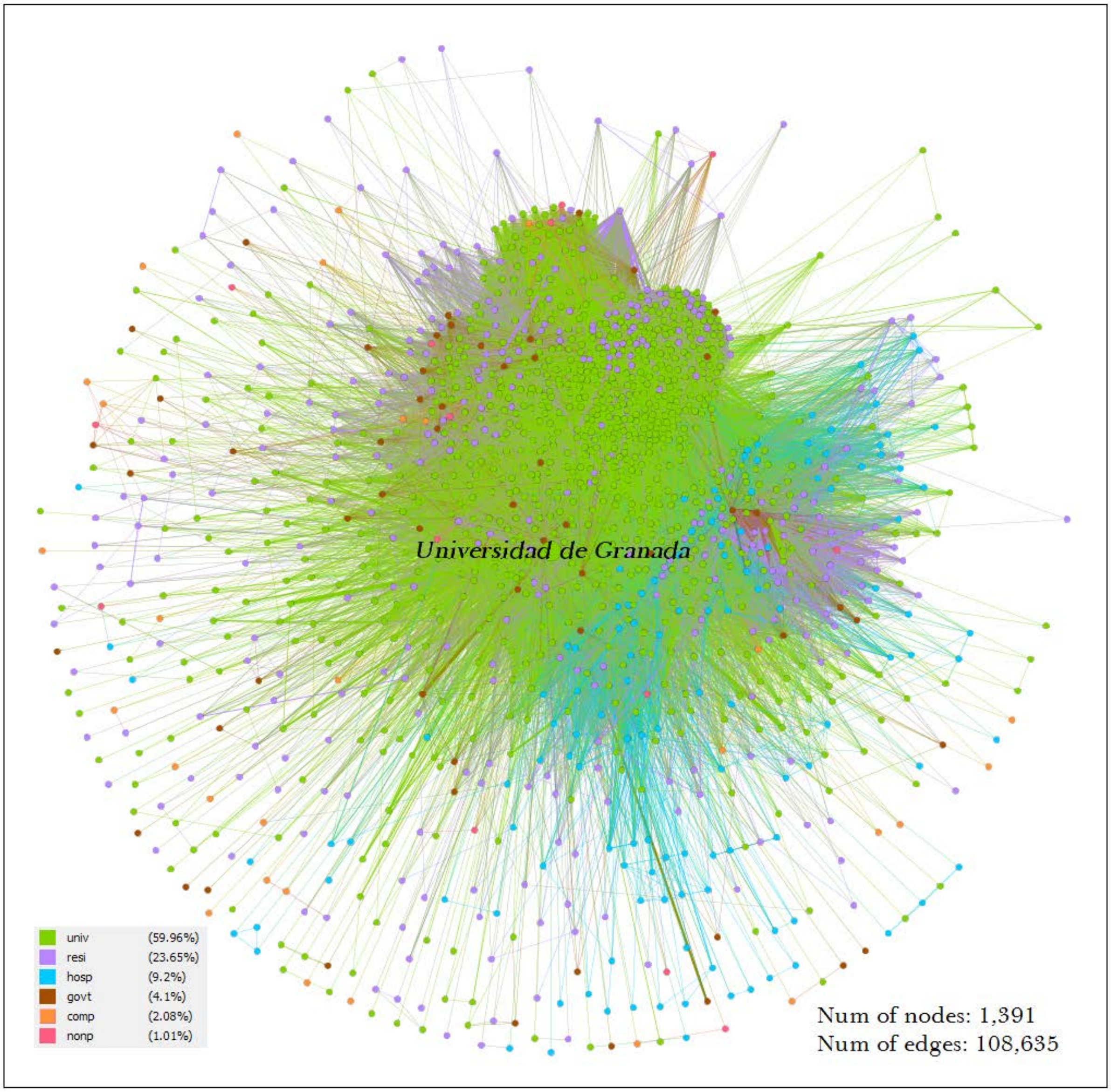

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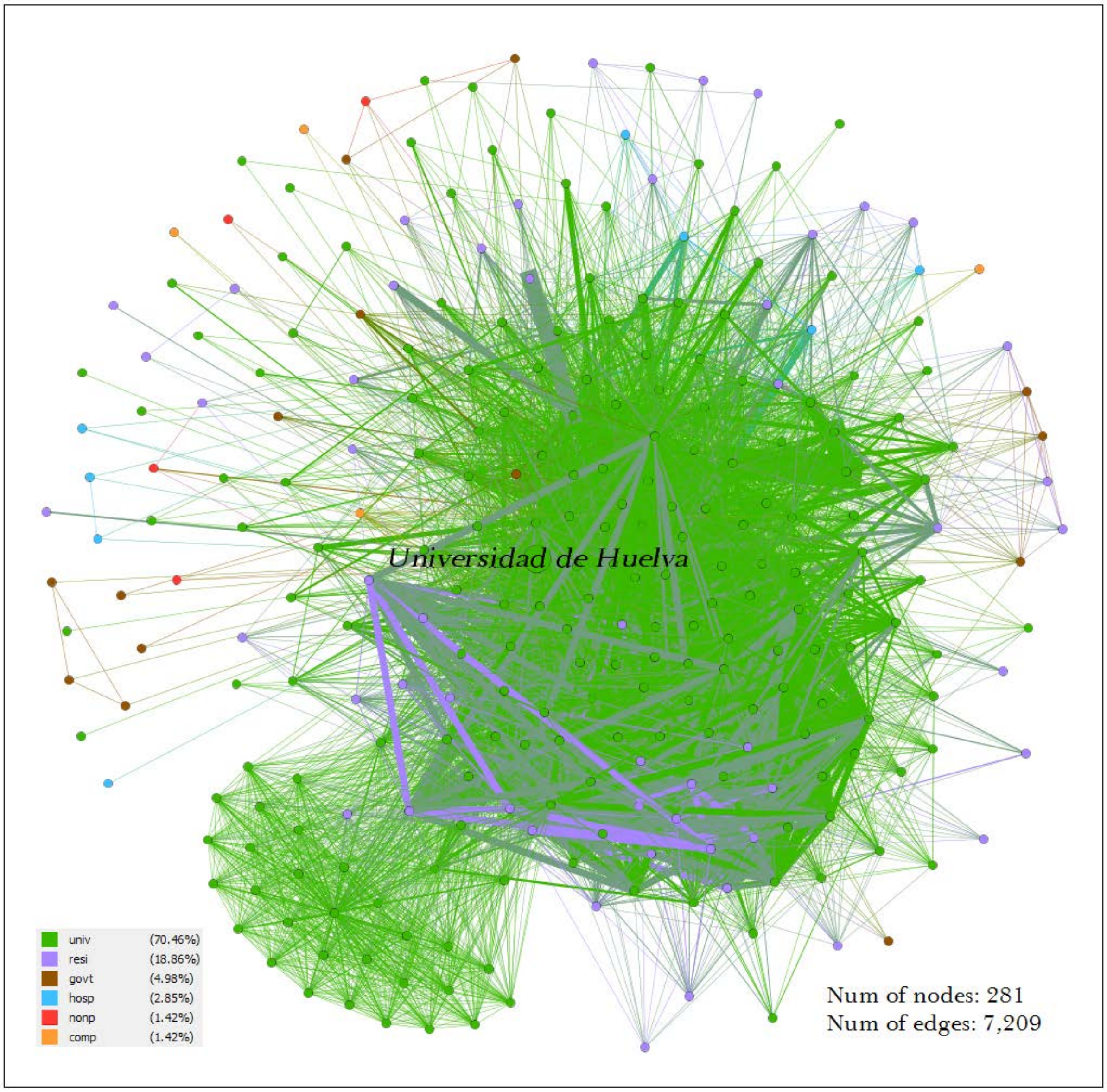

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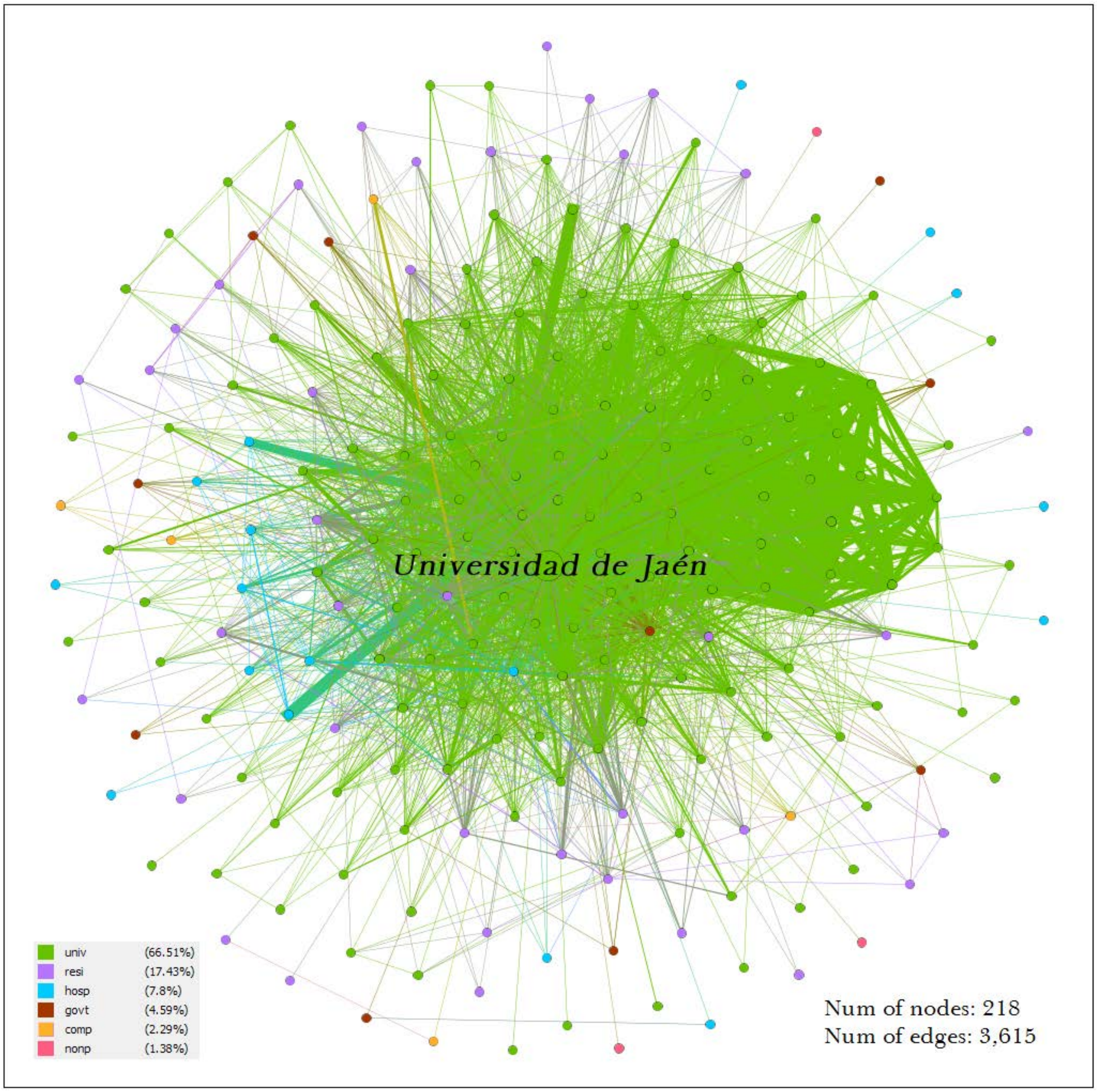

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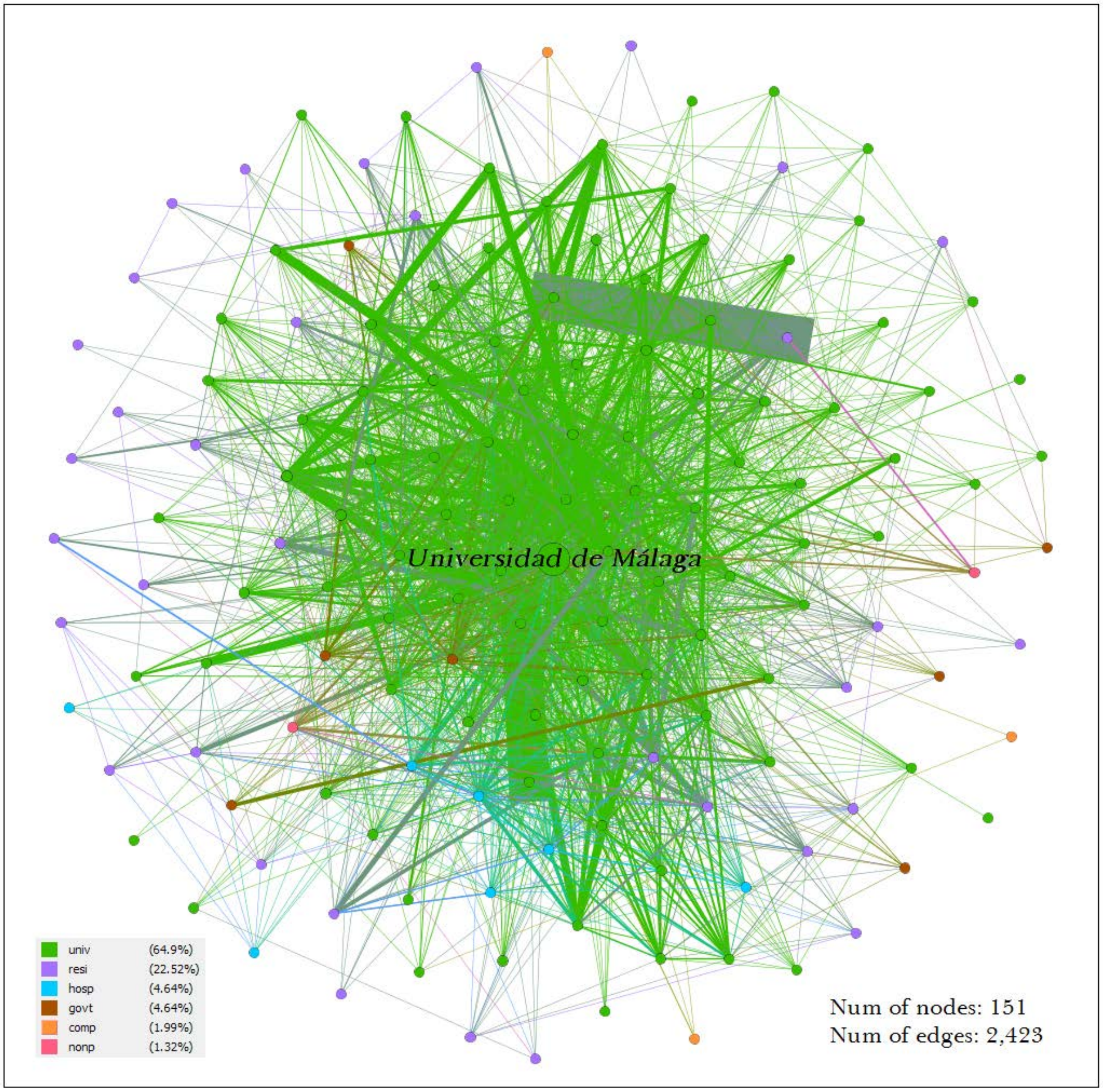

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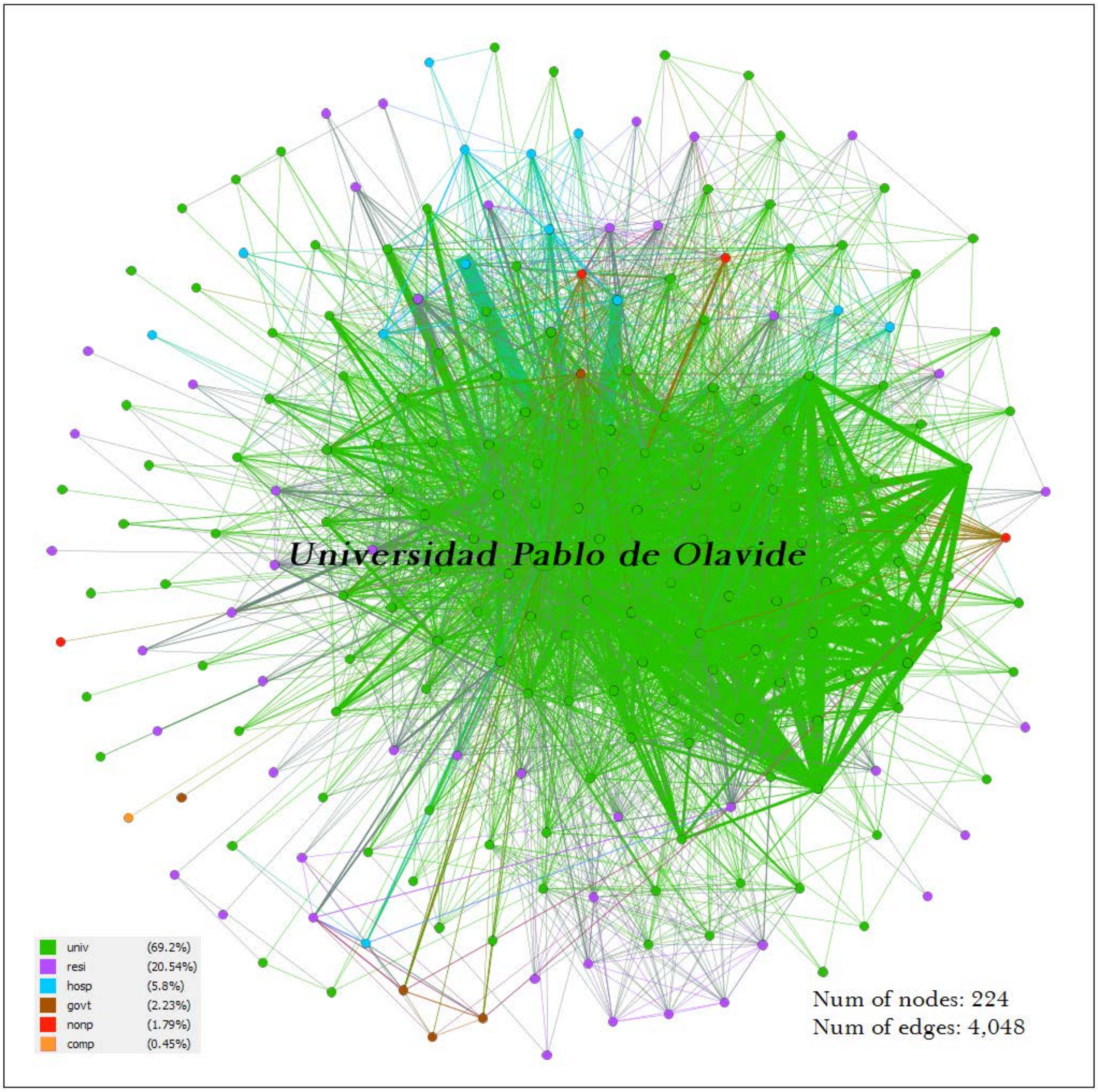

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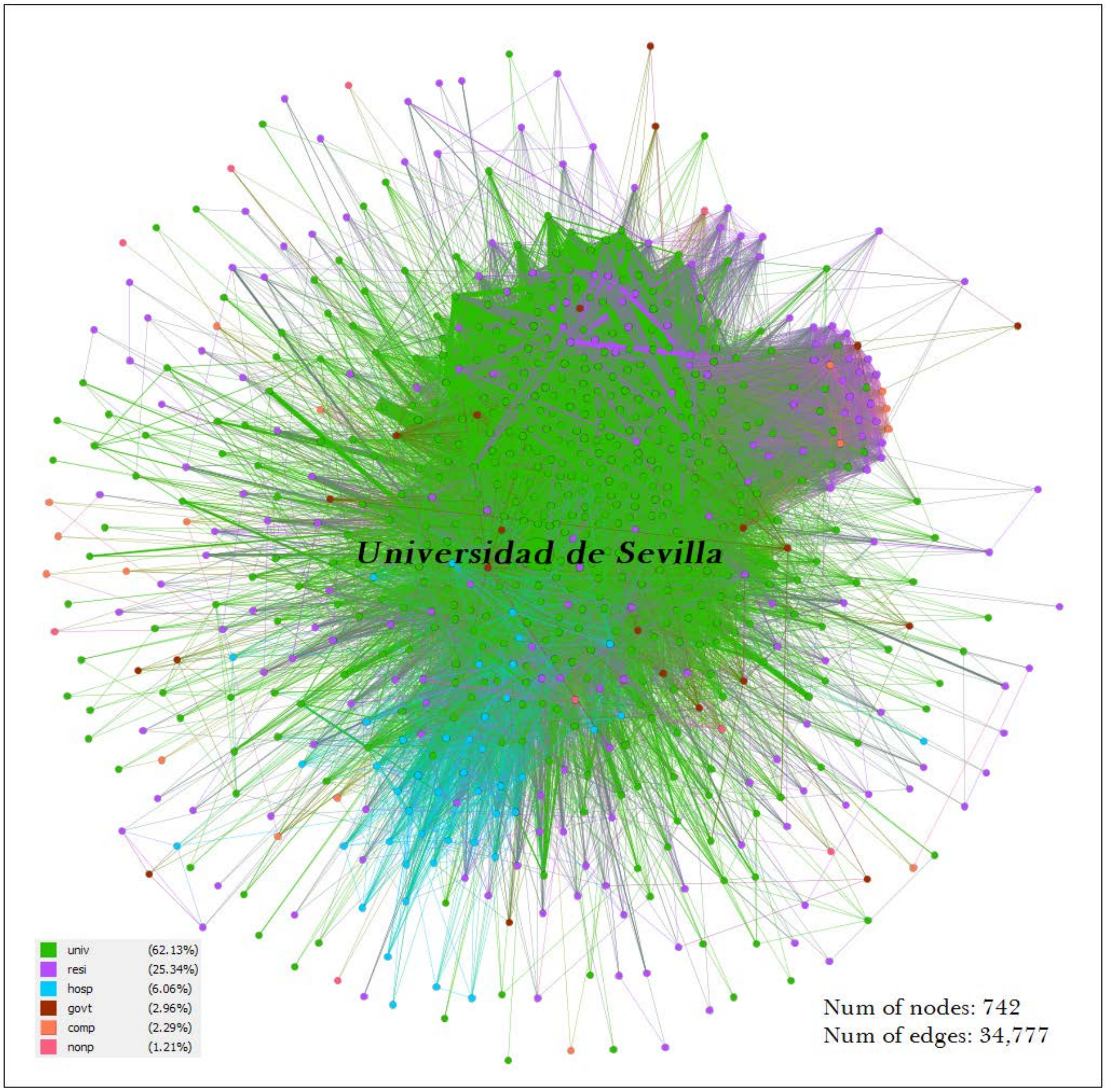

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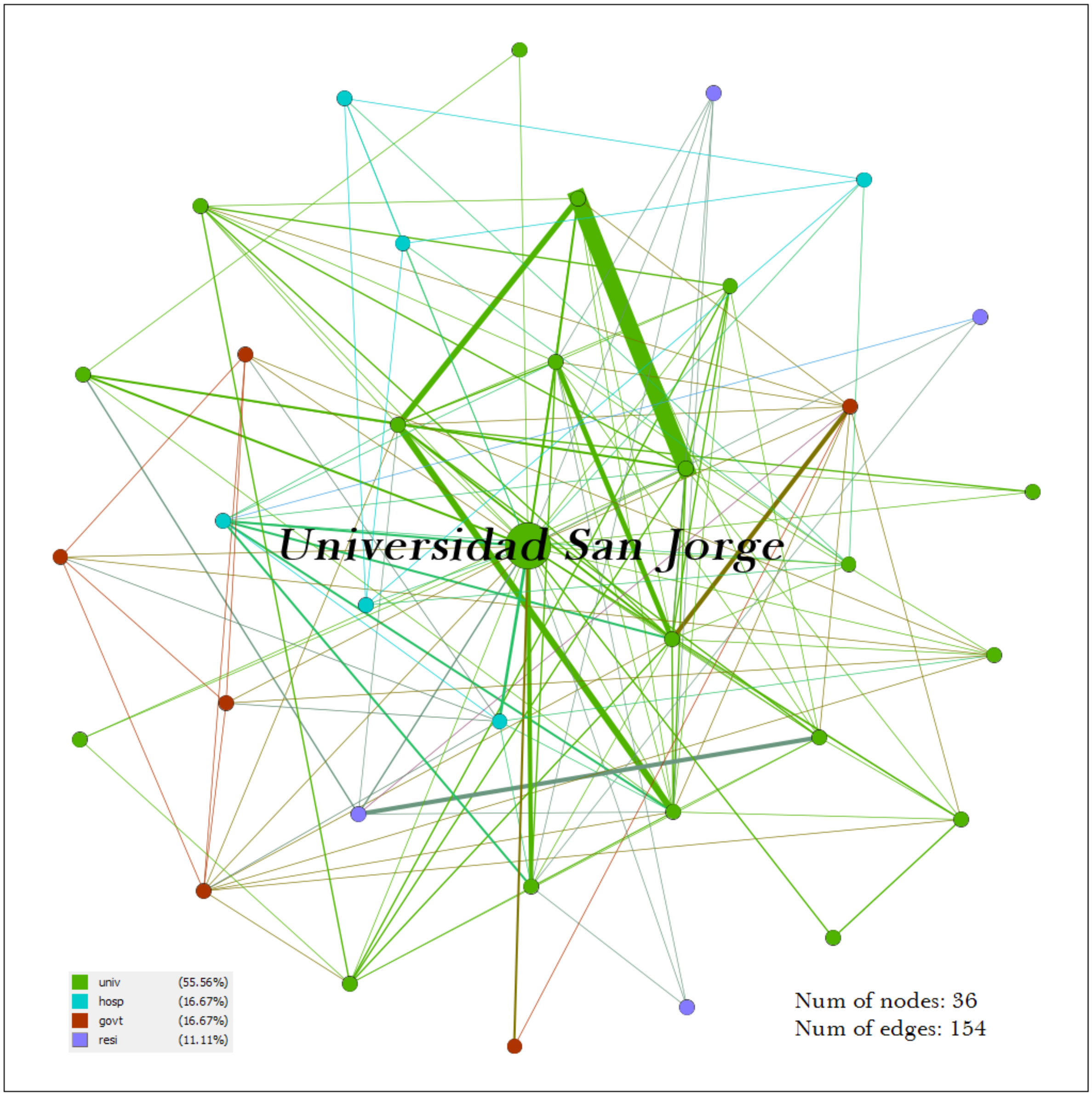

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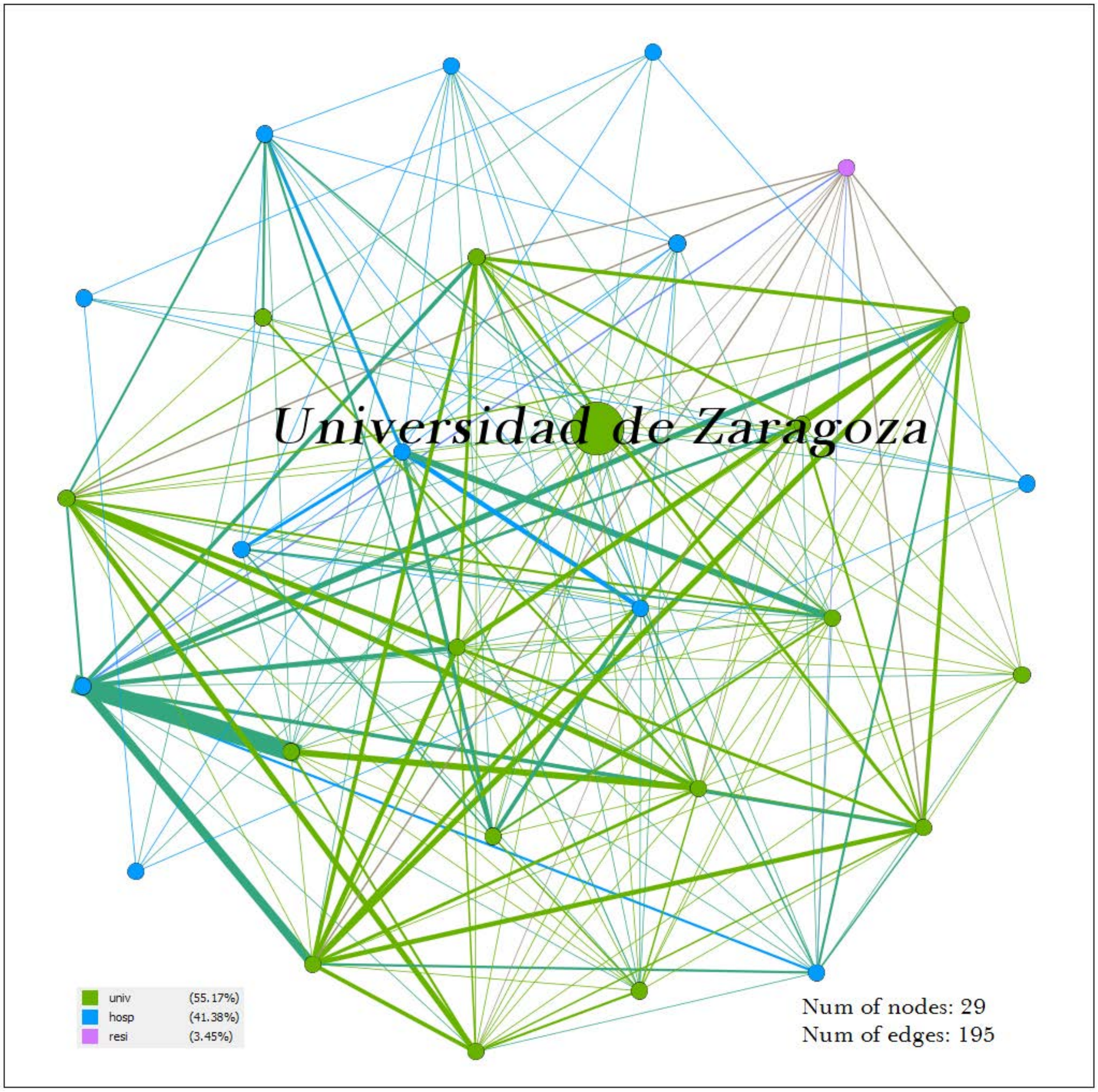

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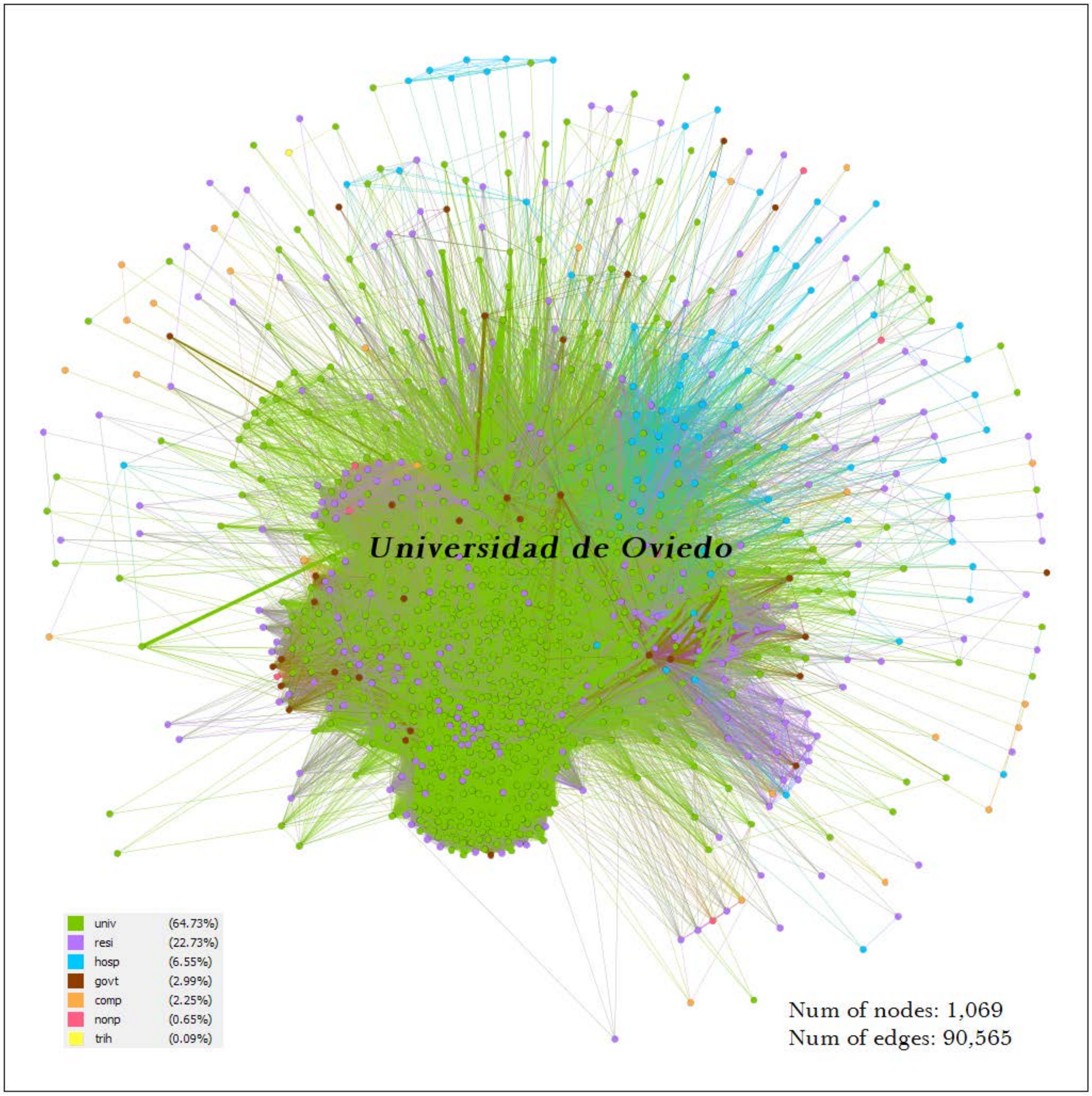
Asturias



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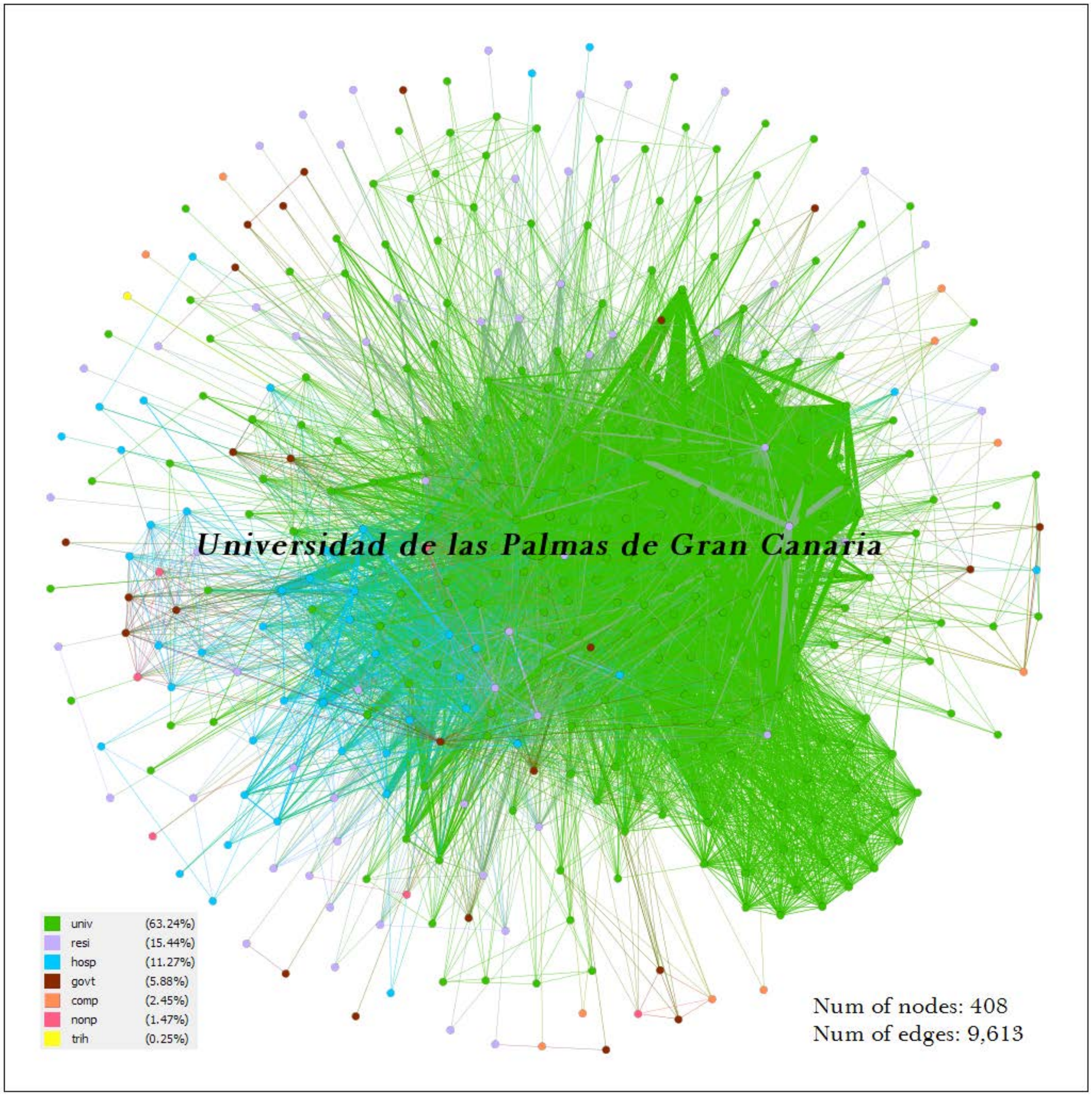

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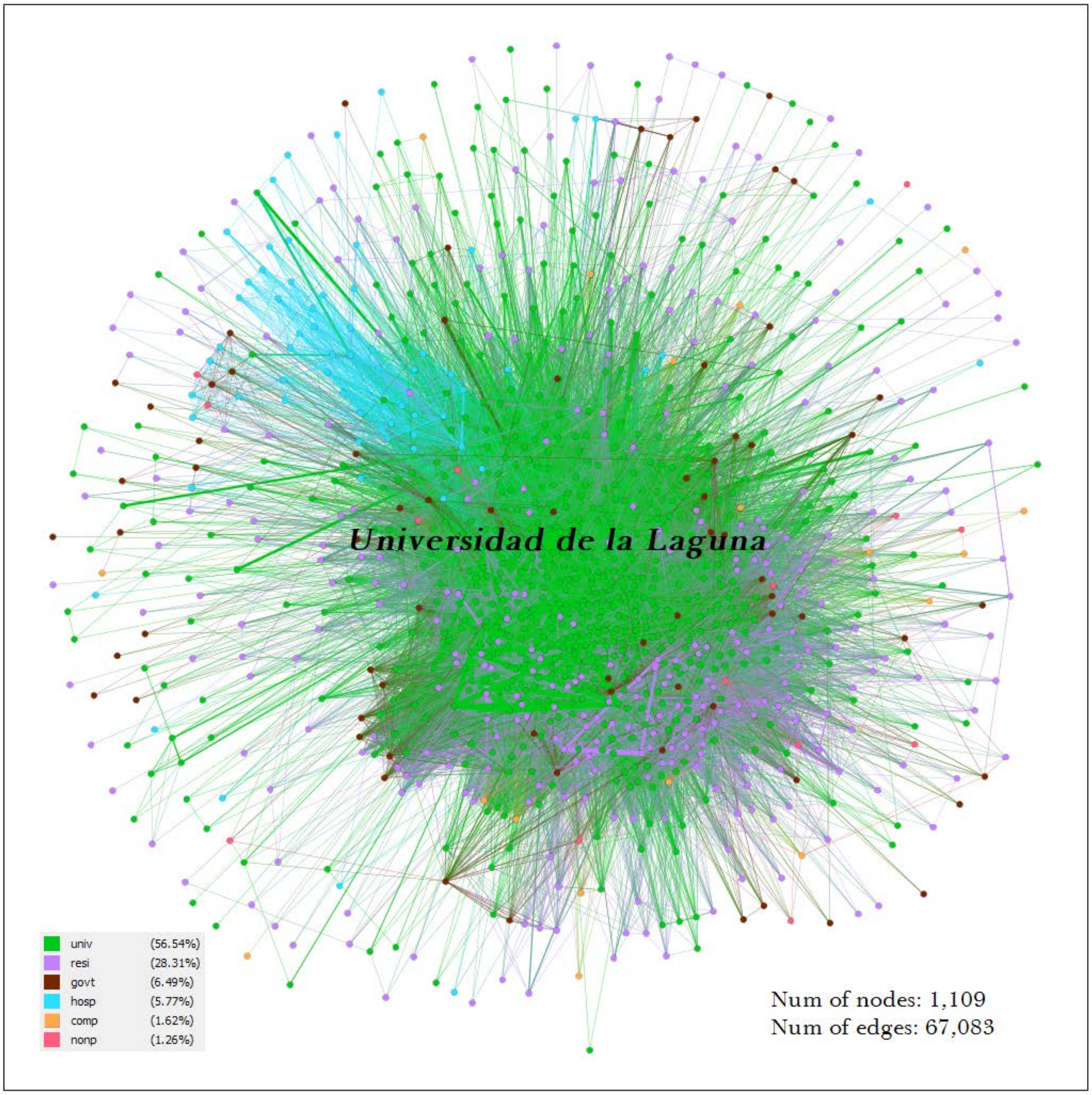

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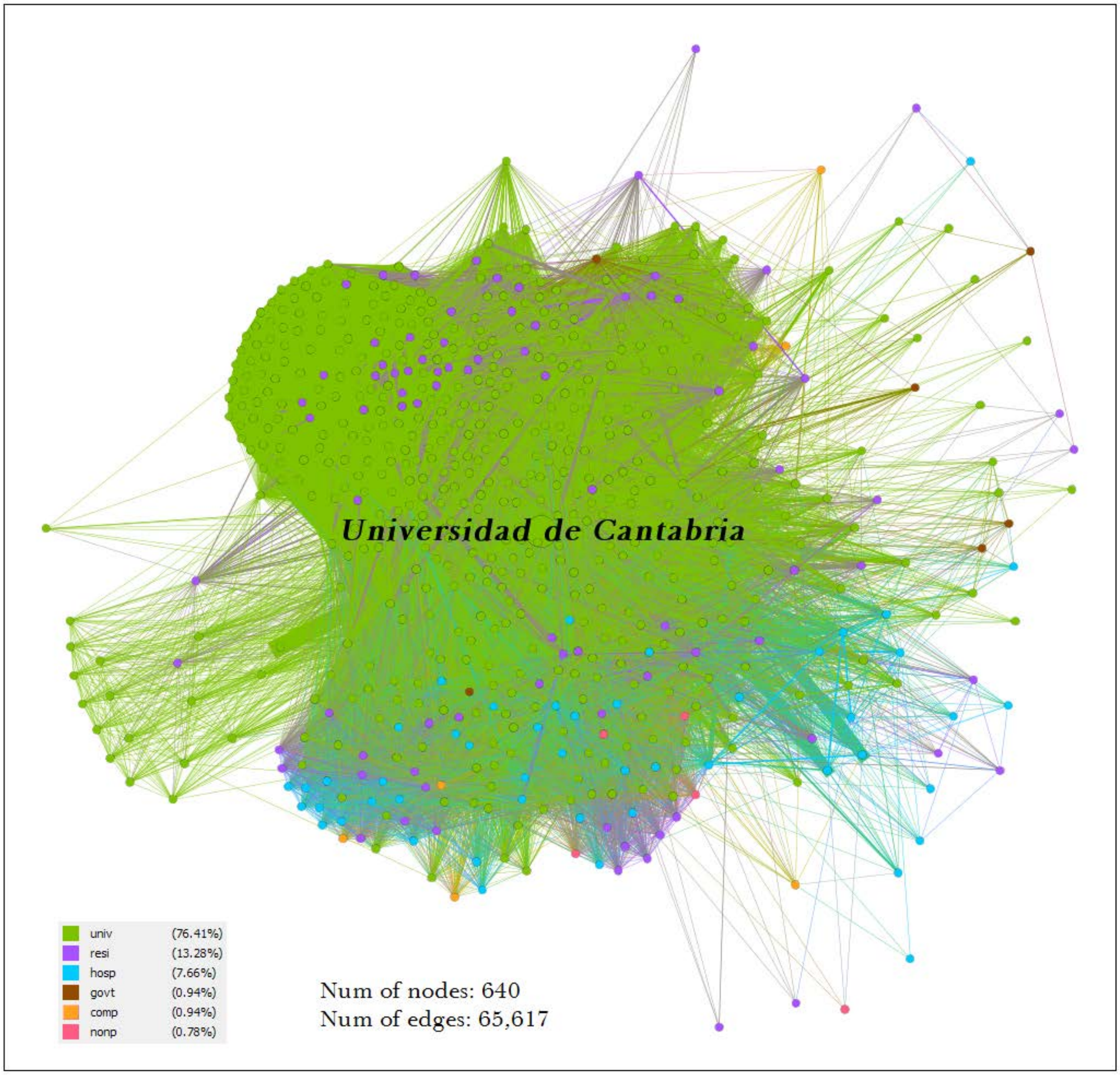
Cantabria



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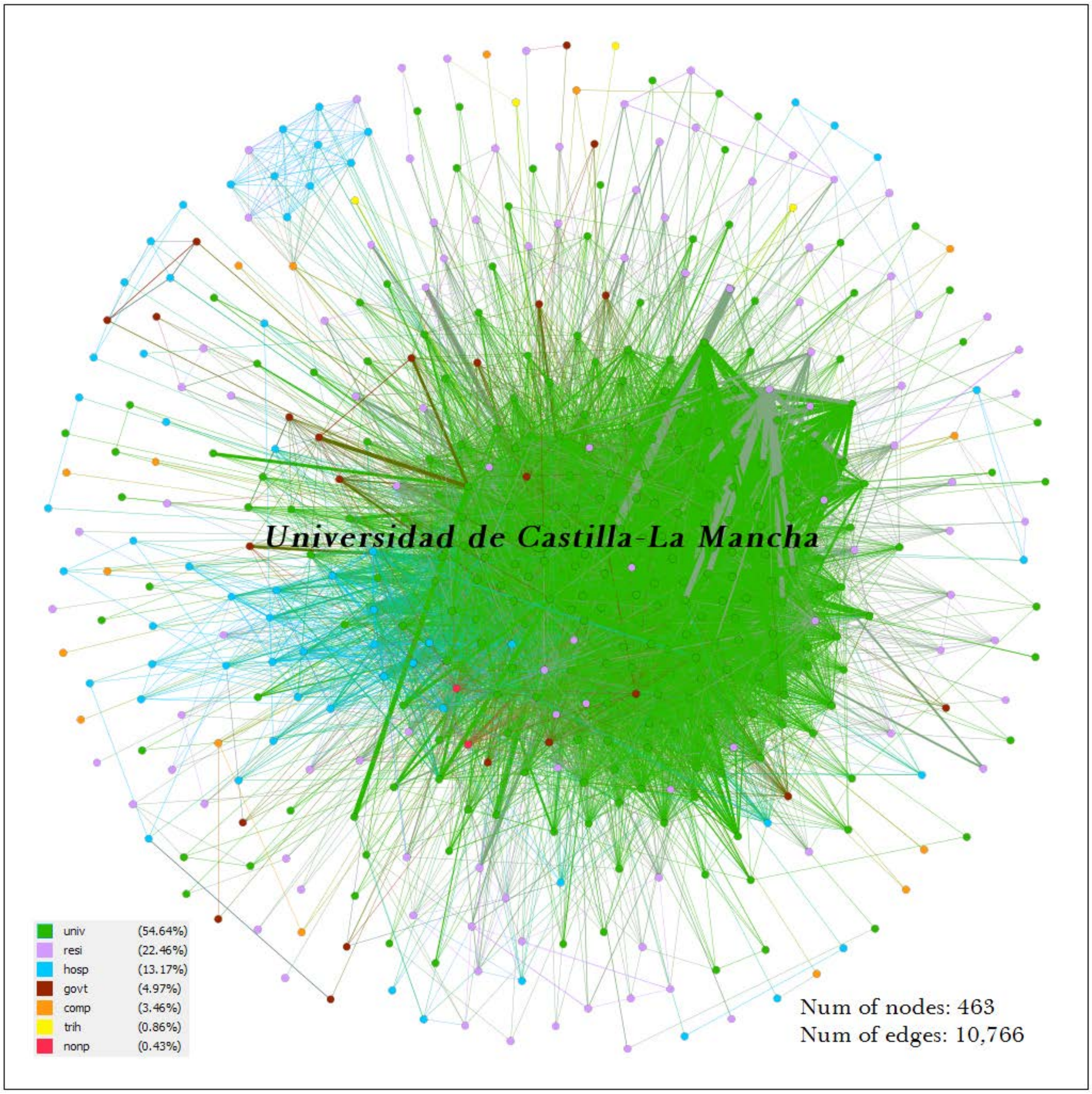
Castilla-La Mancha



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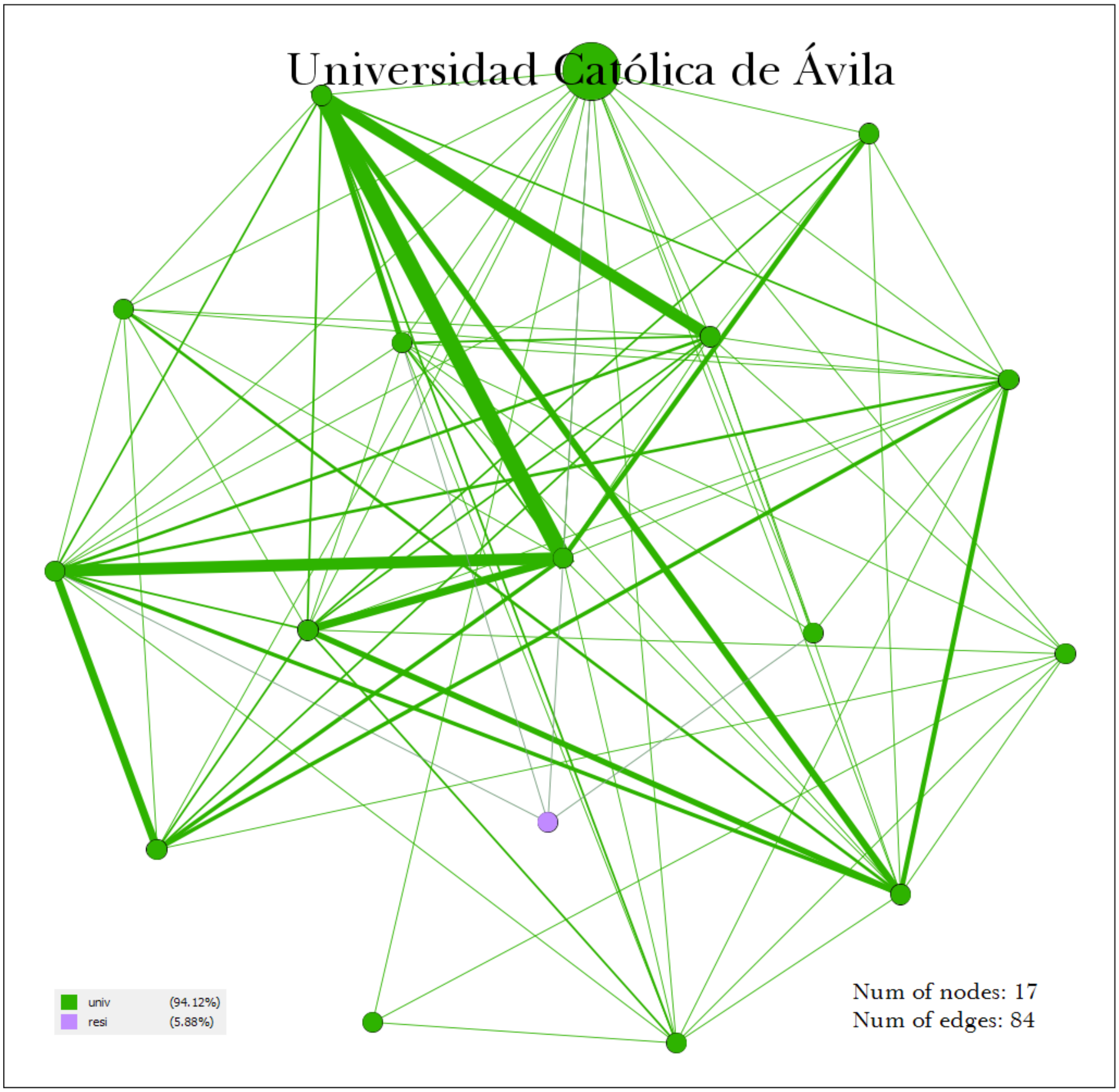
Castilla y León



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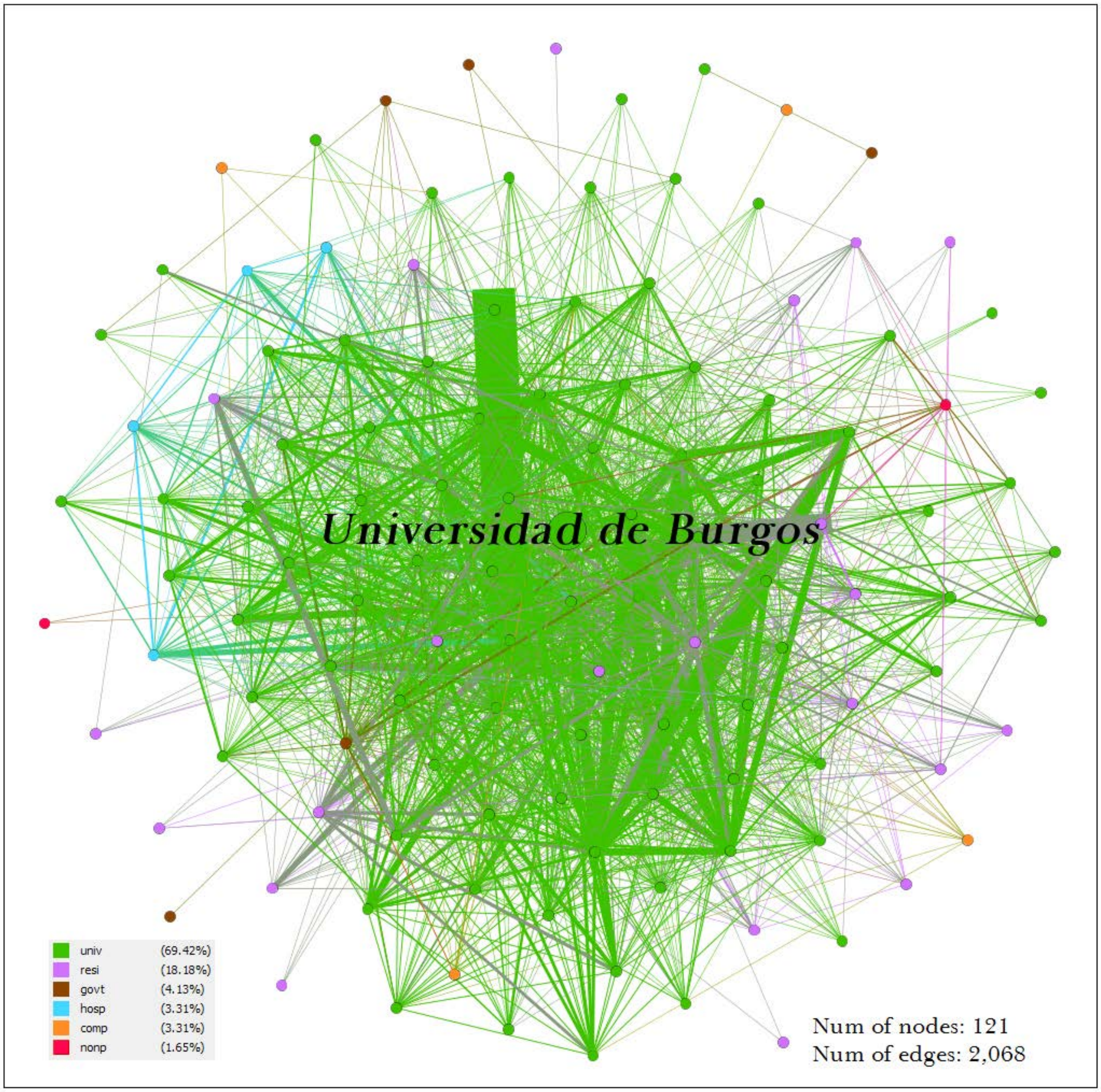

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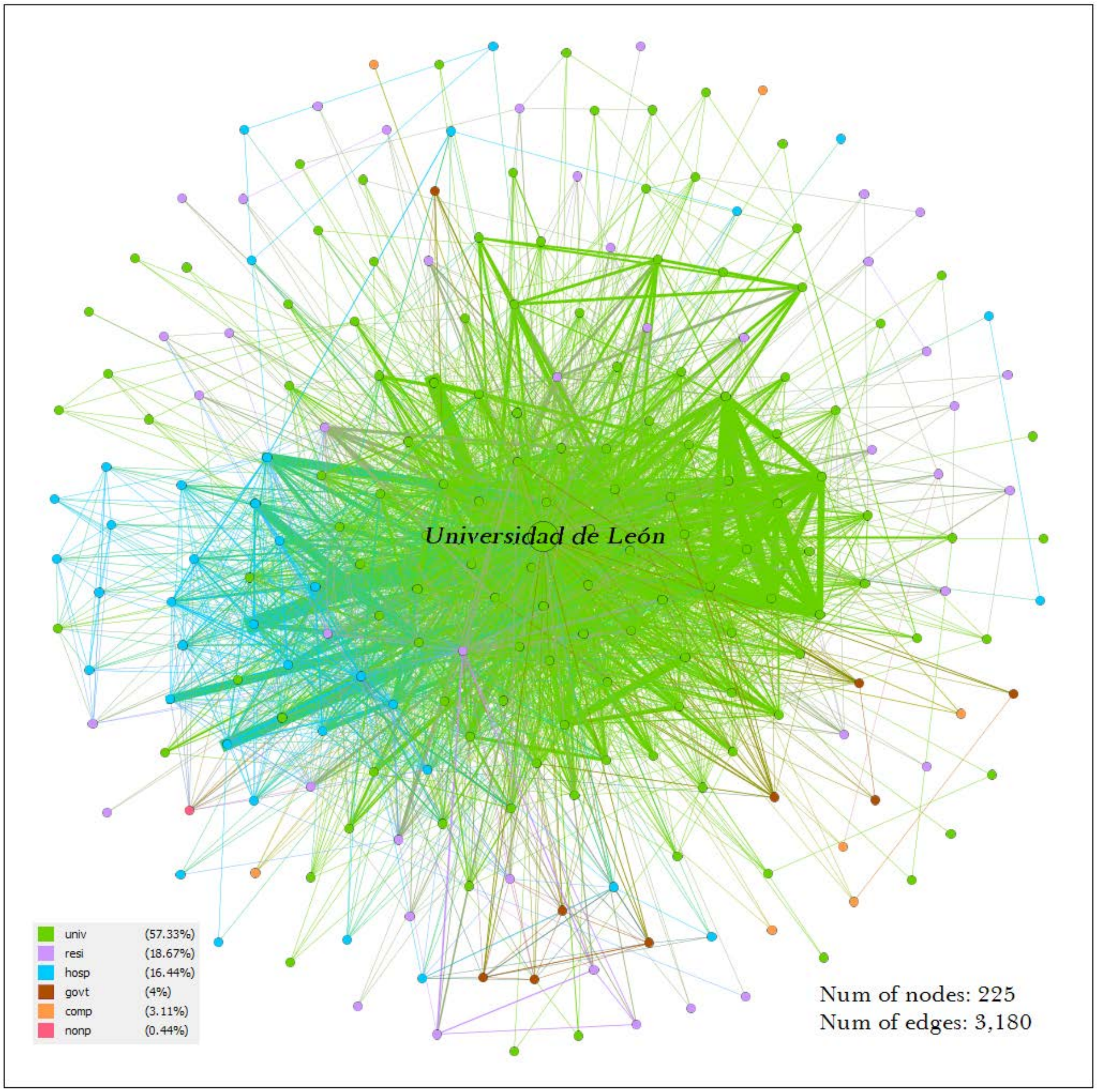

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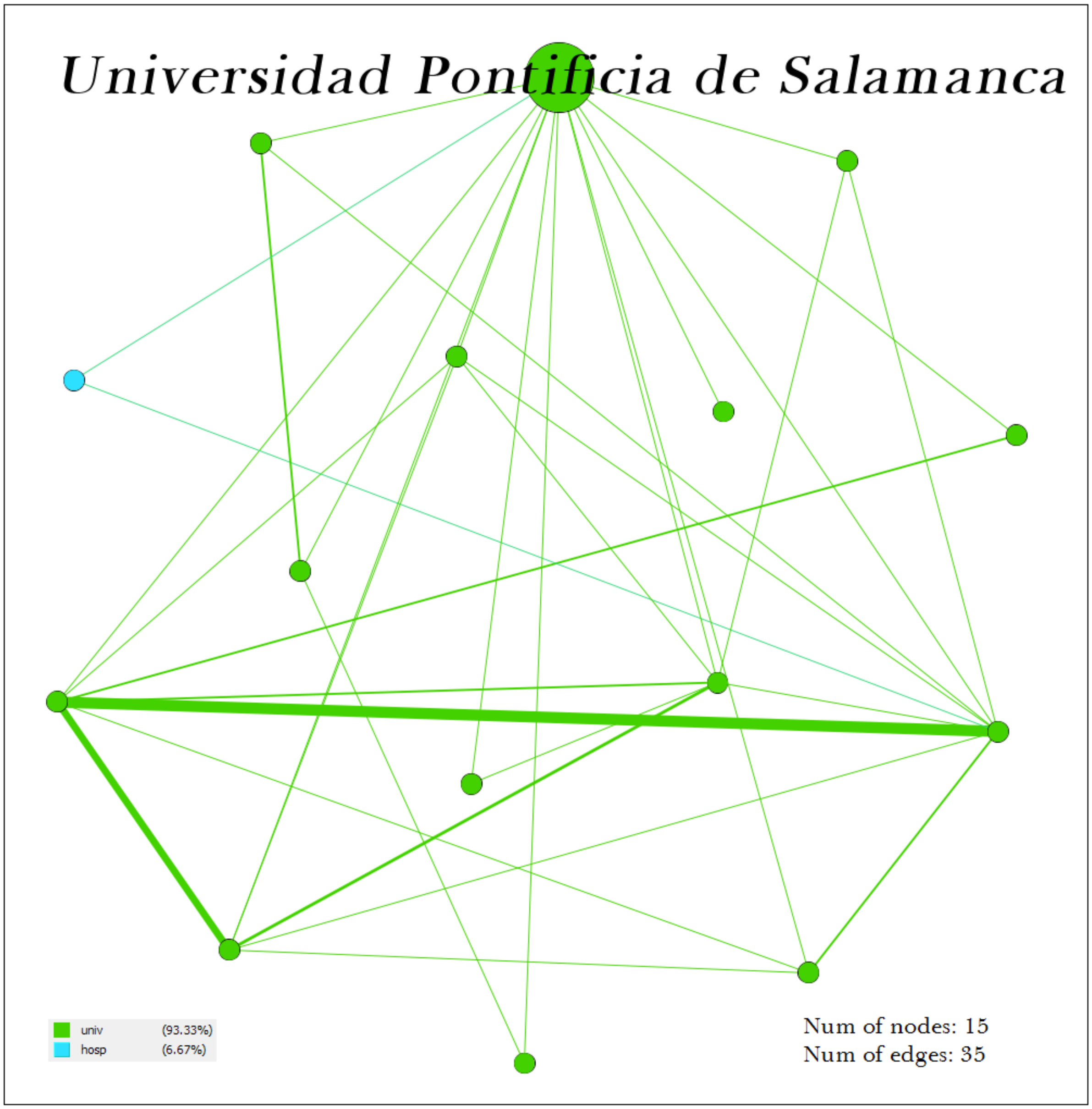

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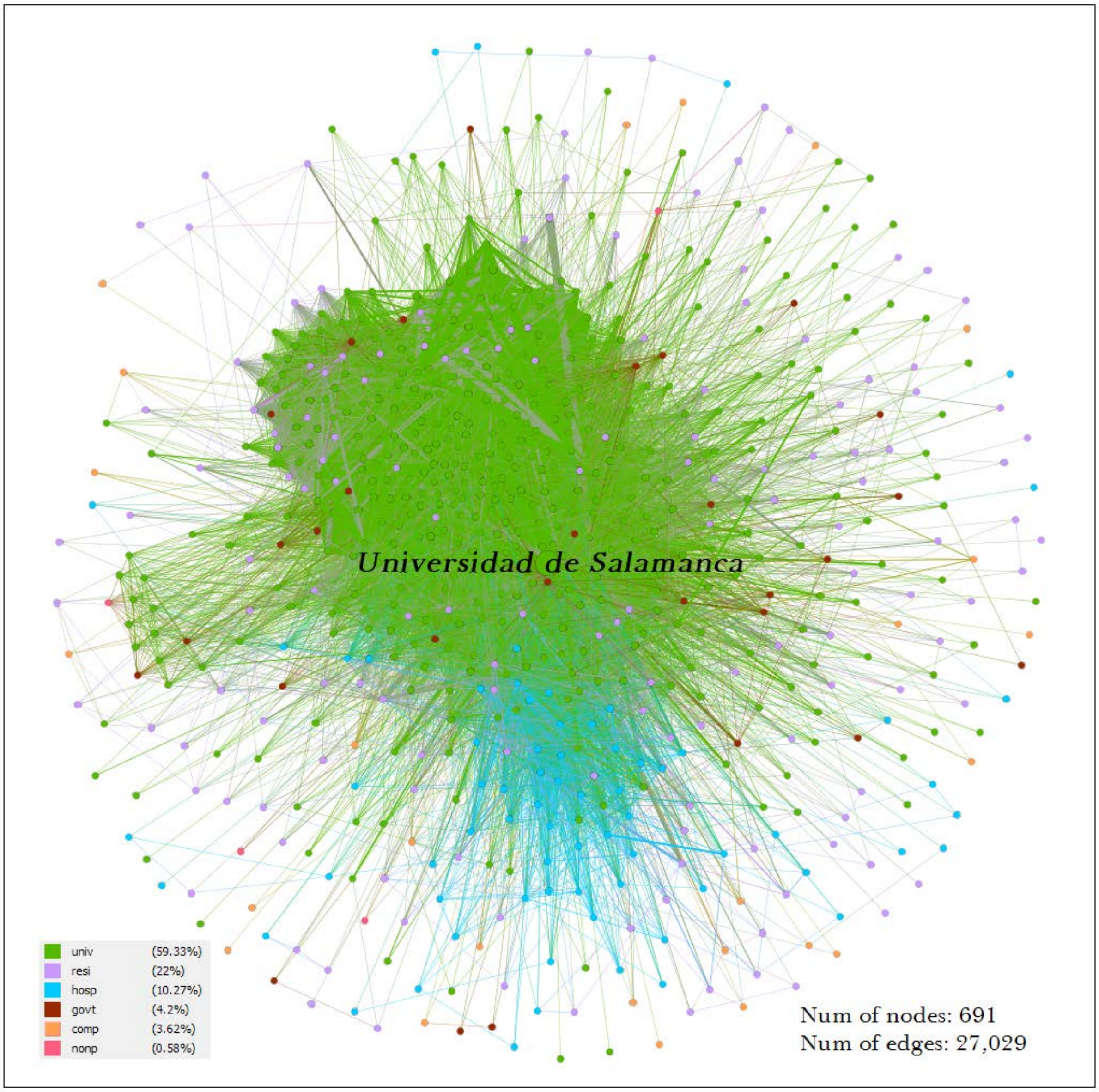

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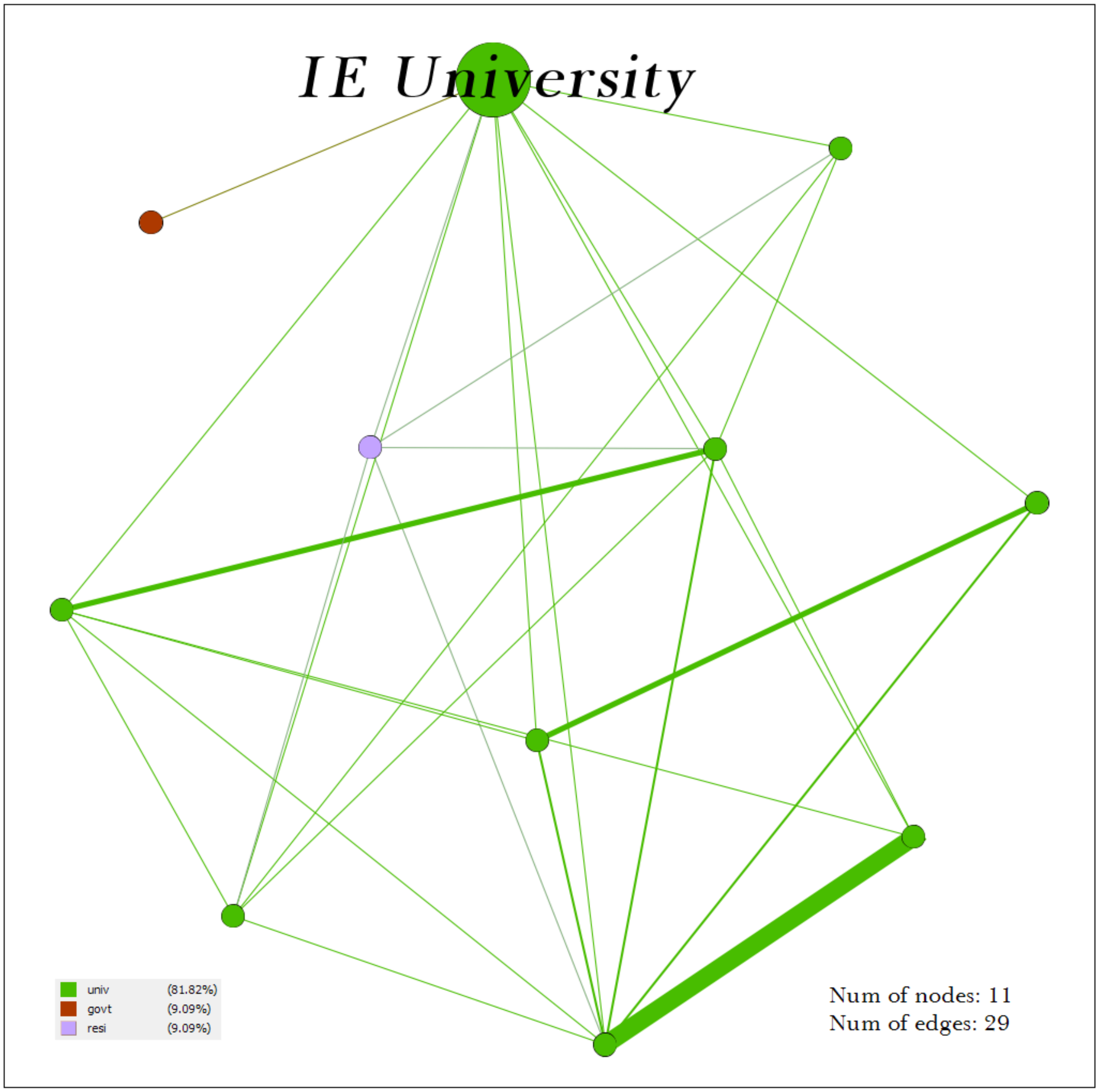

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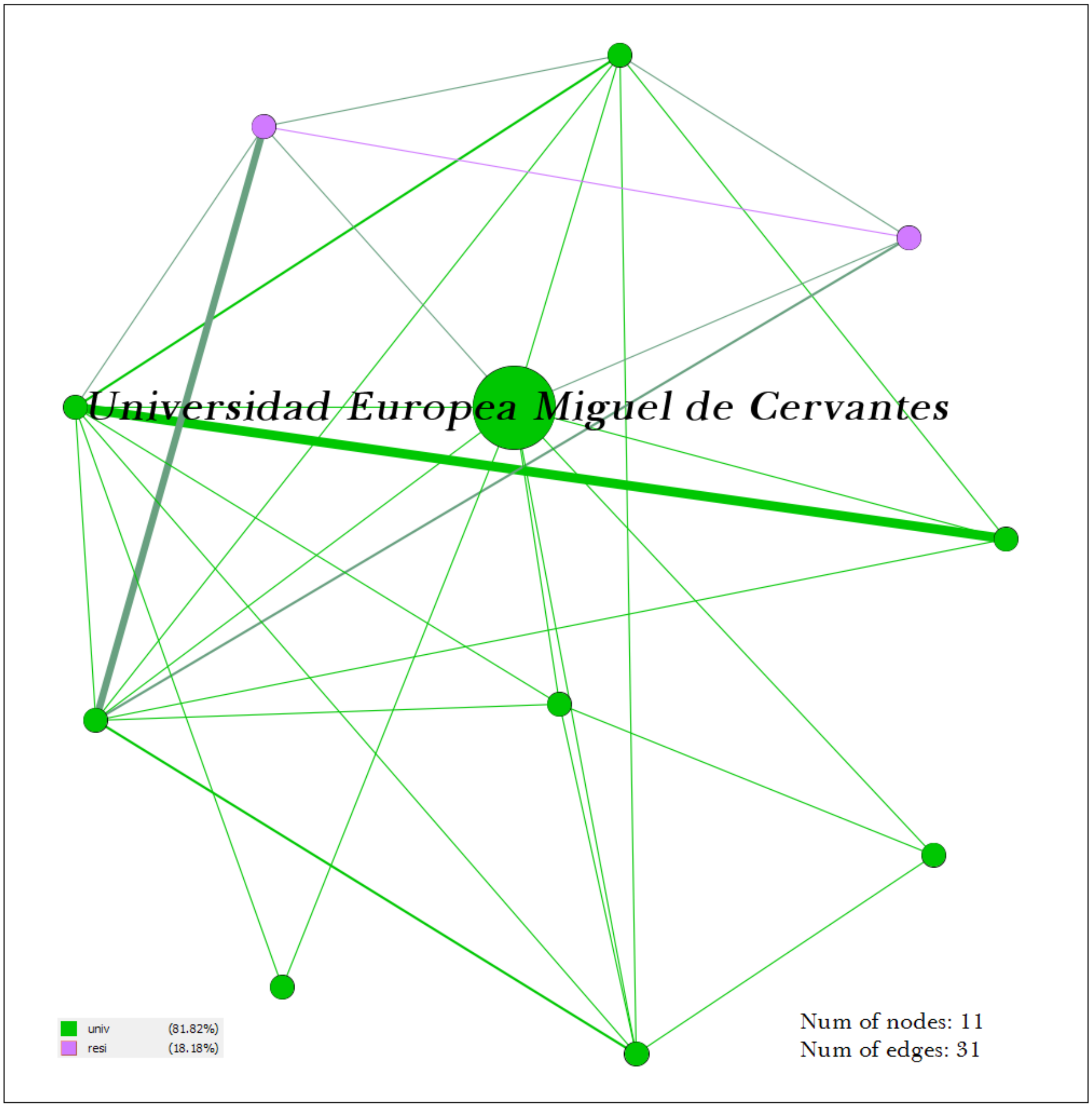

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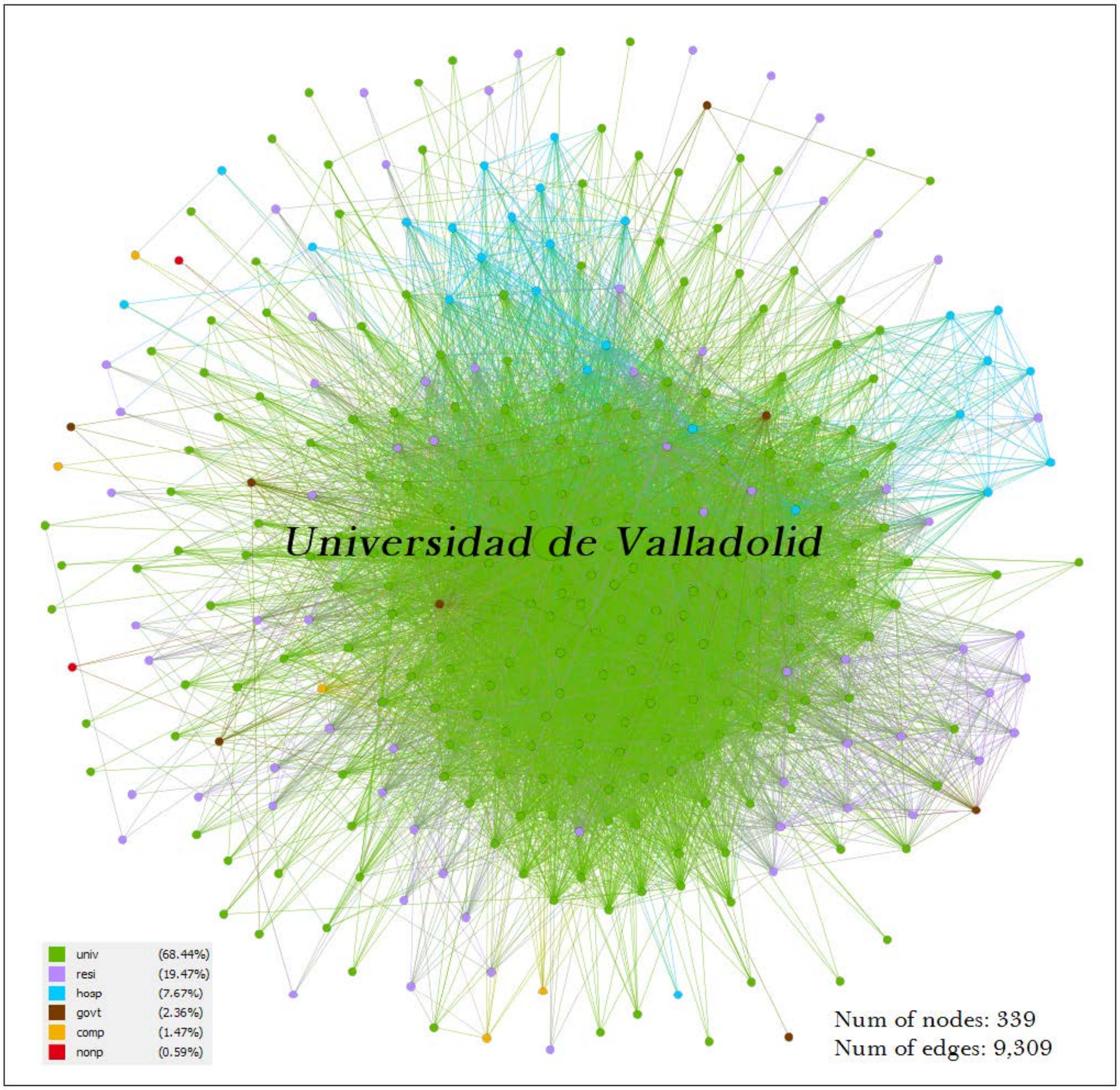

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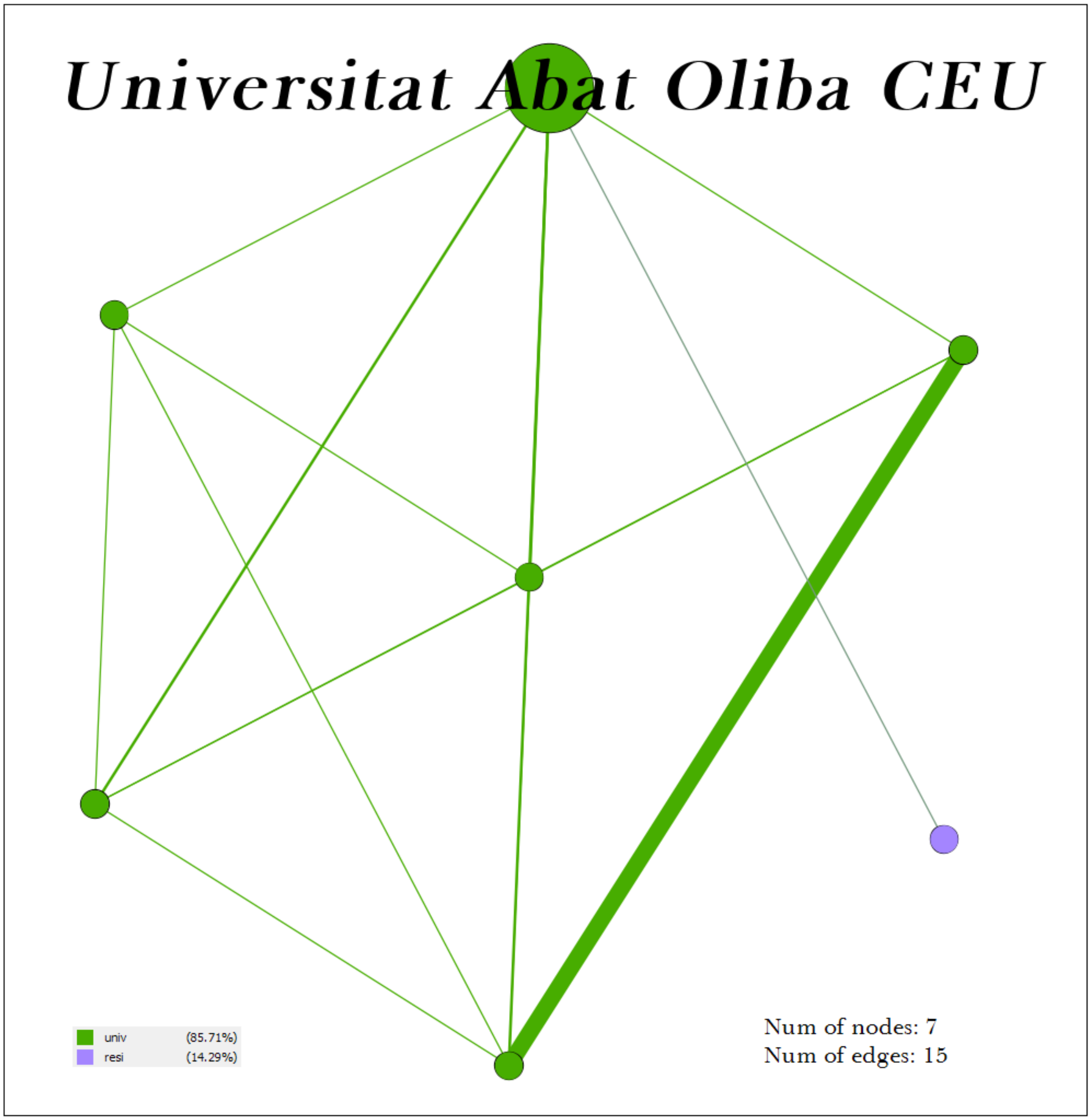
Cataluña



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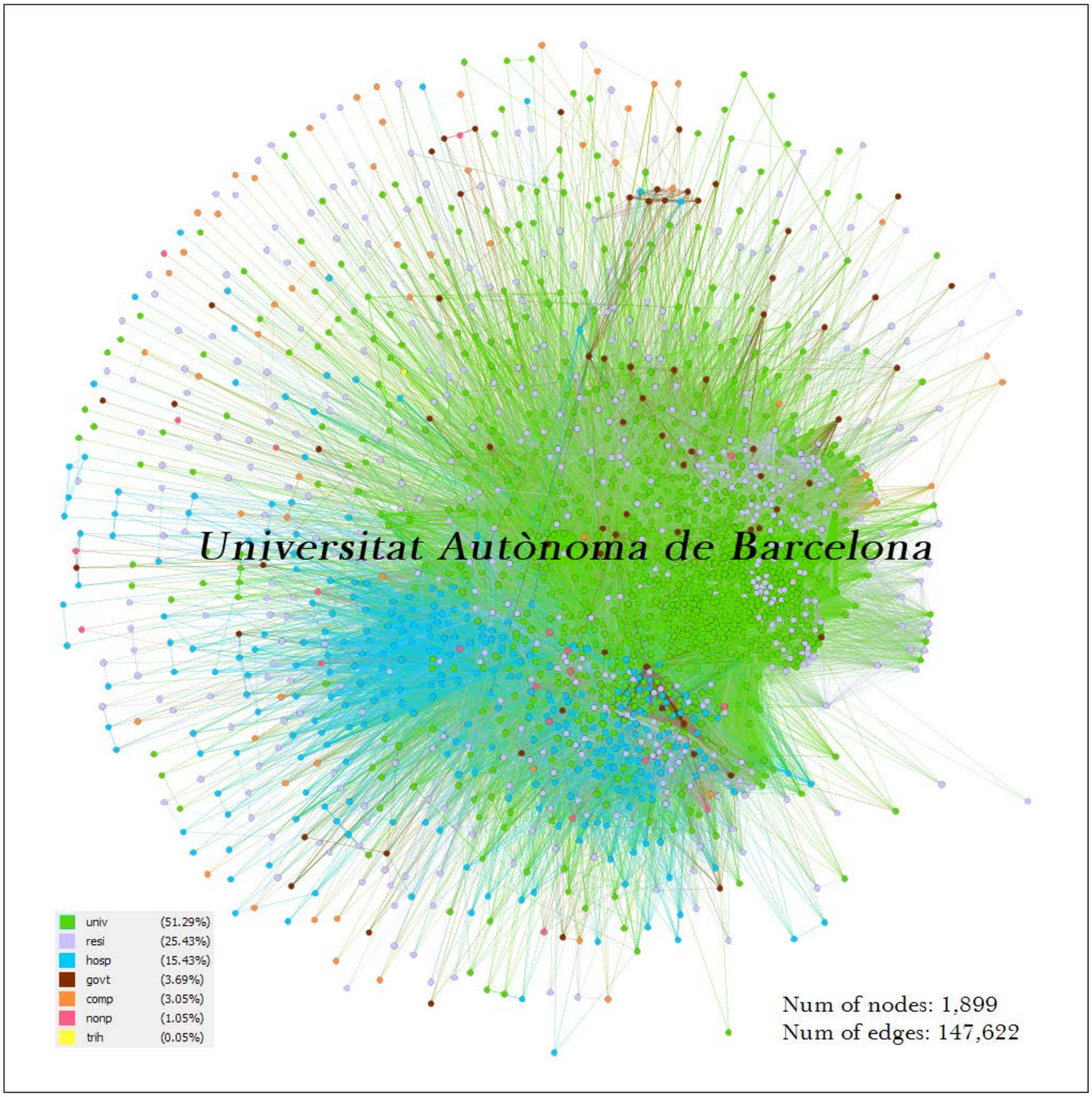

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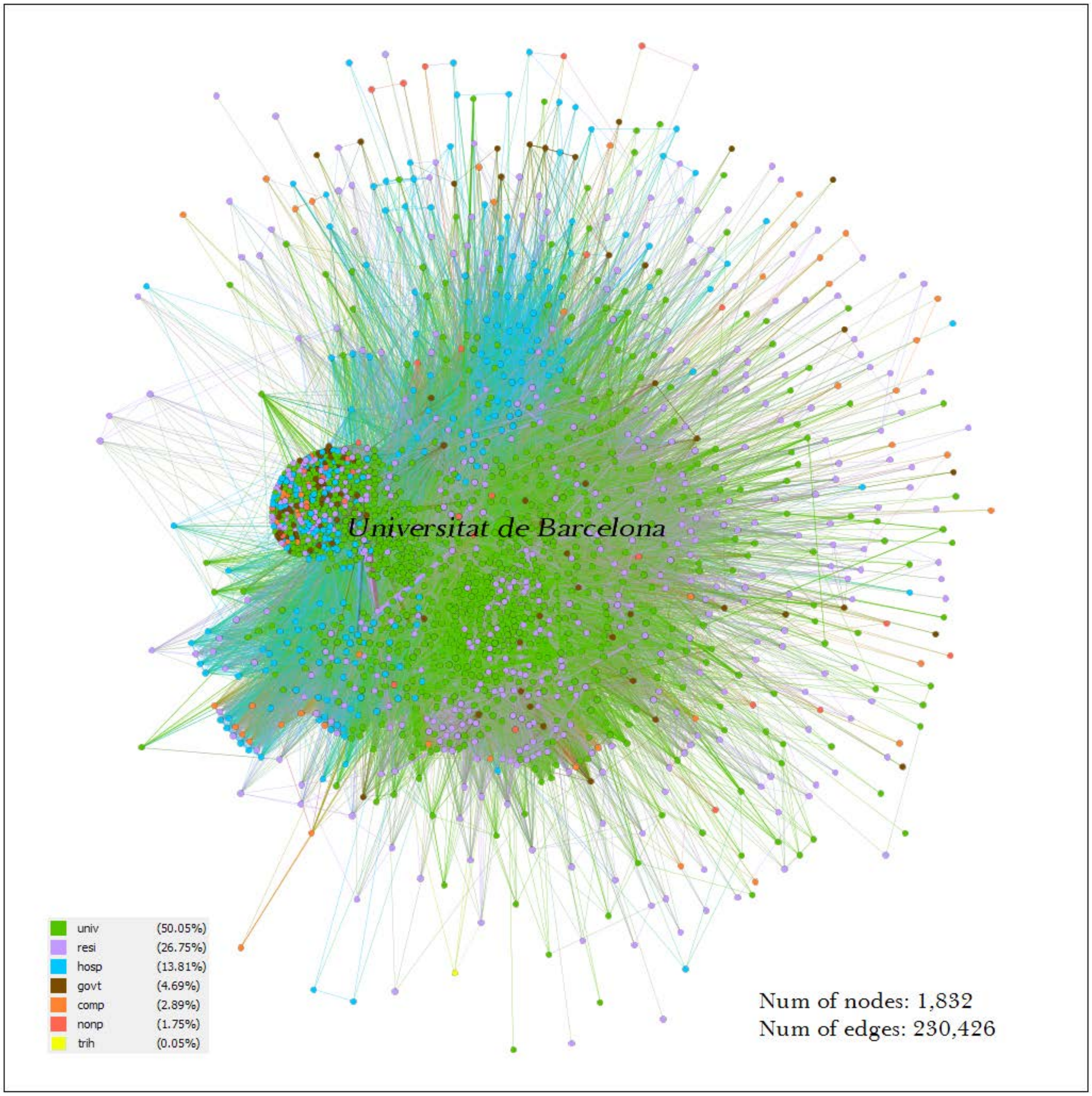

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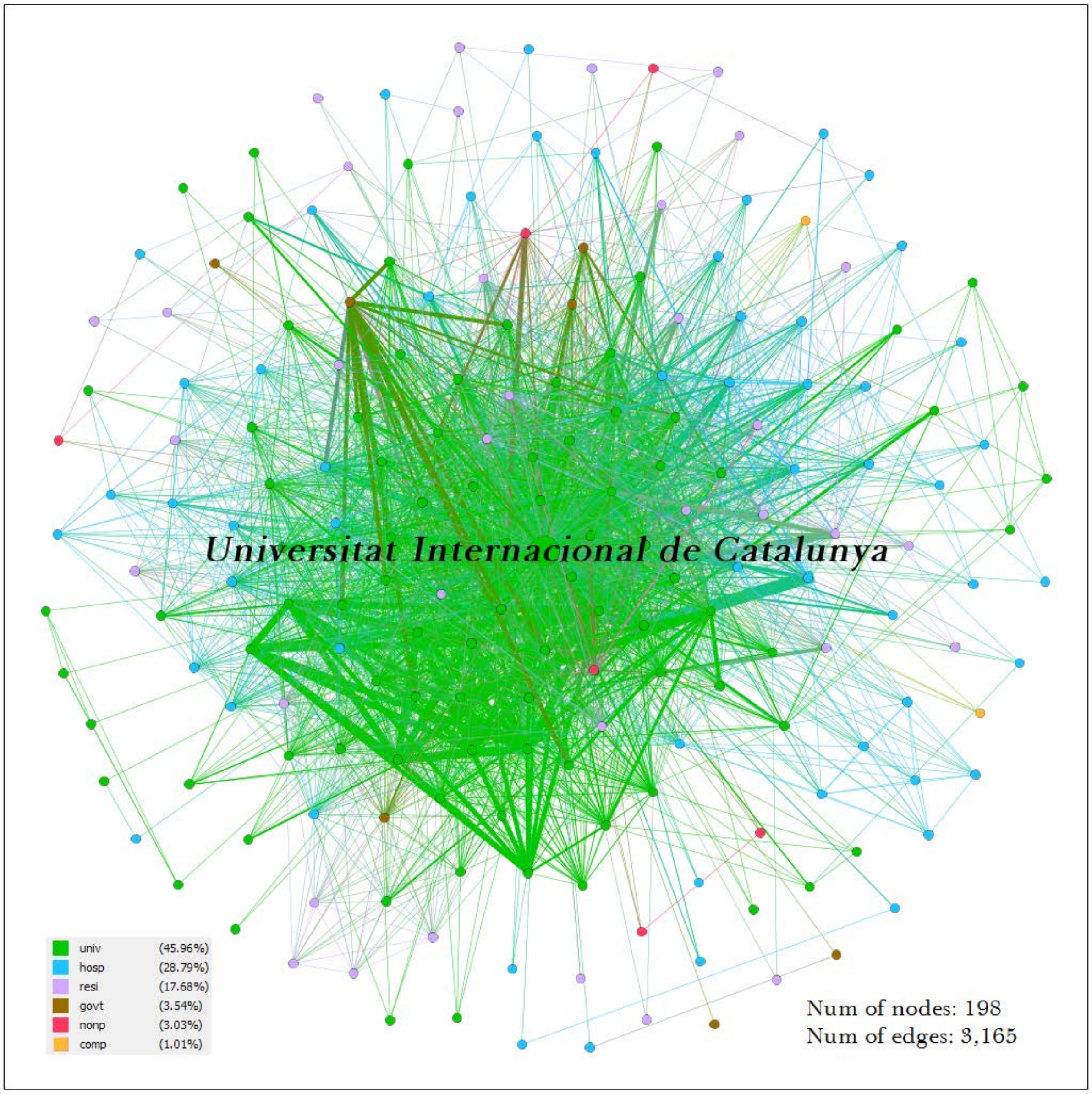

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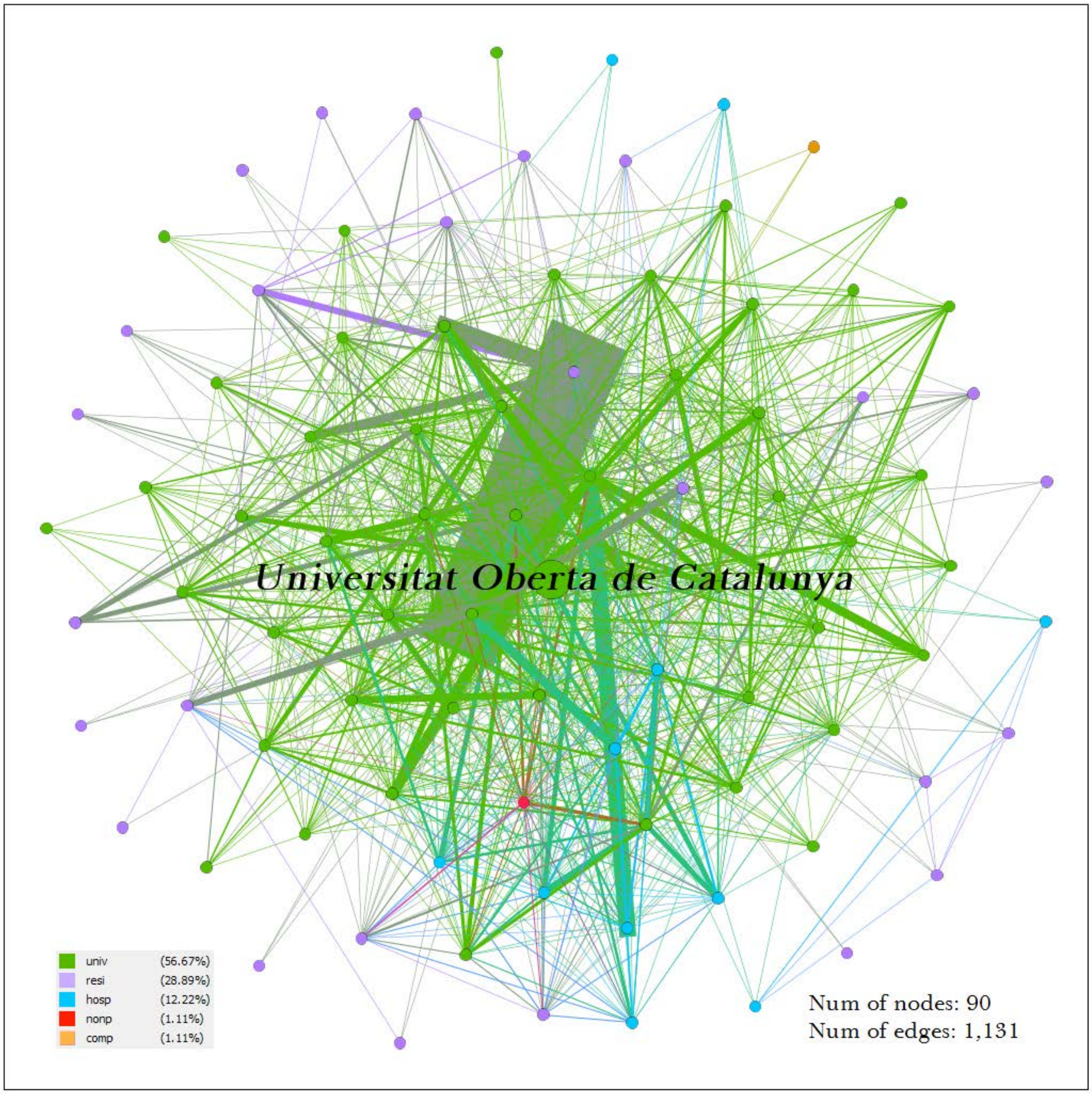

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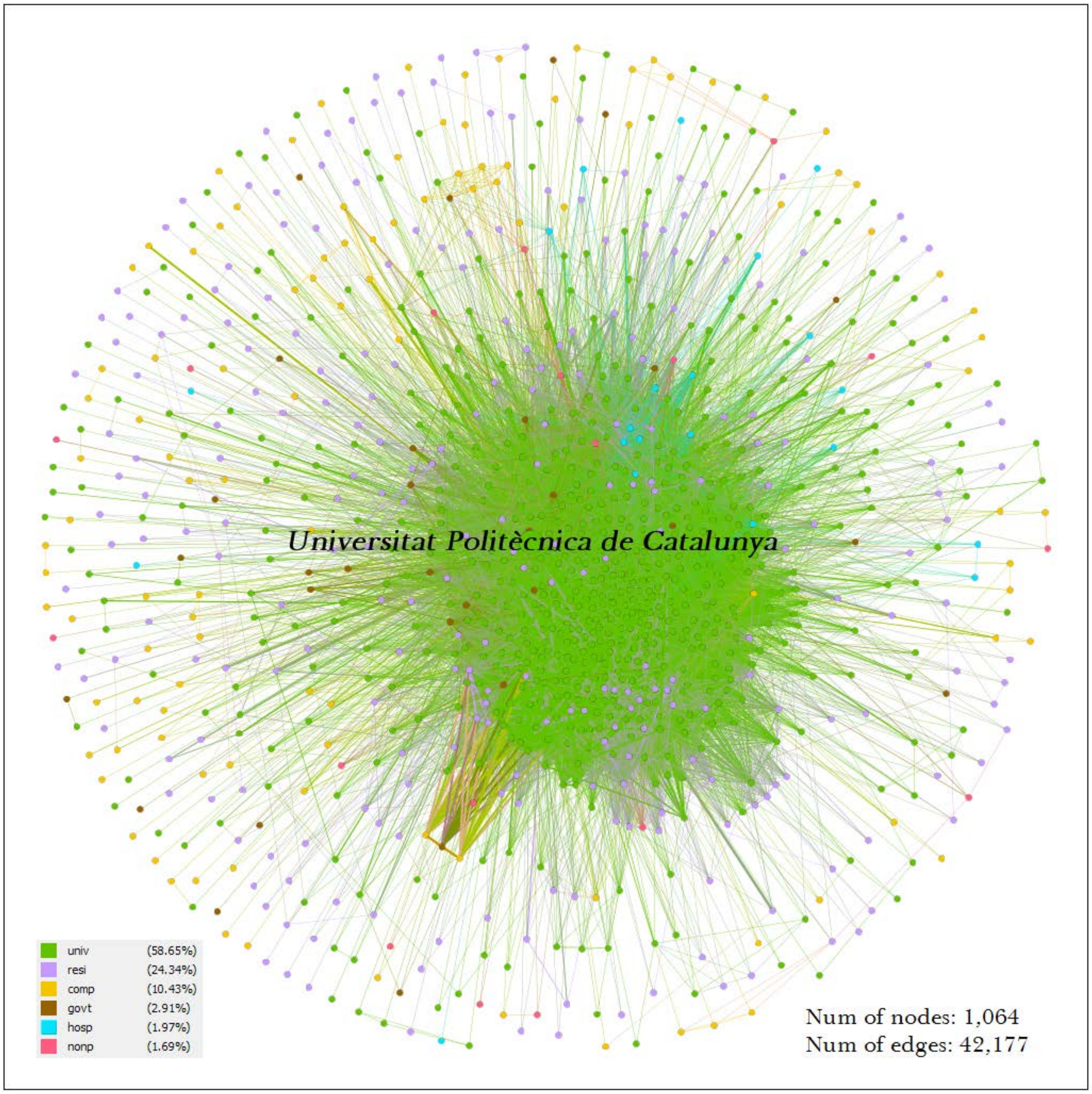

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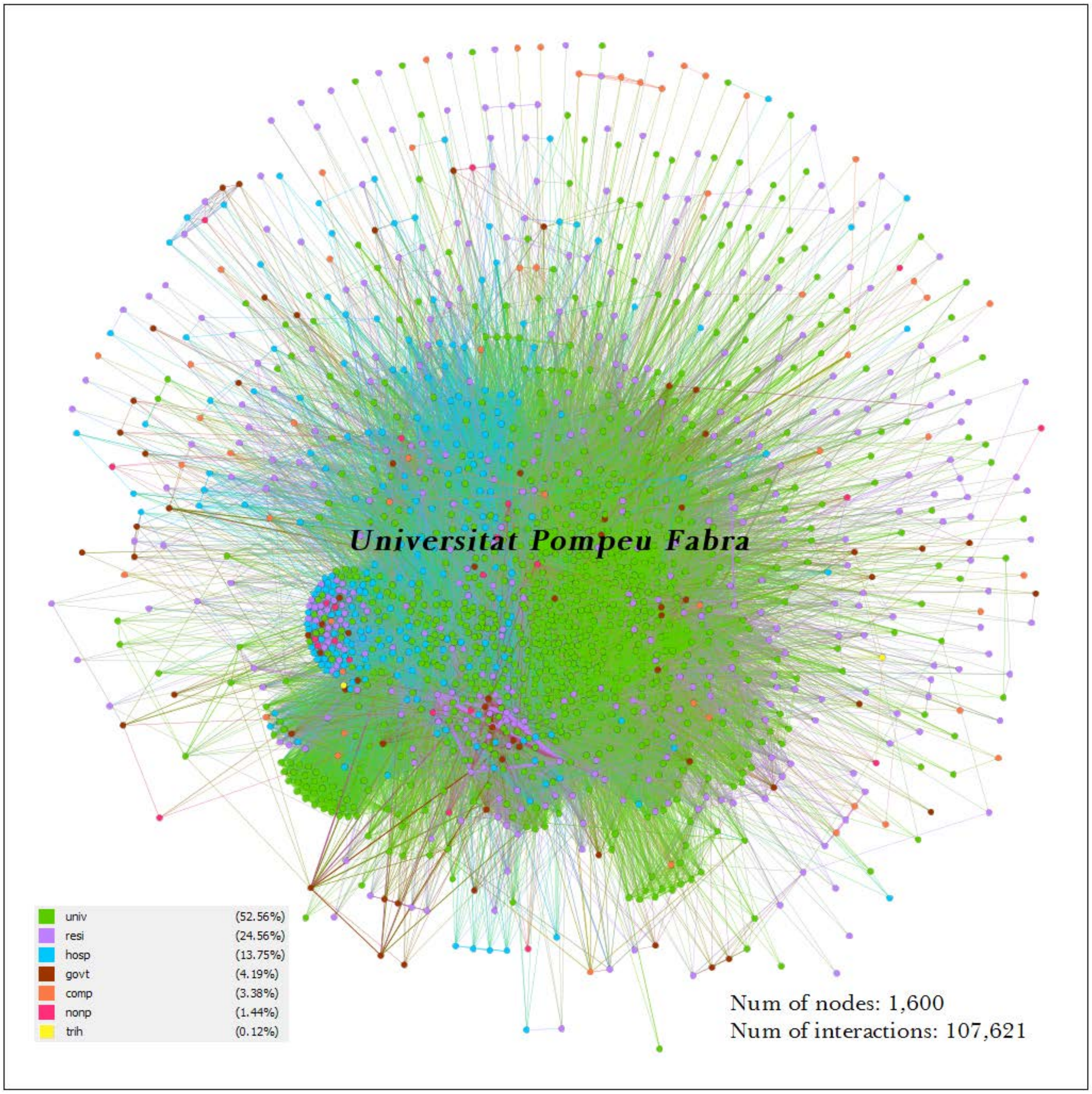

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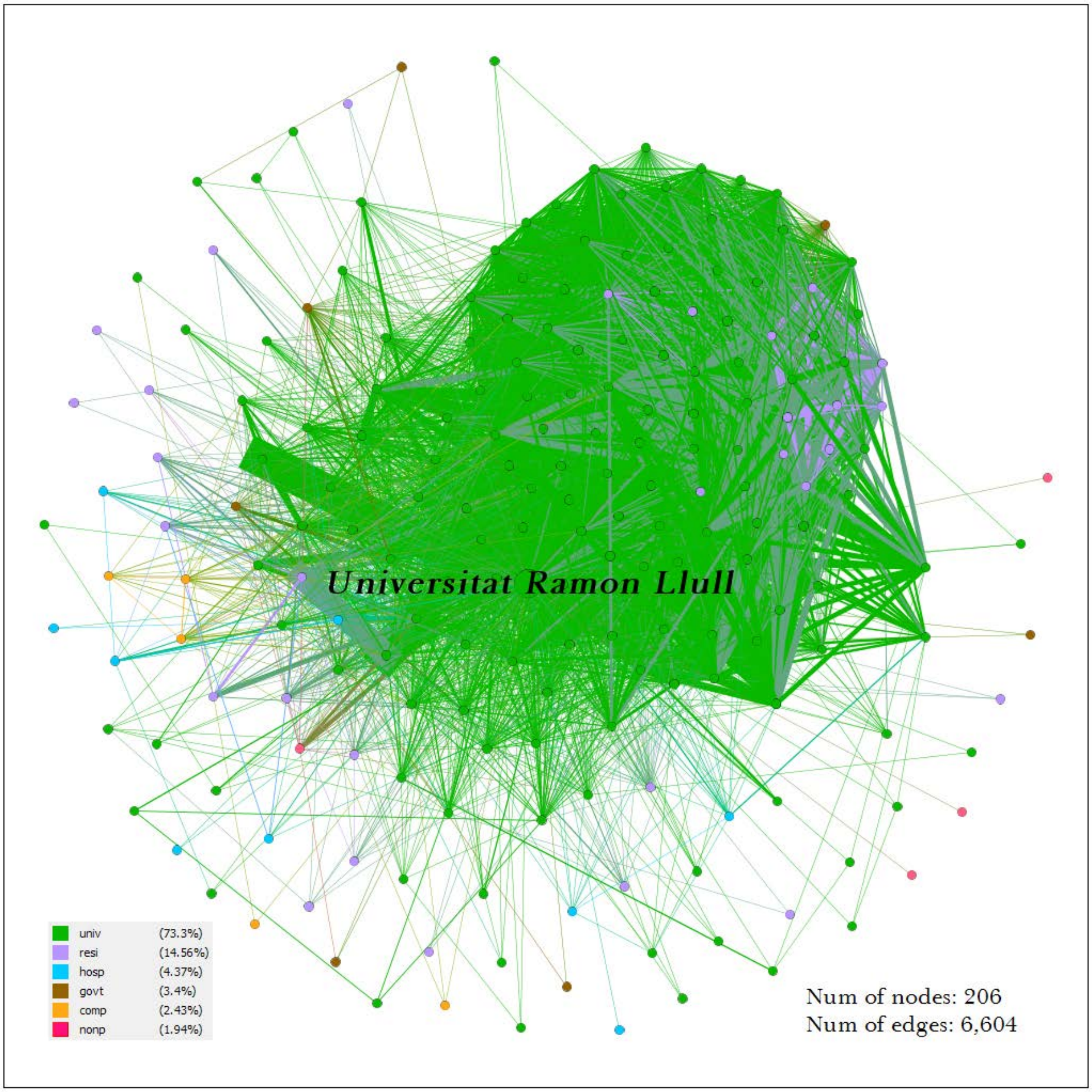

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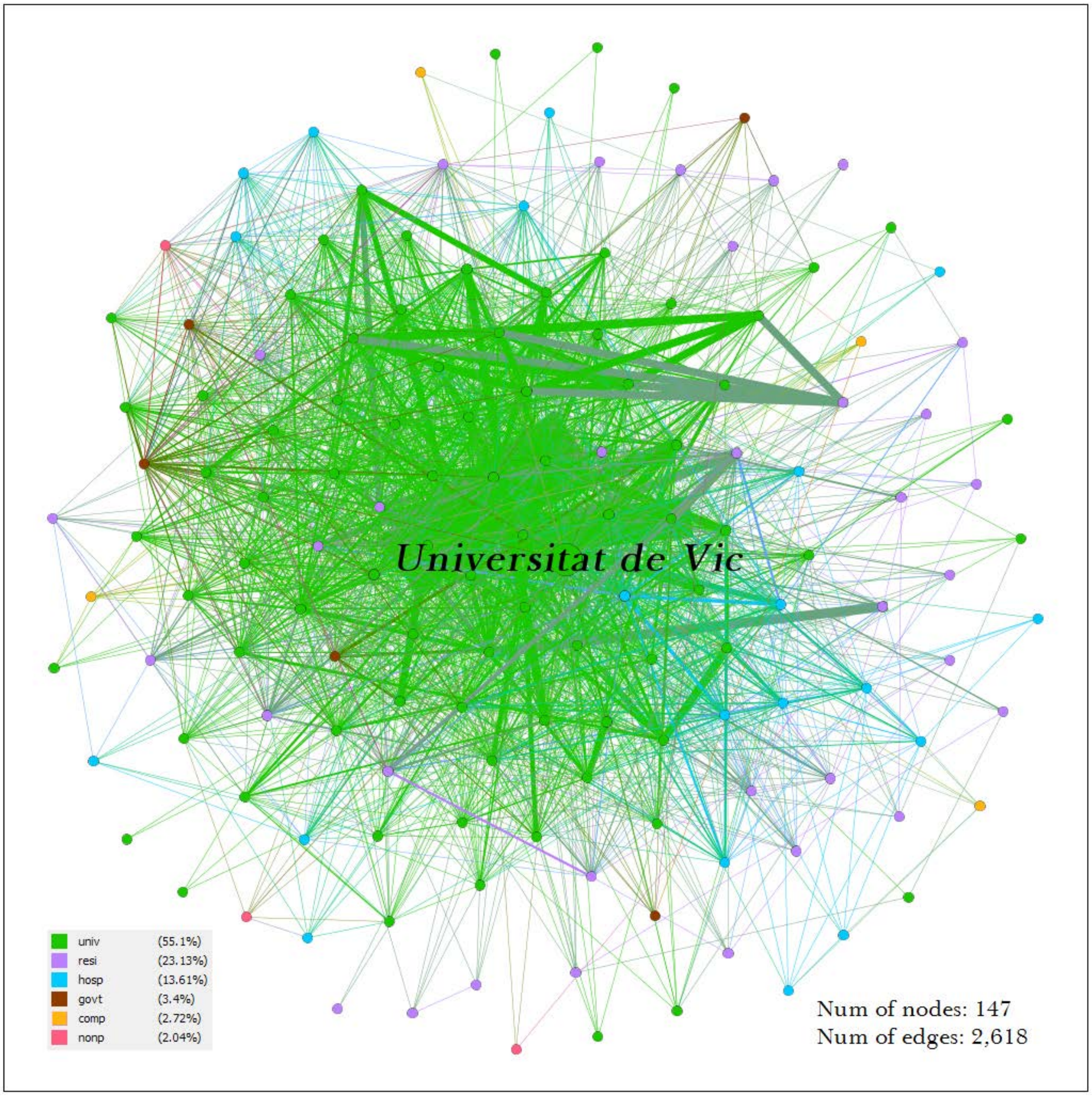

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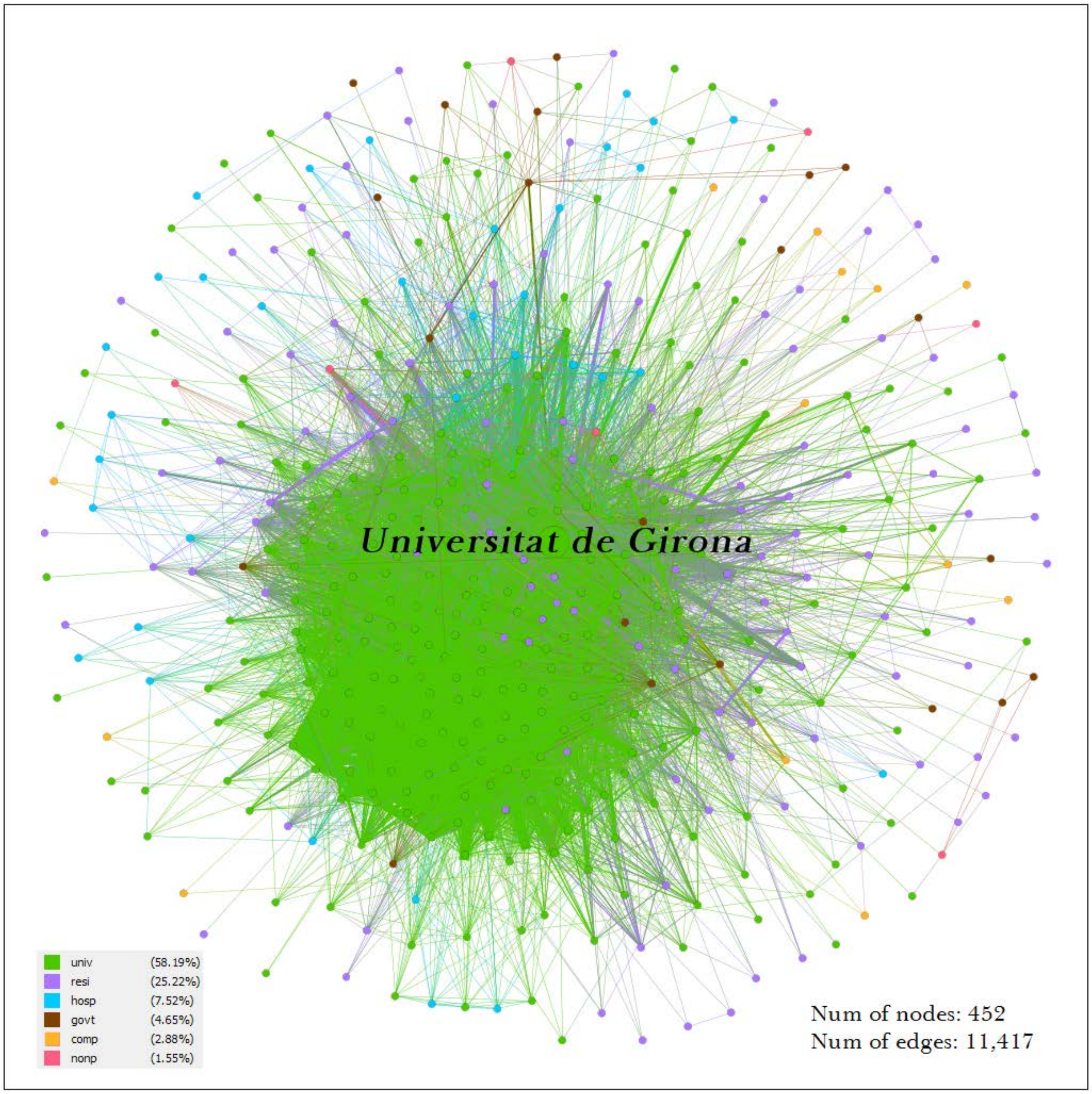

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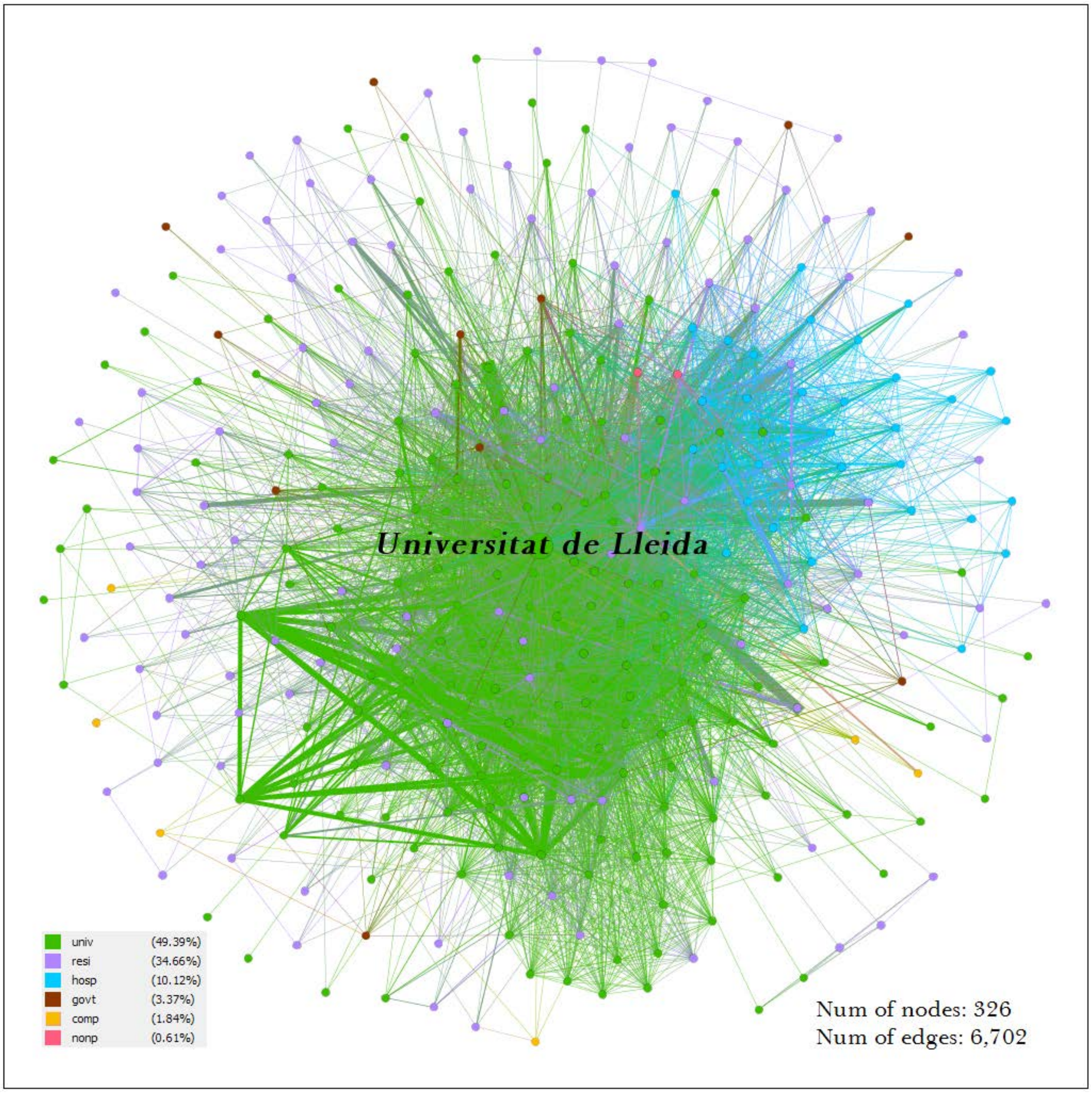

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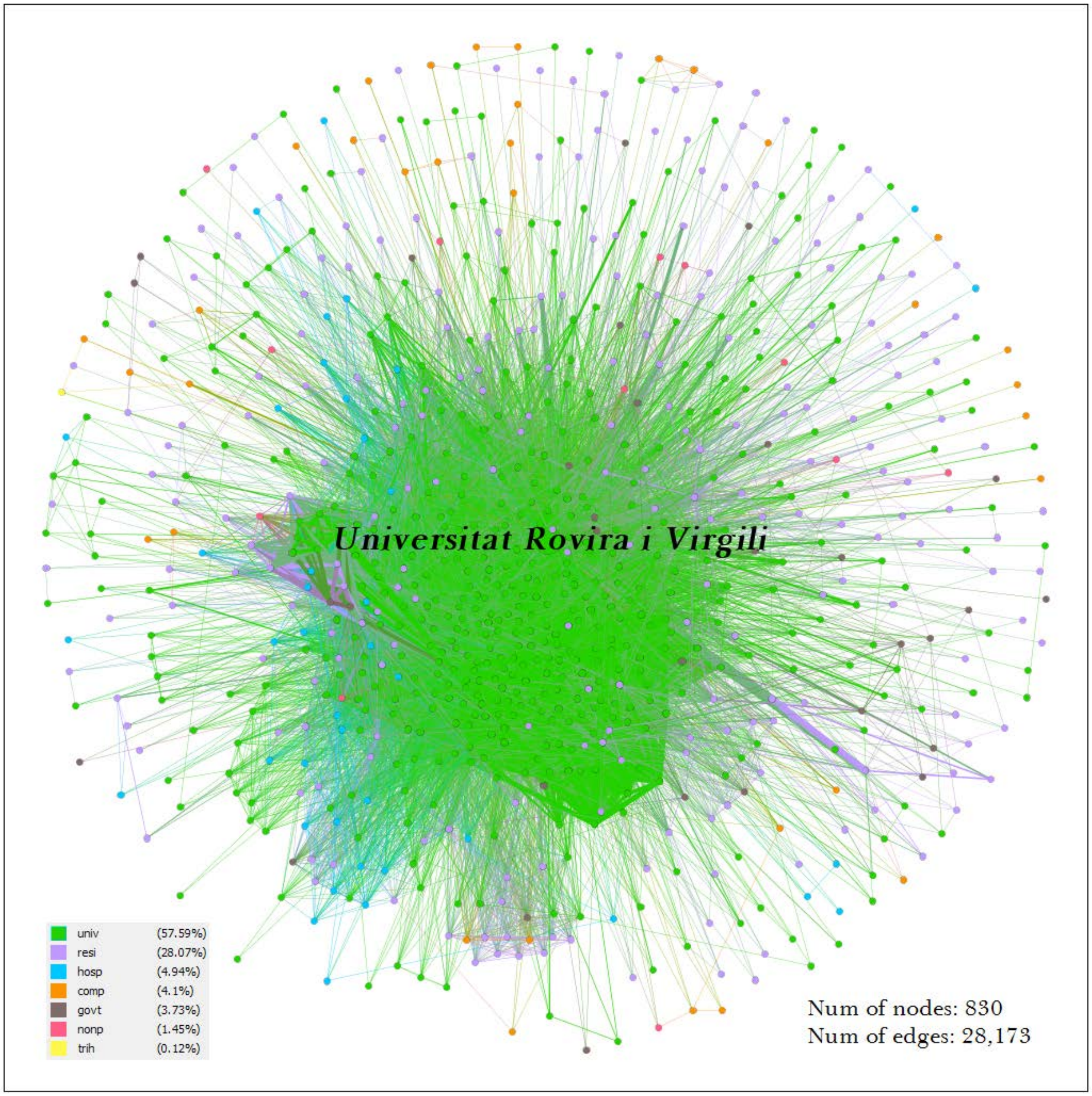

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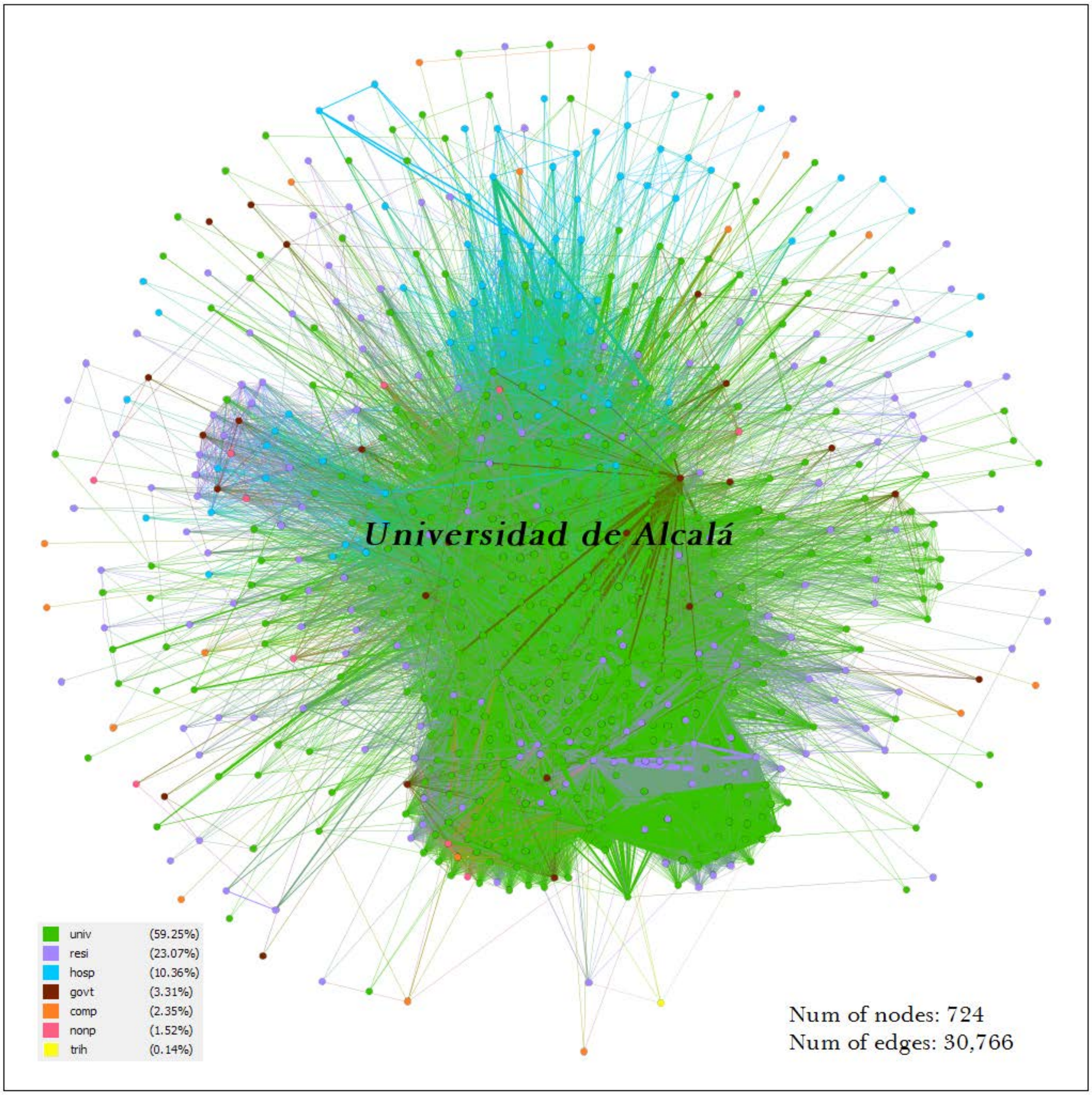
Comunidad de Madrid



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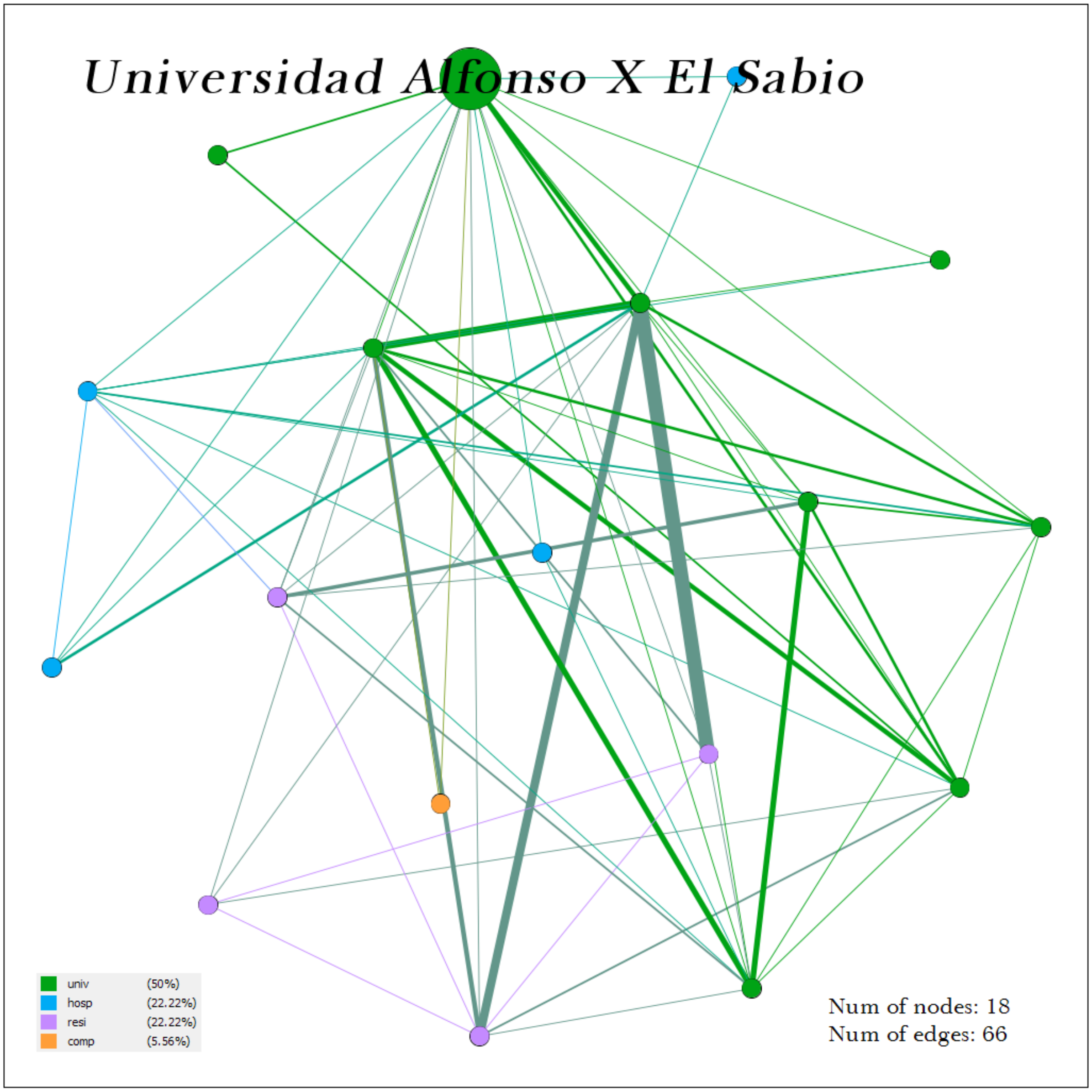

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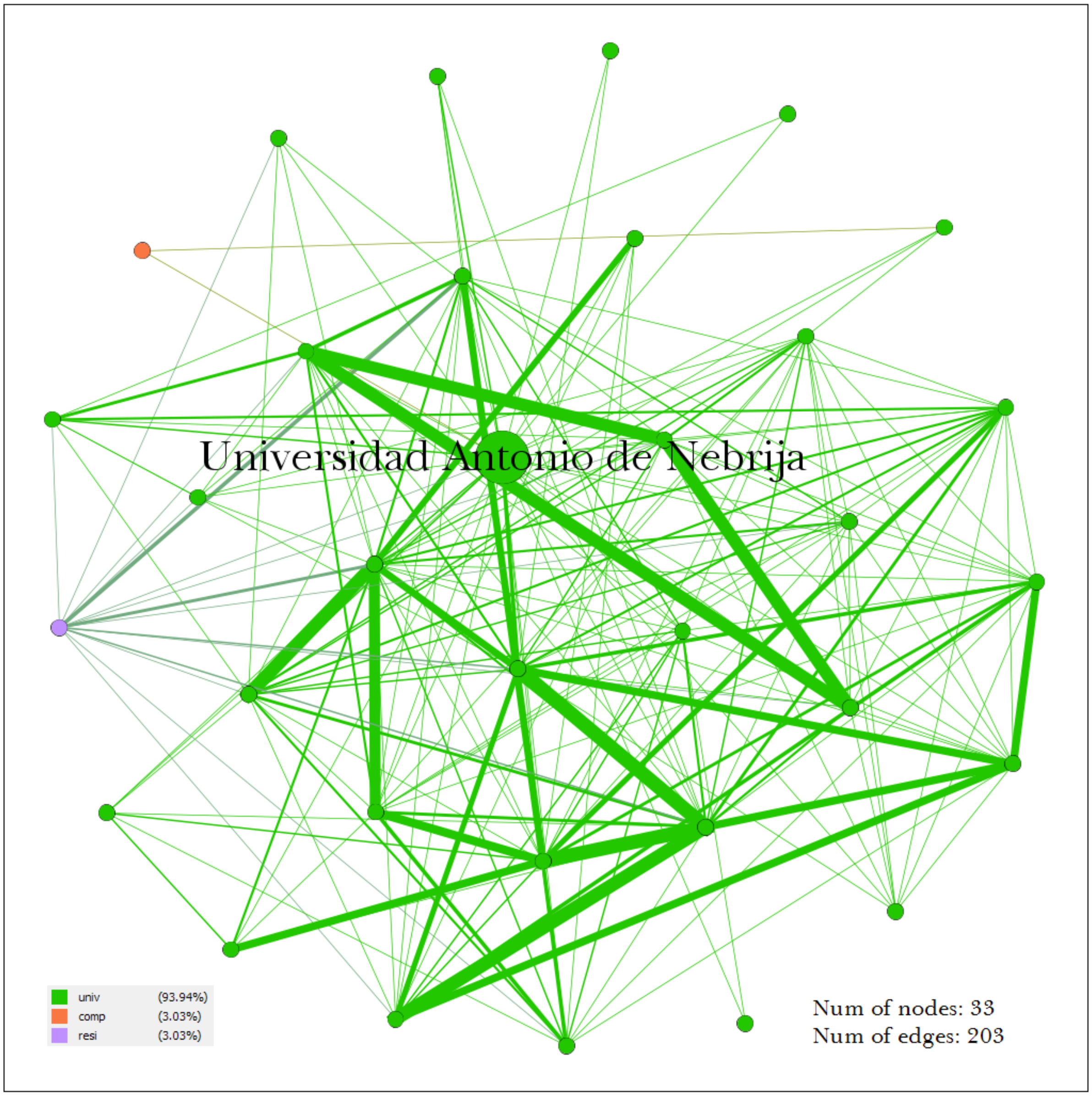

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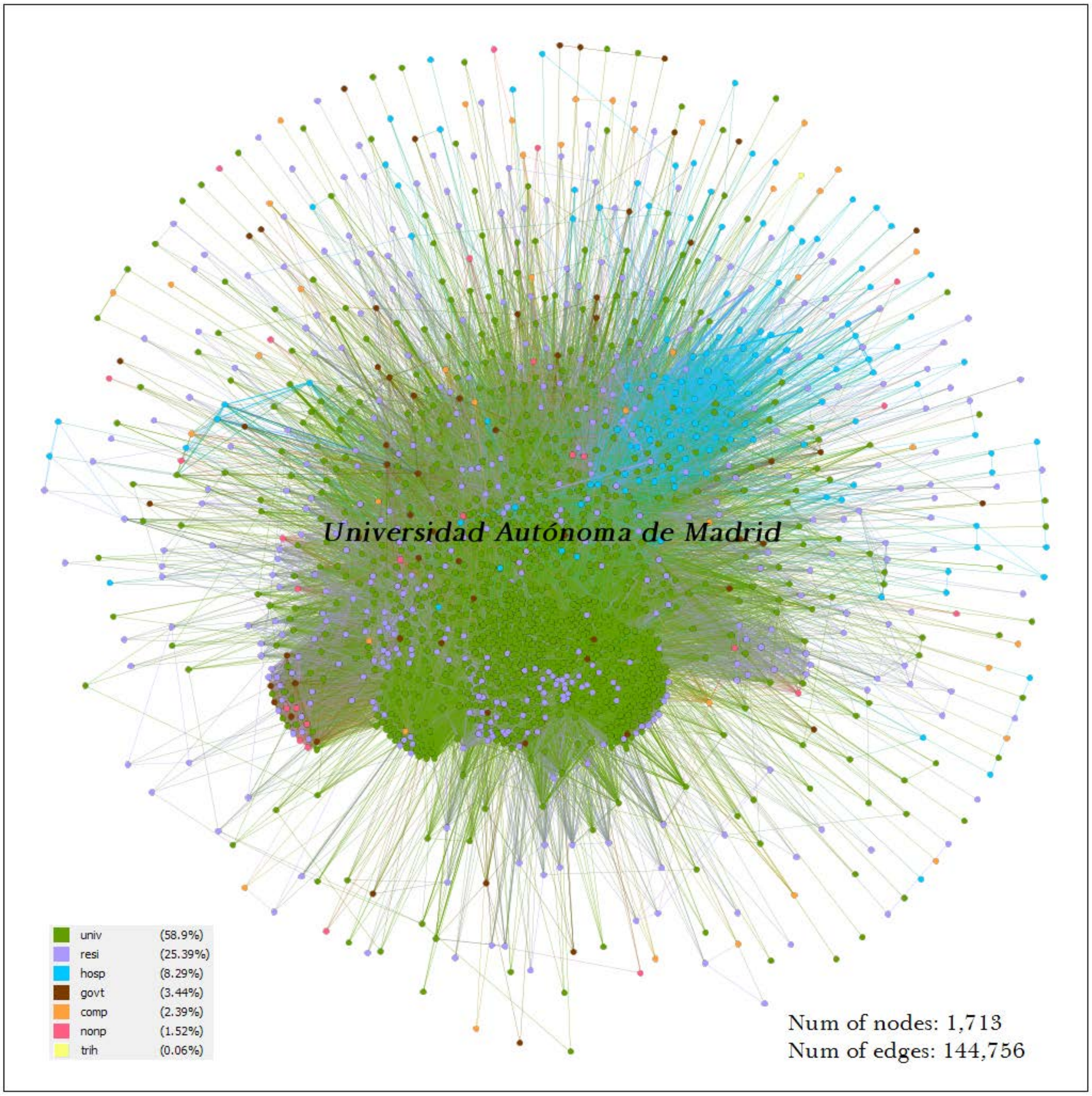

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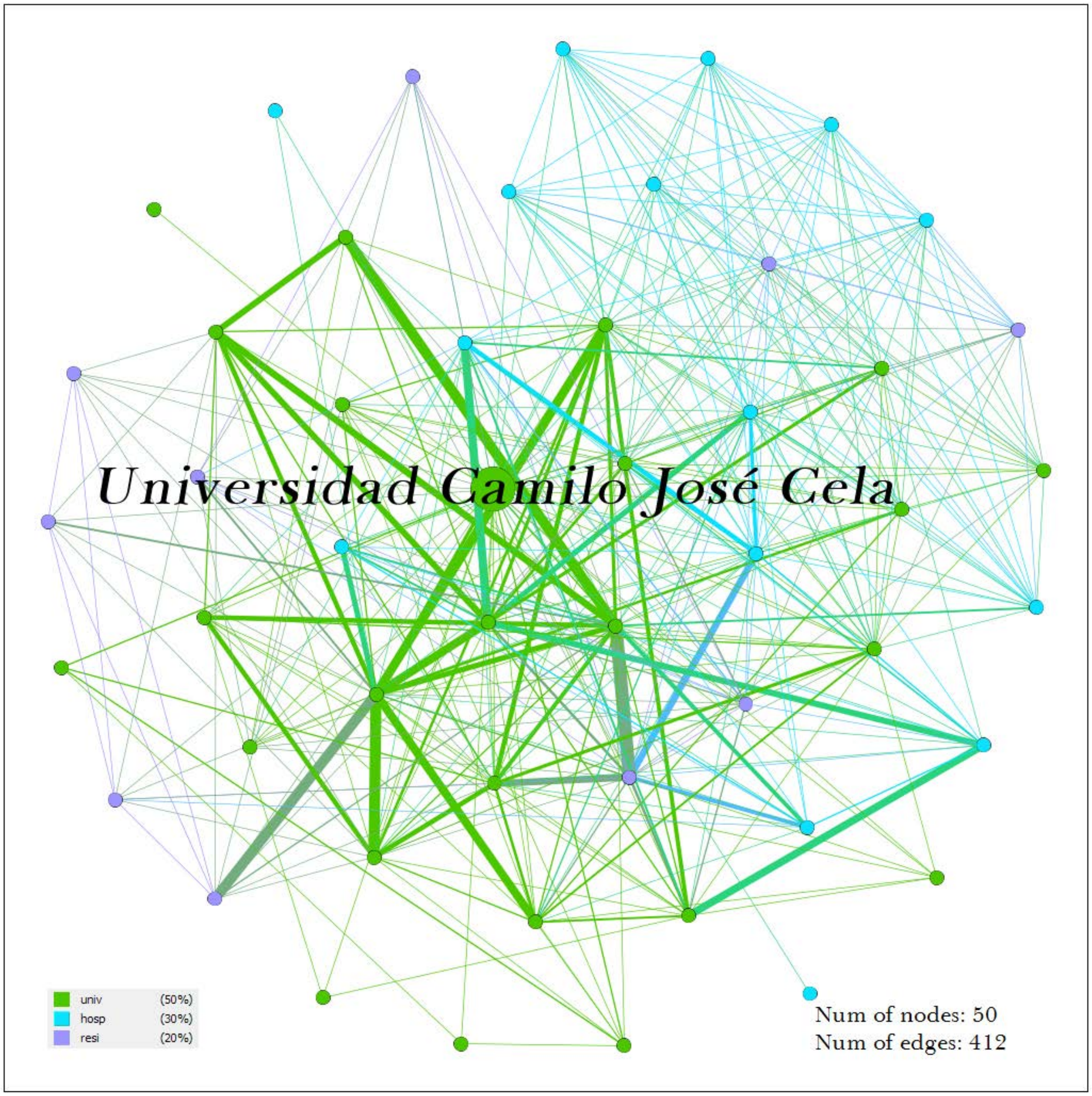

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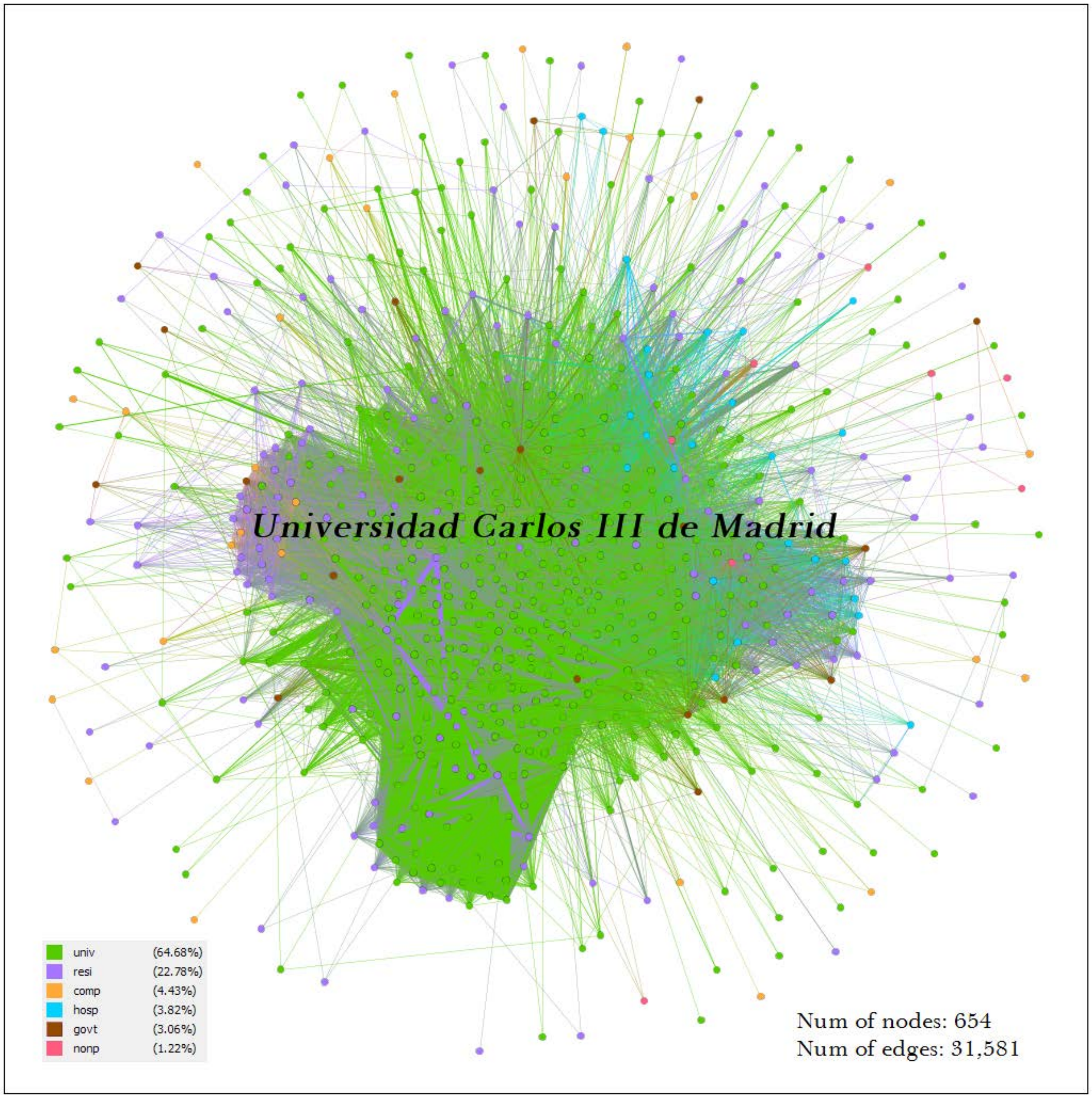

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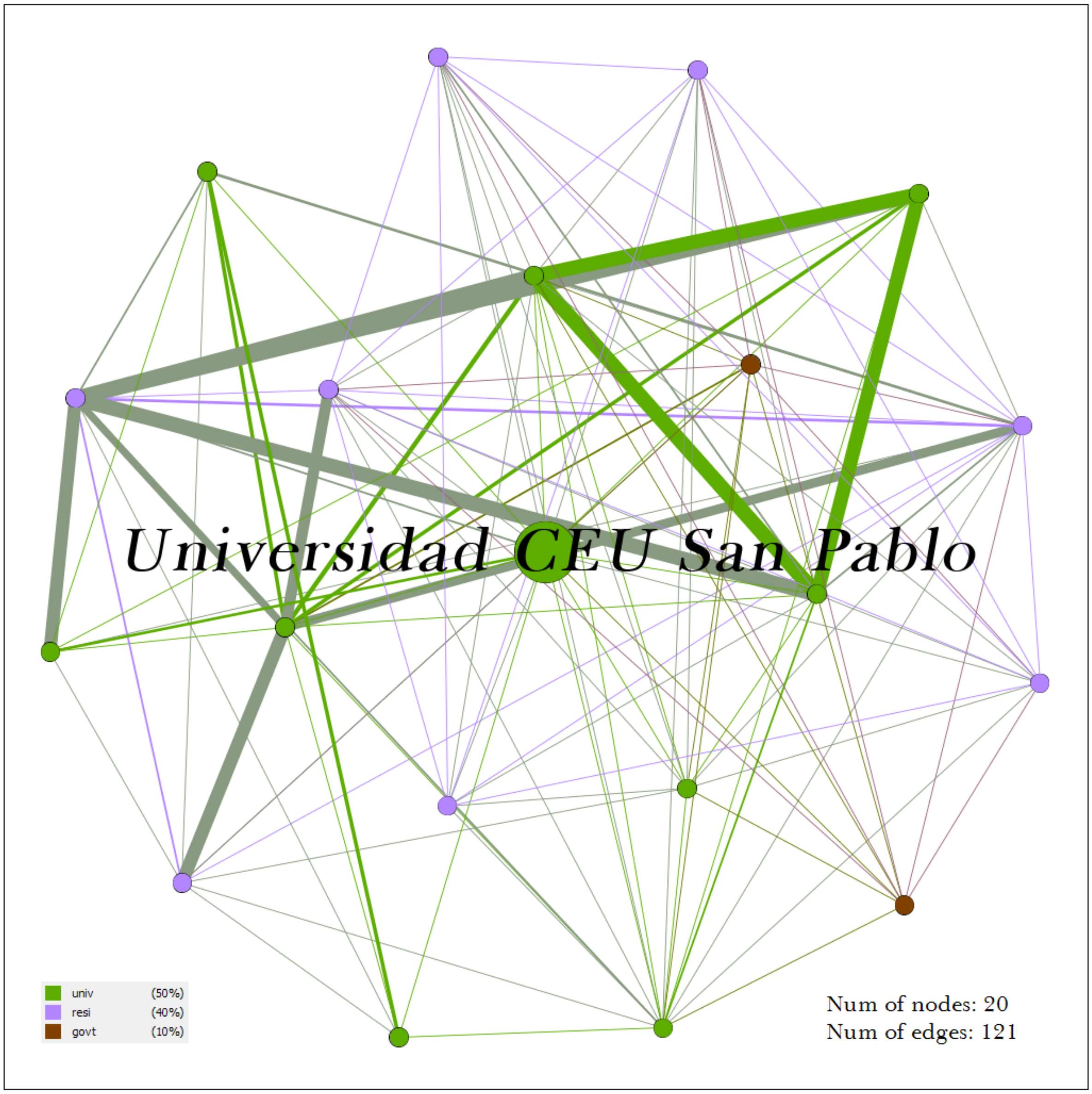


Figure A1.44. Subgraph of the *Universidad CEU San Pablo.* Fruchterman-Reingold Layout.

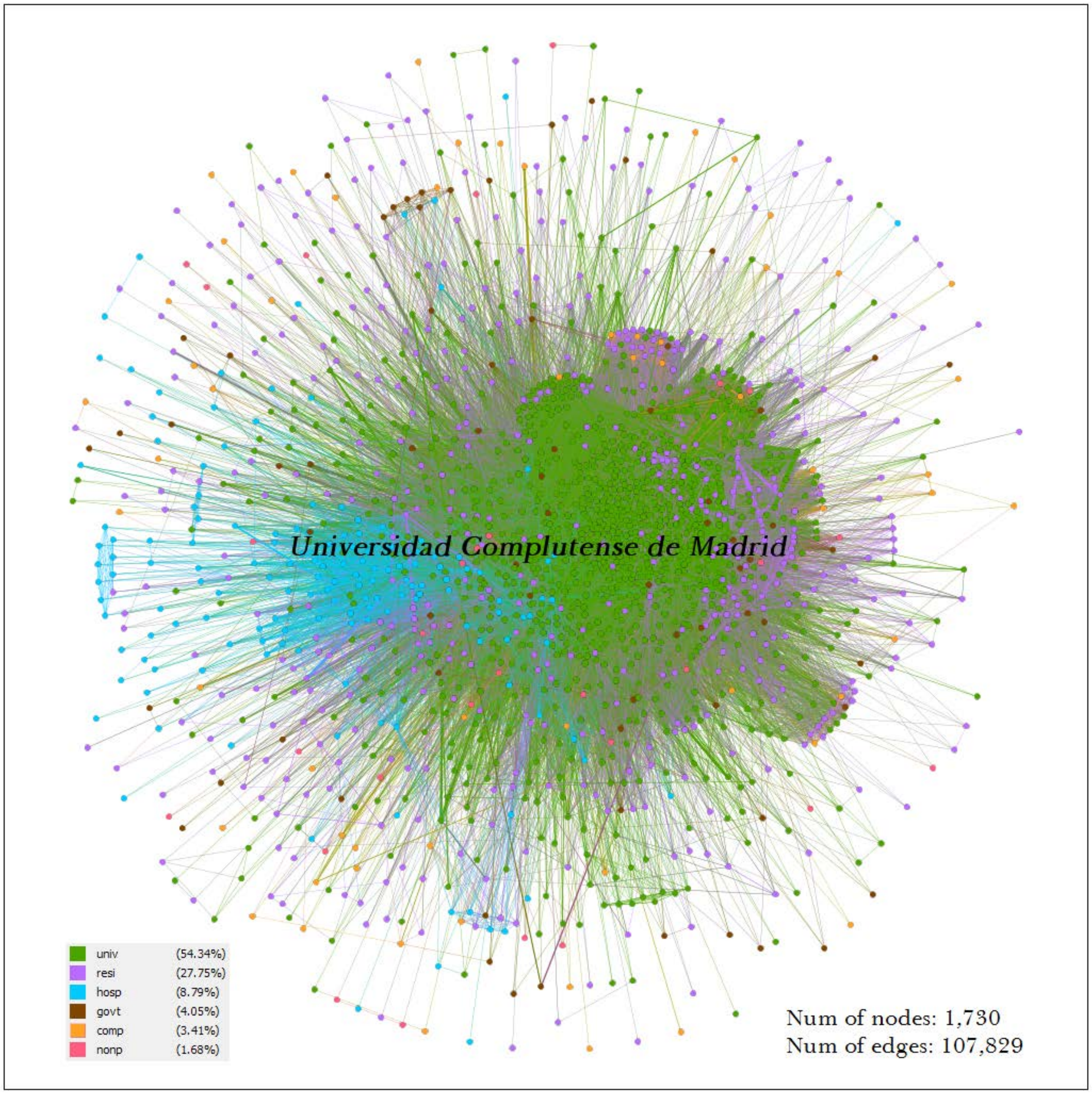
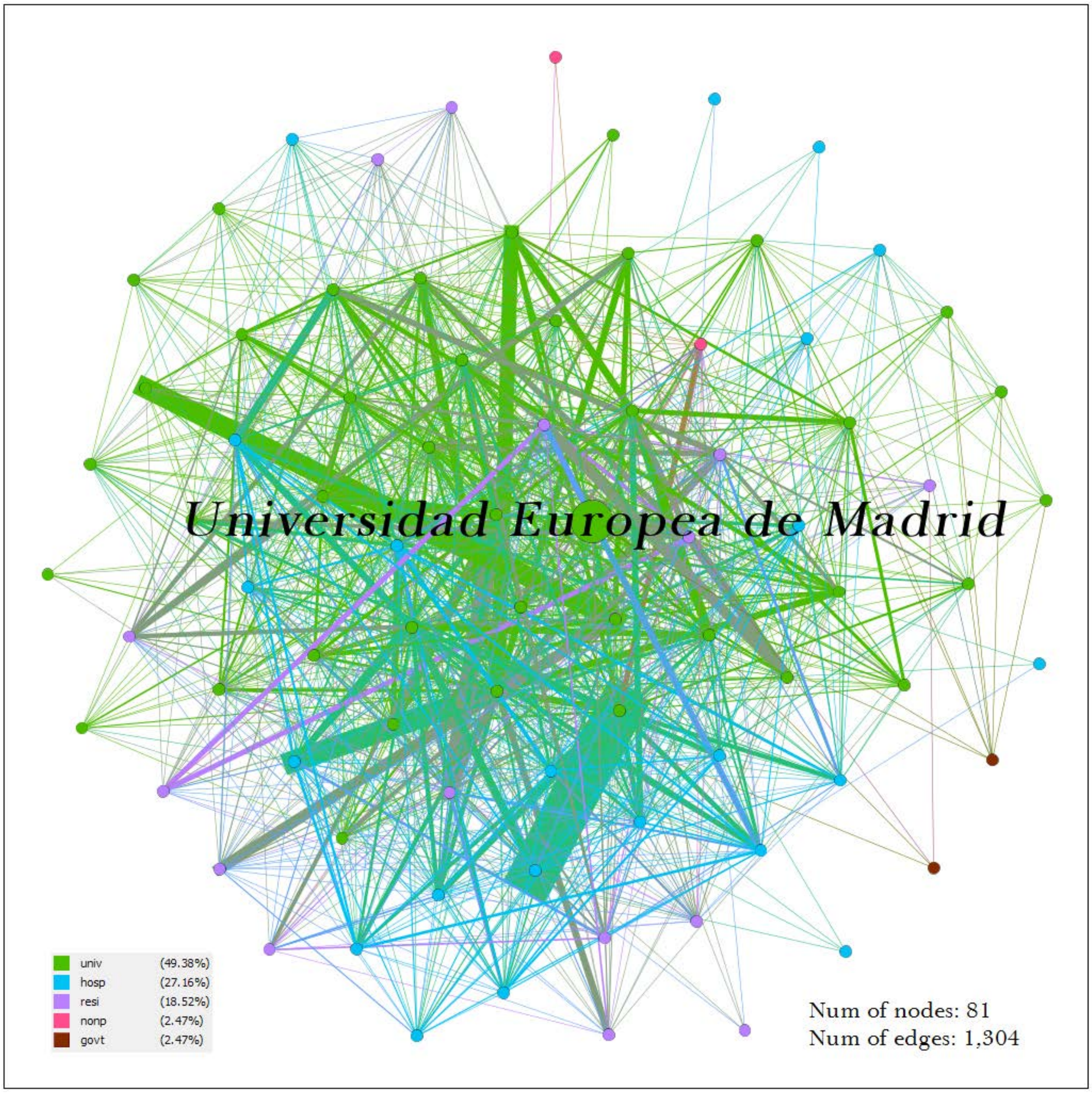


Figure A1.45. Subgraph of the *Universidad Complutense de Madrid.* Fruchterman-Reingold Layout.



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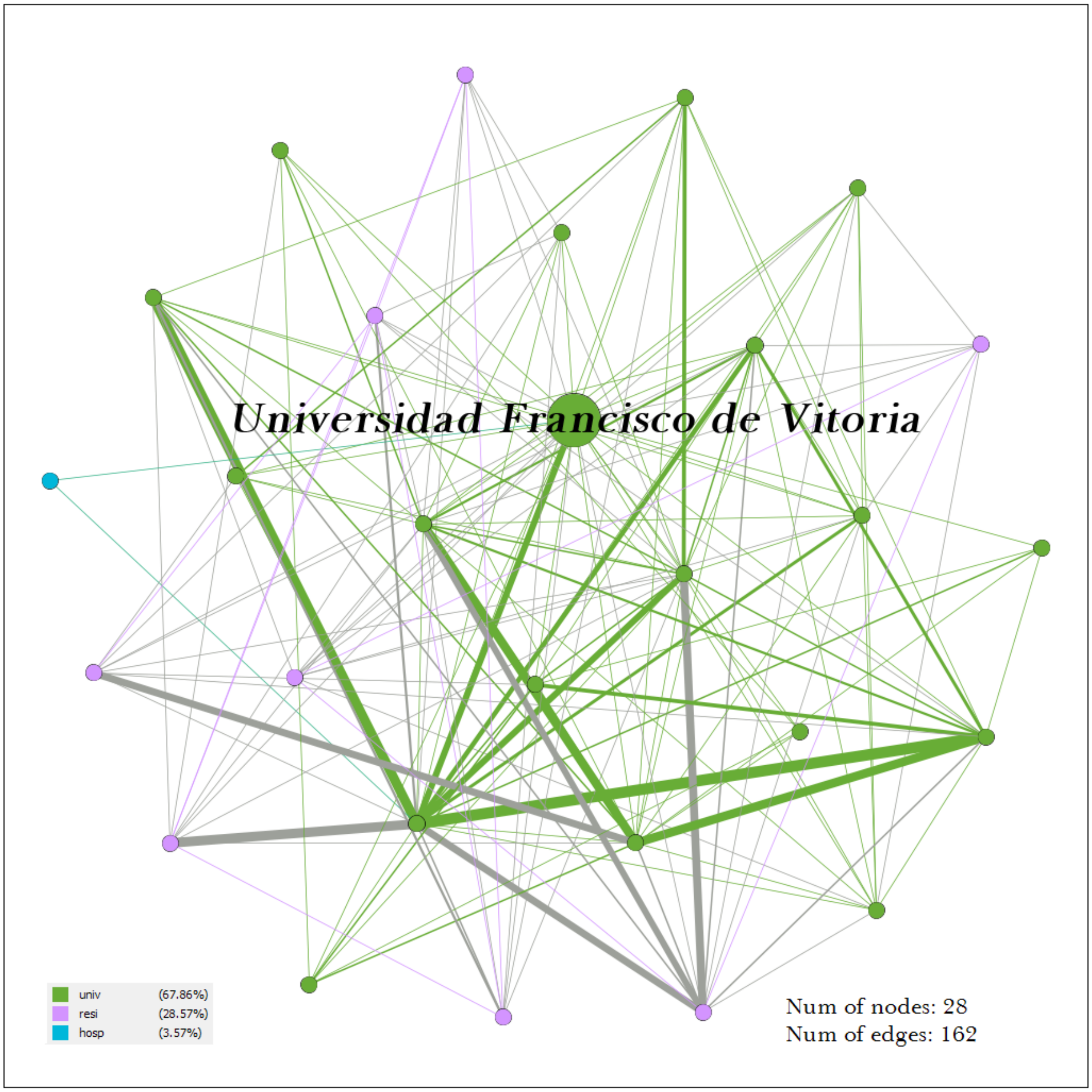

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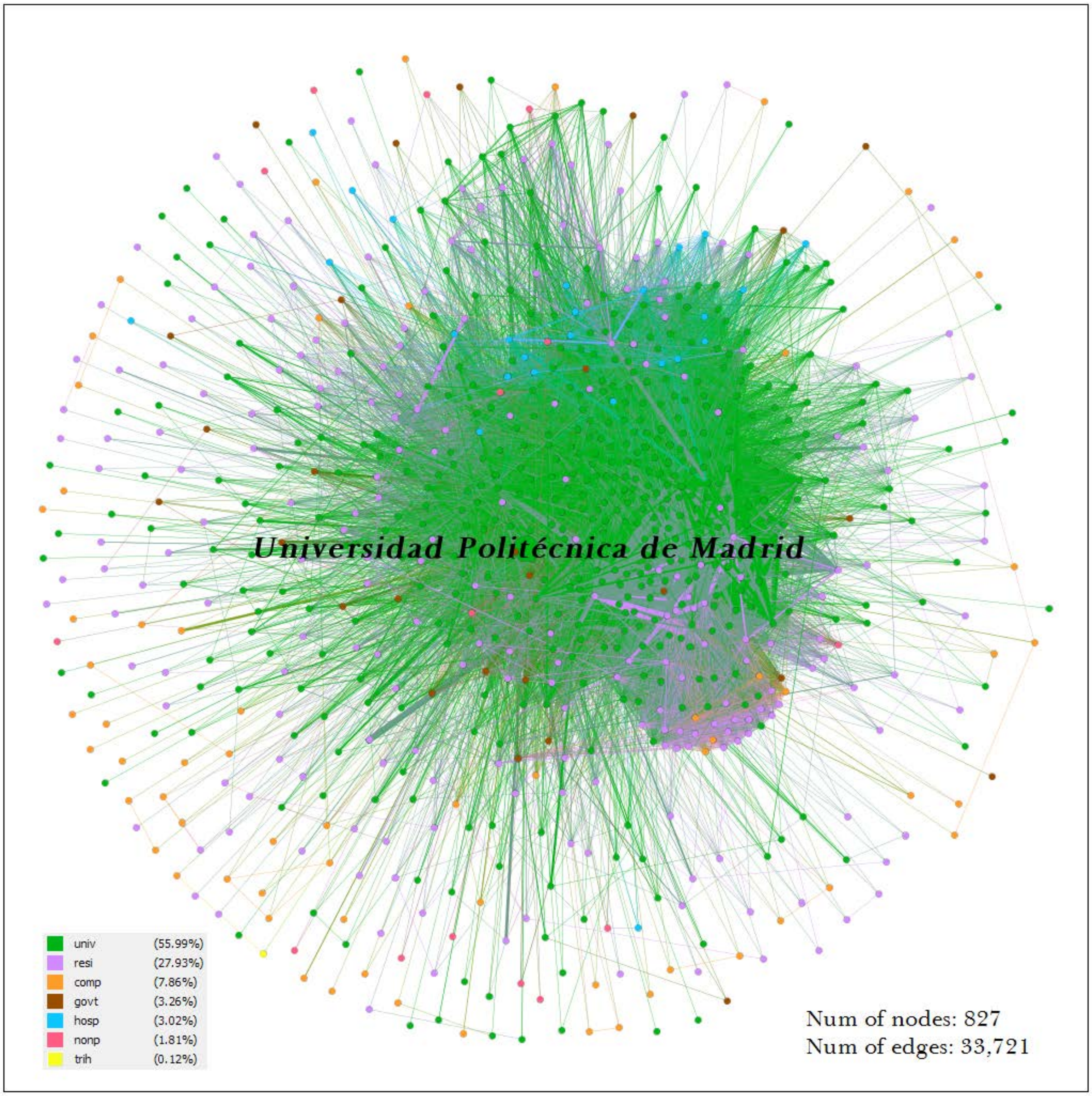
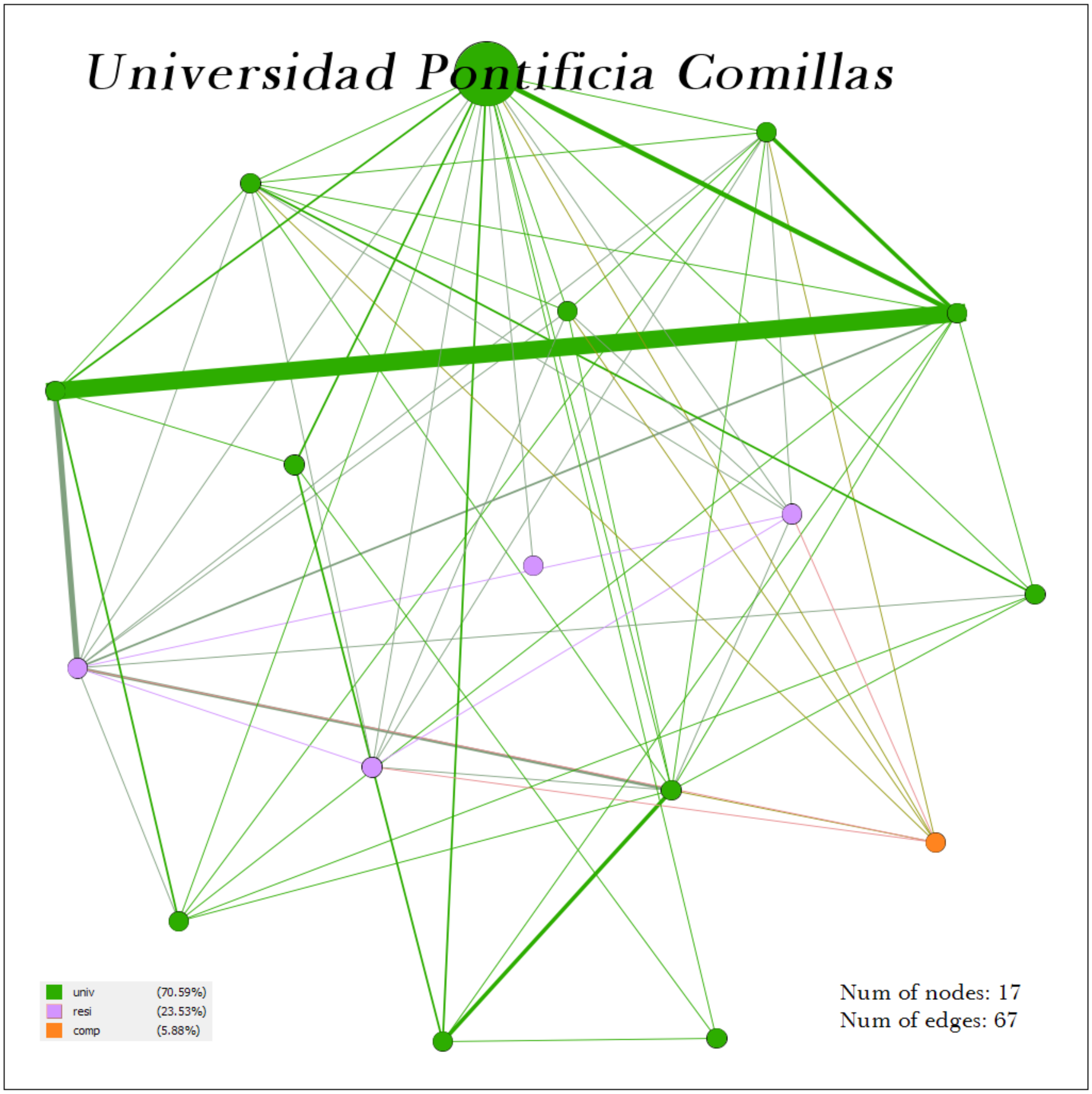


Figure A1.48. Subgraph of the *Universidad Politécnica de Madrid.* Fruchterman-Reingold Layout.



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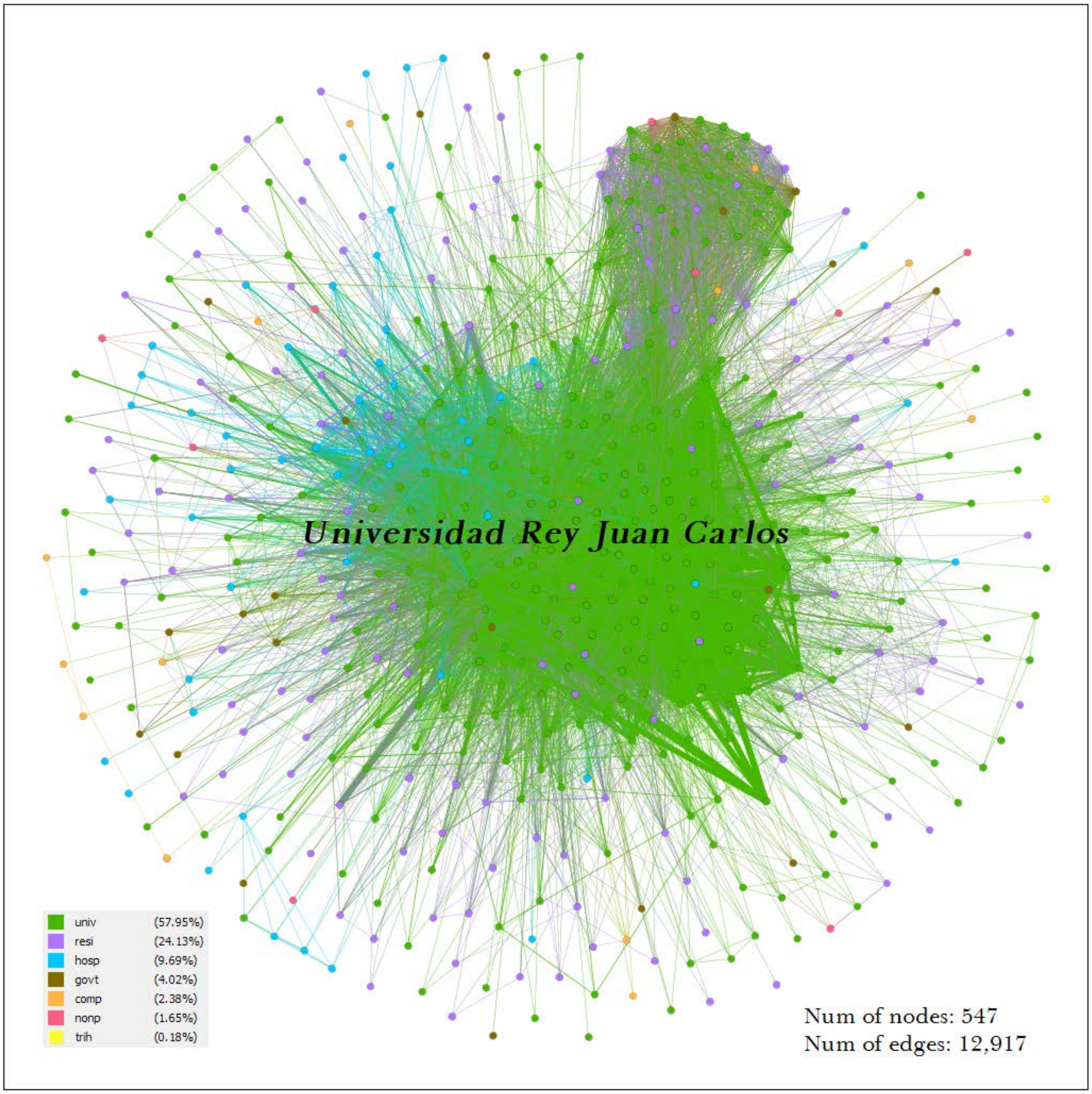

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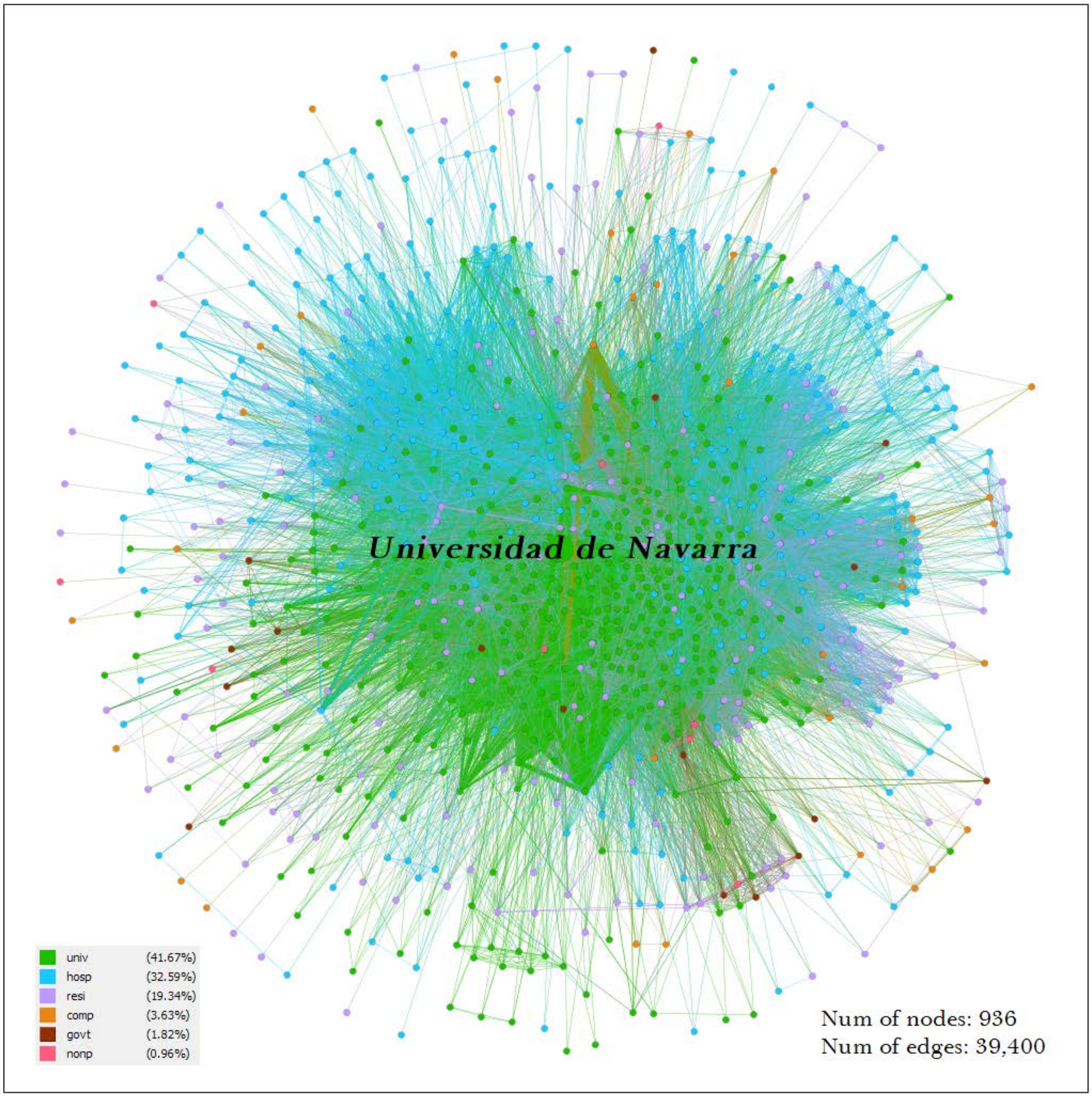
Comunidad Foral de Navarra



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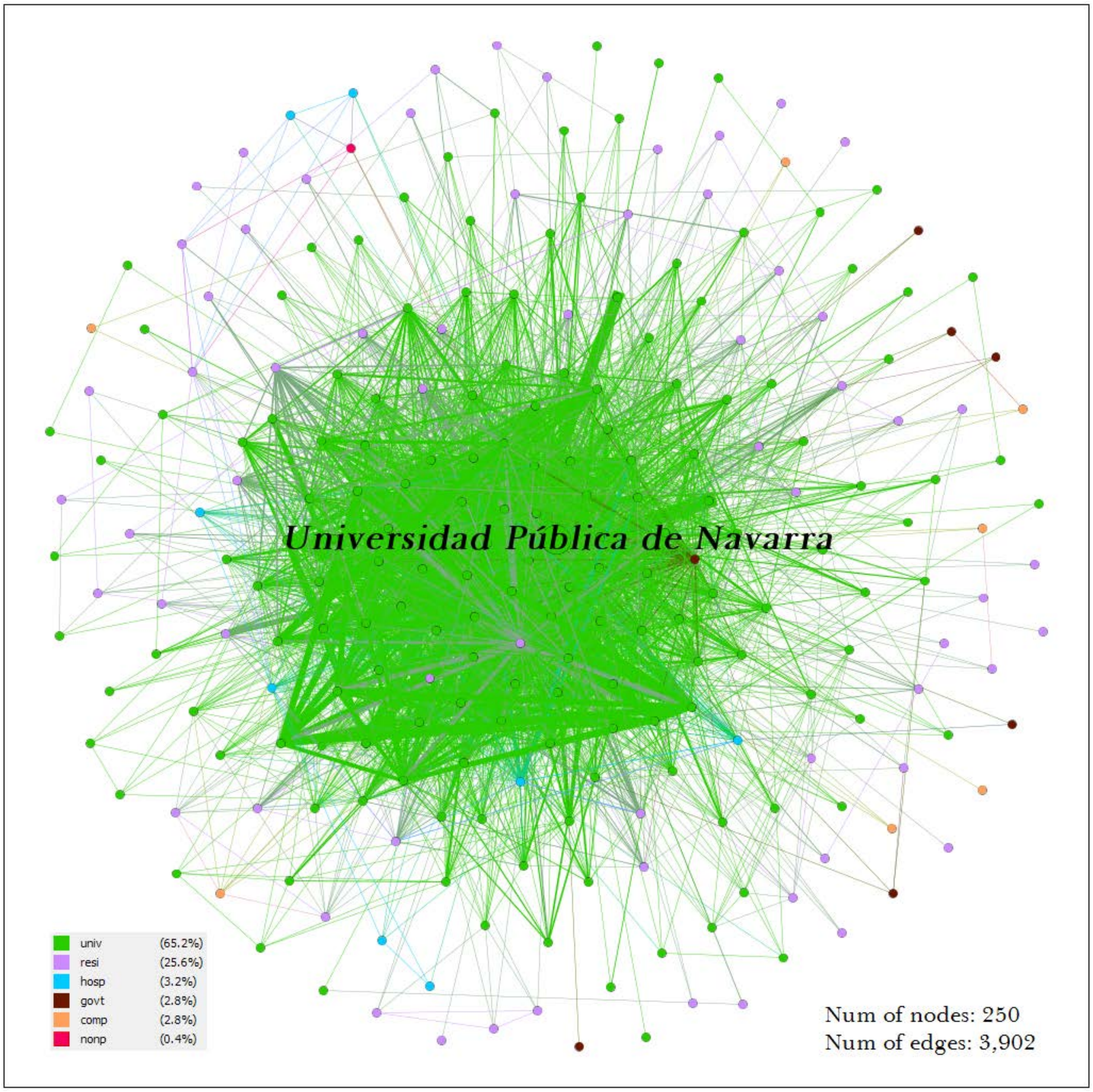


Figure A1.52. Subgraph of the *Universidad Pública de Navarra.* Fruchterman-Reingold Layout.

Comunidad Valenciana

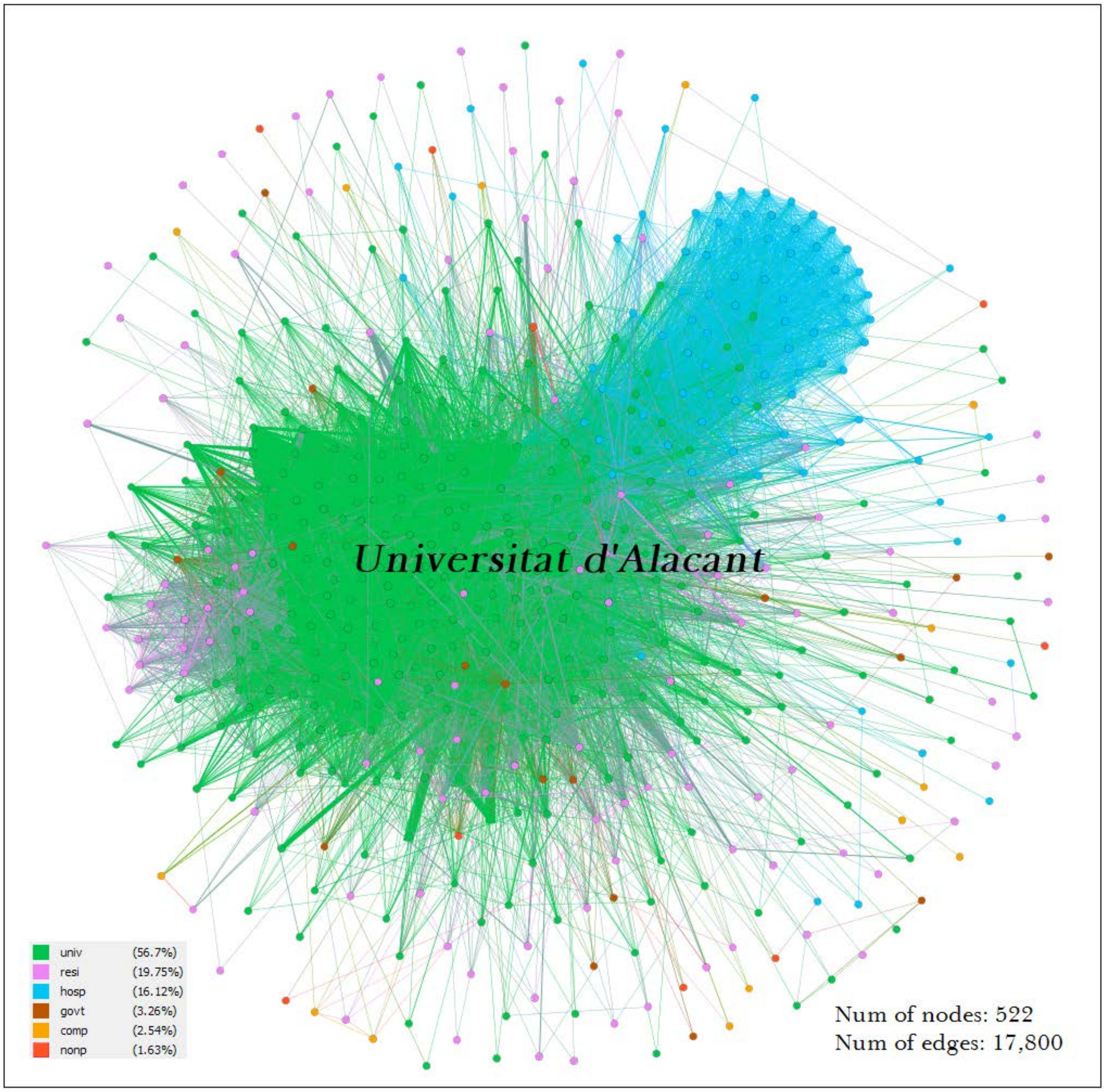


Figure A1.53. Subgraph of the *Universitat d'Alacant*. Fruchterman-Reingold Layout.

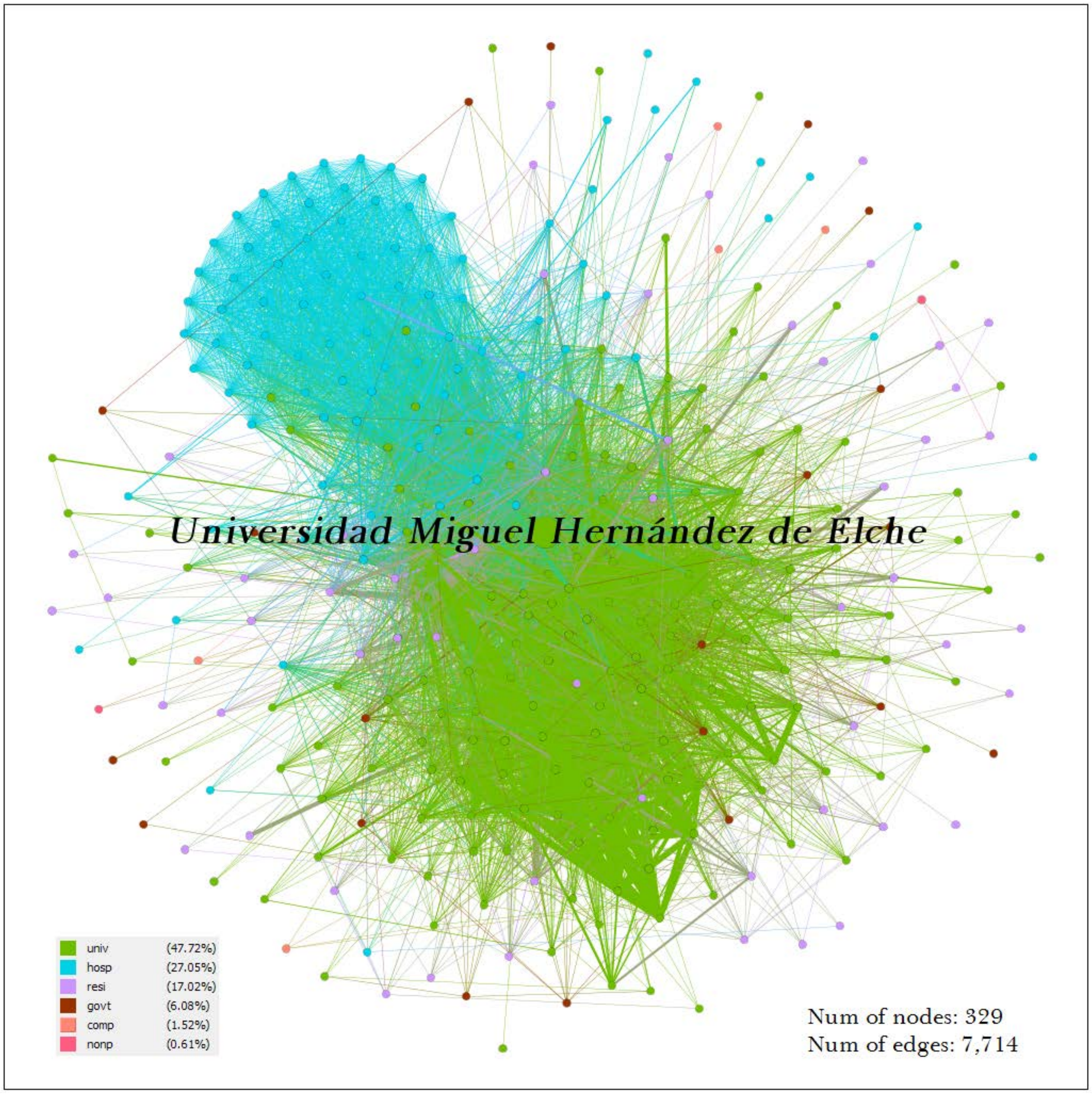
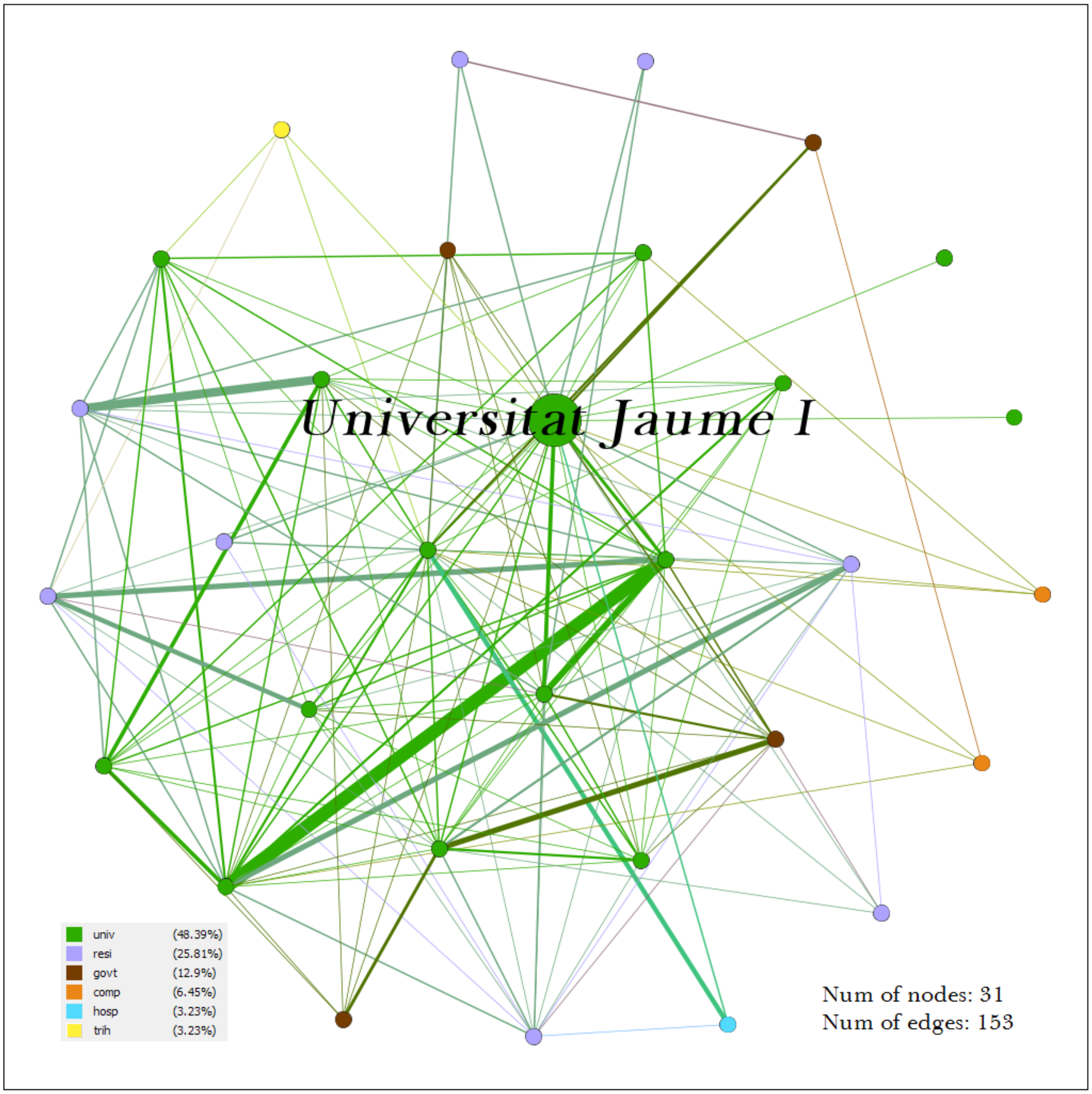


Figure A1.54. Subgraph of the *Universitat Miguel Hernández de Elche*. Fruchterman-Reingold Layout.



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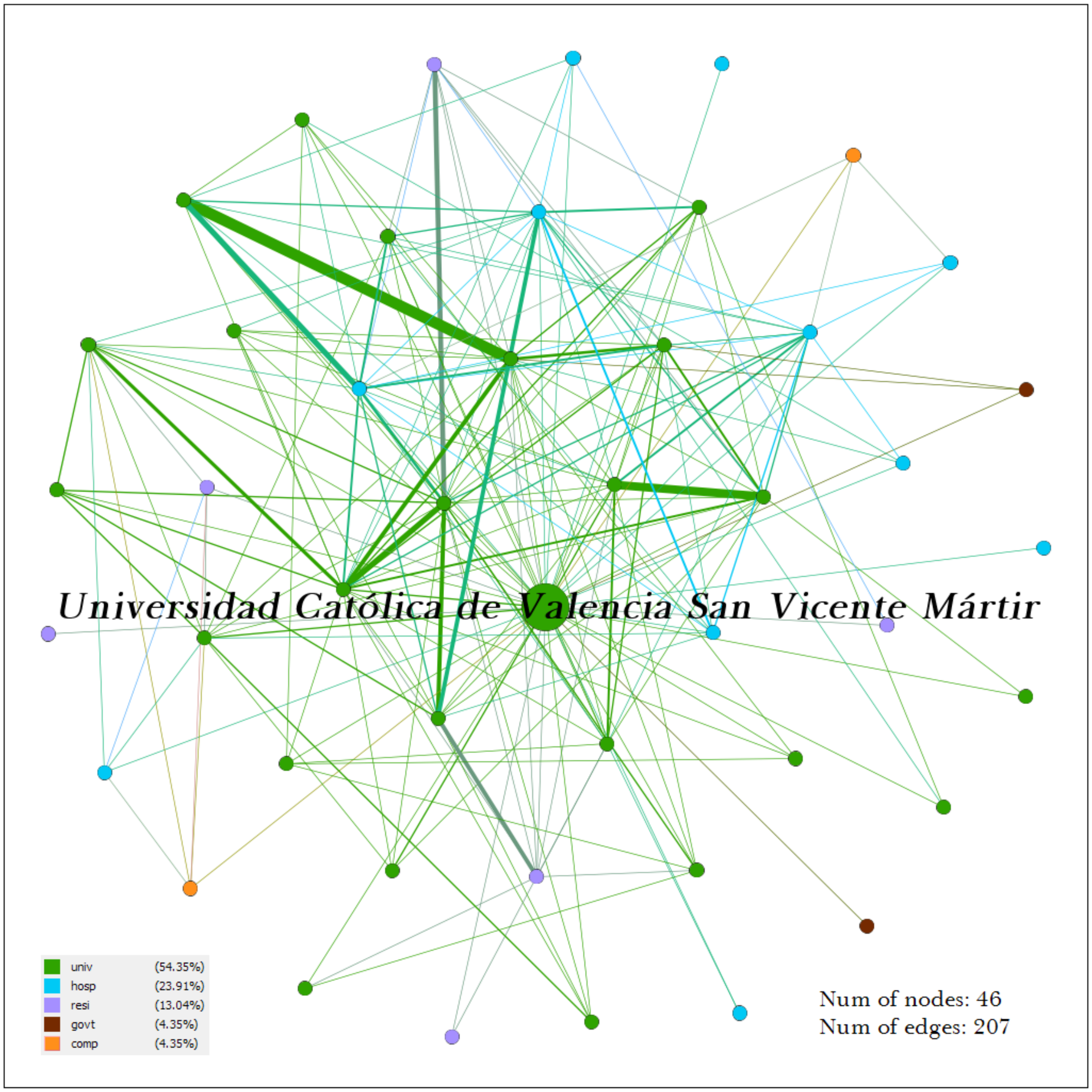

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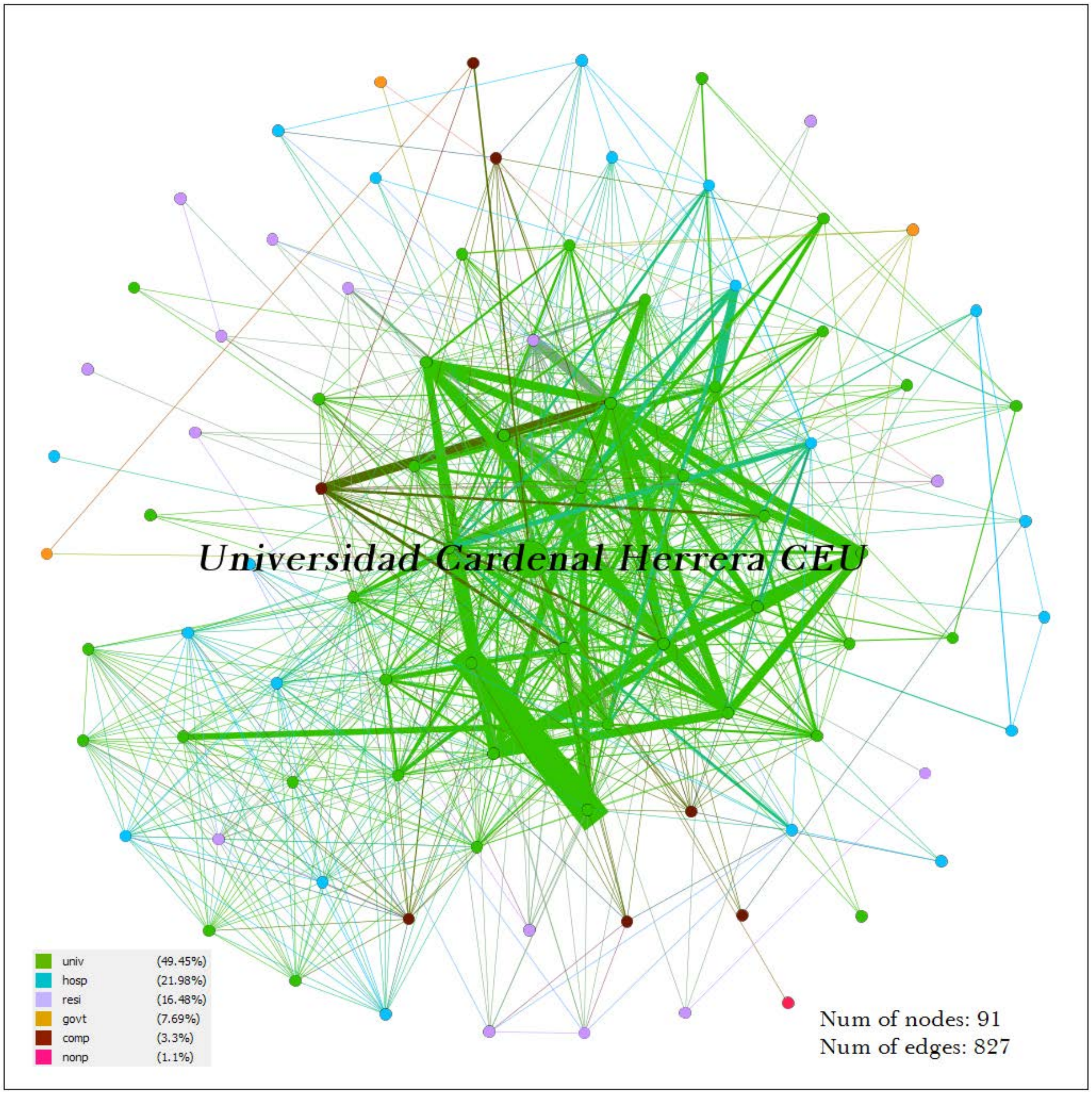
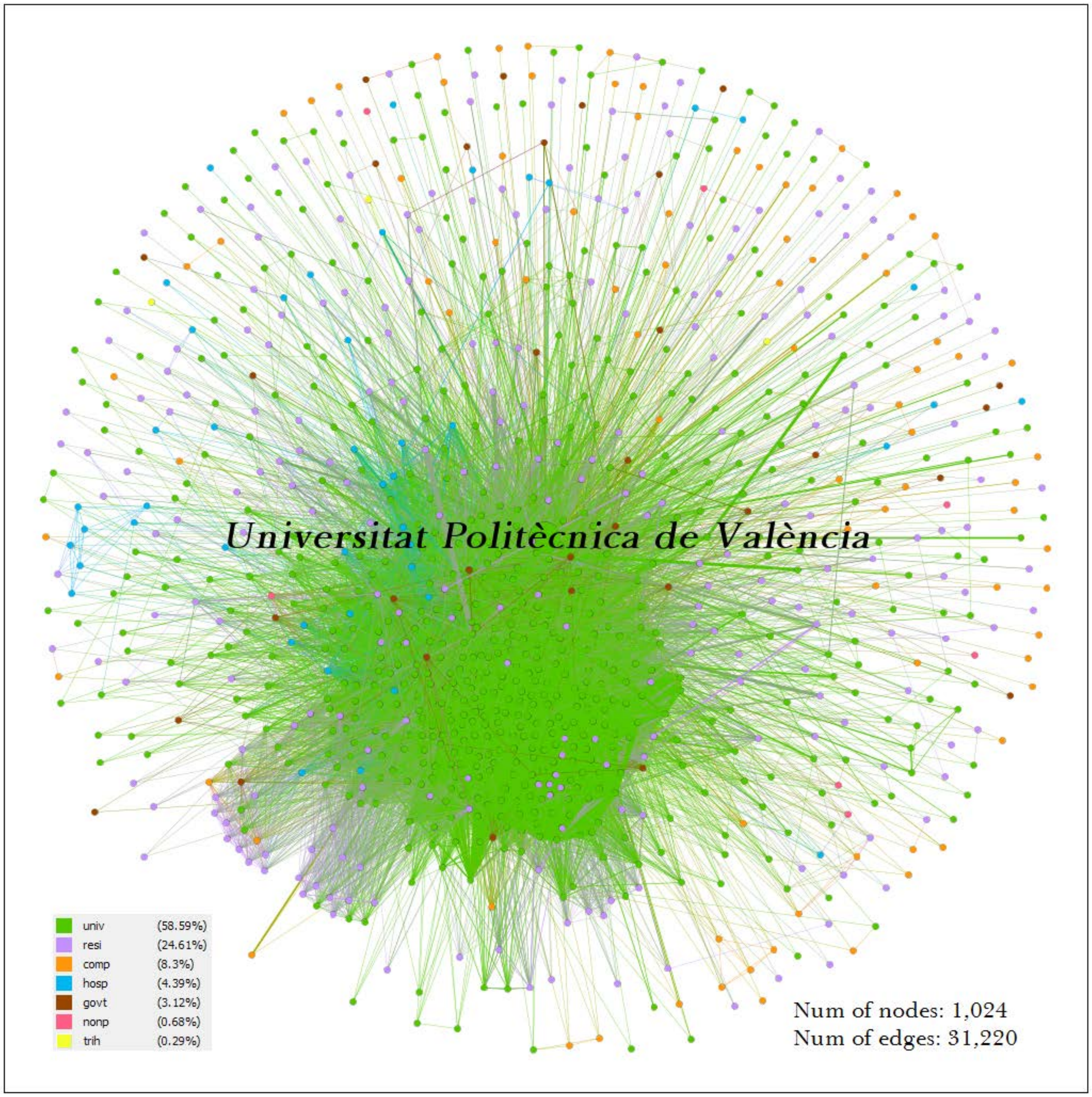


Figure A1.57. Subgraph of the *Universidad Cardenal Herrera CEU*. Fruchterman-Reingold Layout.



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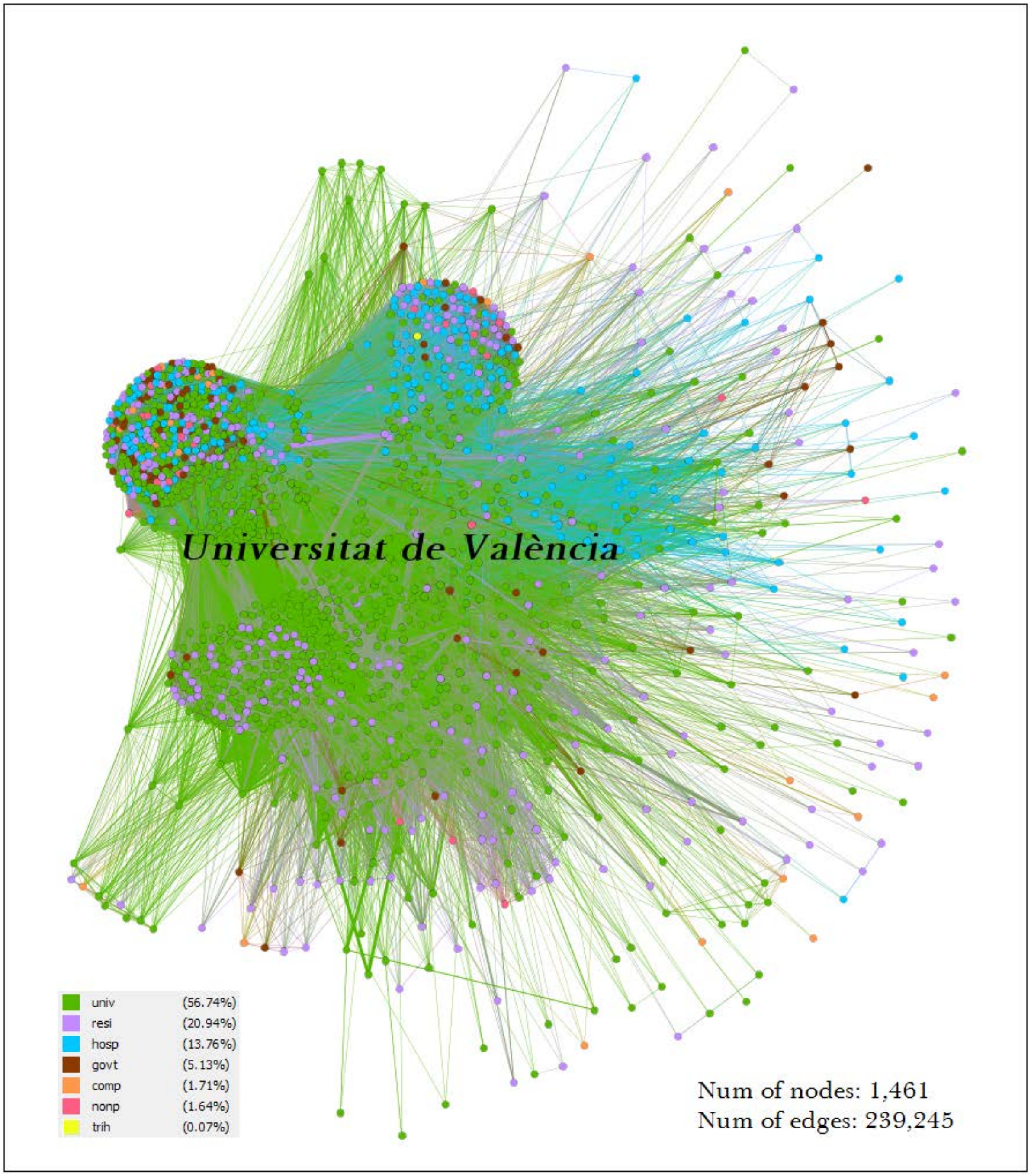


Figure A1.59. Subgraph of the *Universitat de València.* Fruchterman-Reingold Layout.

Extremadura

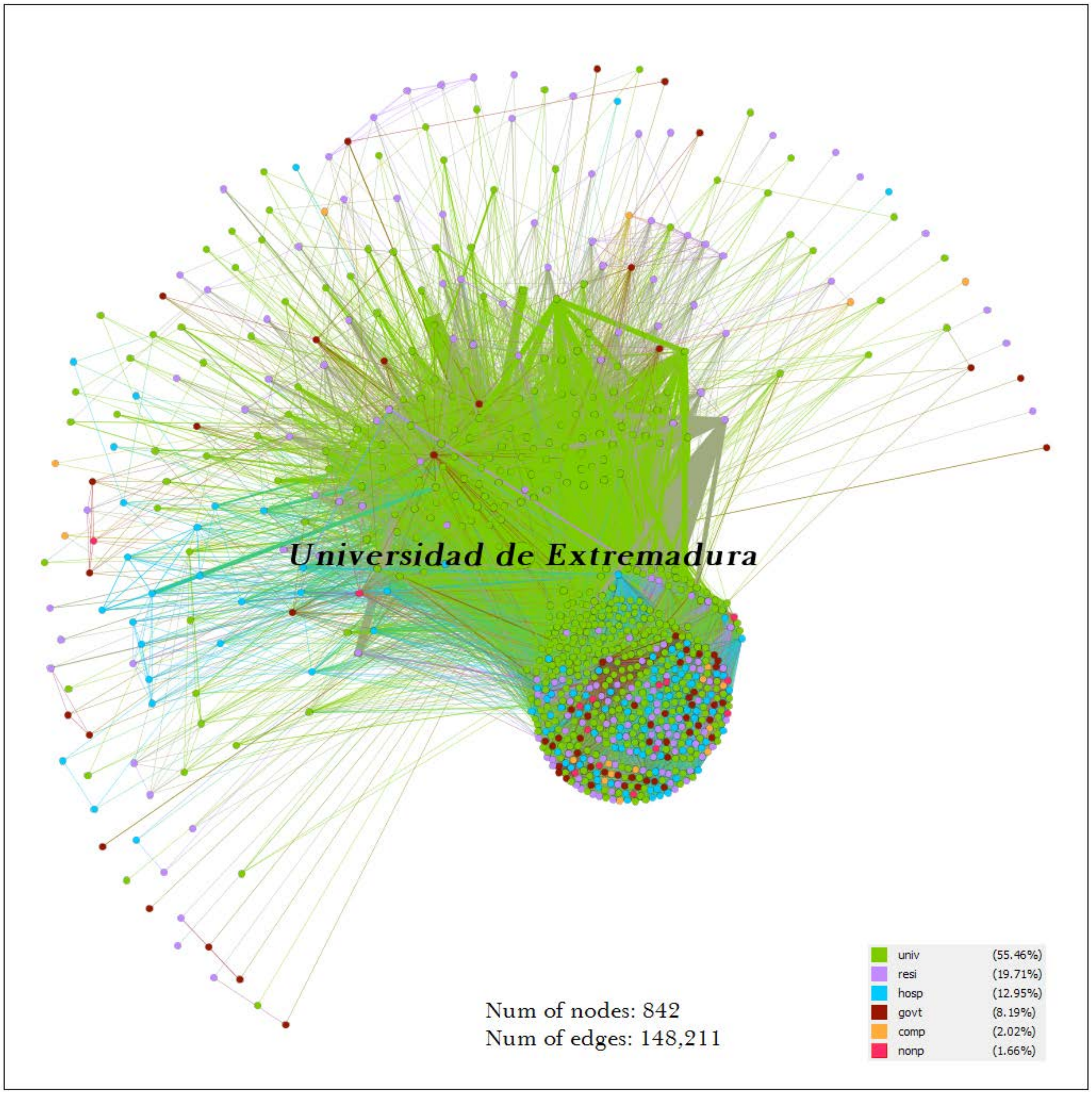
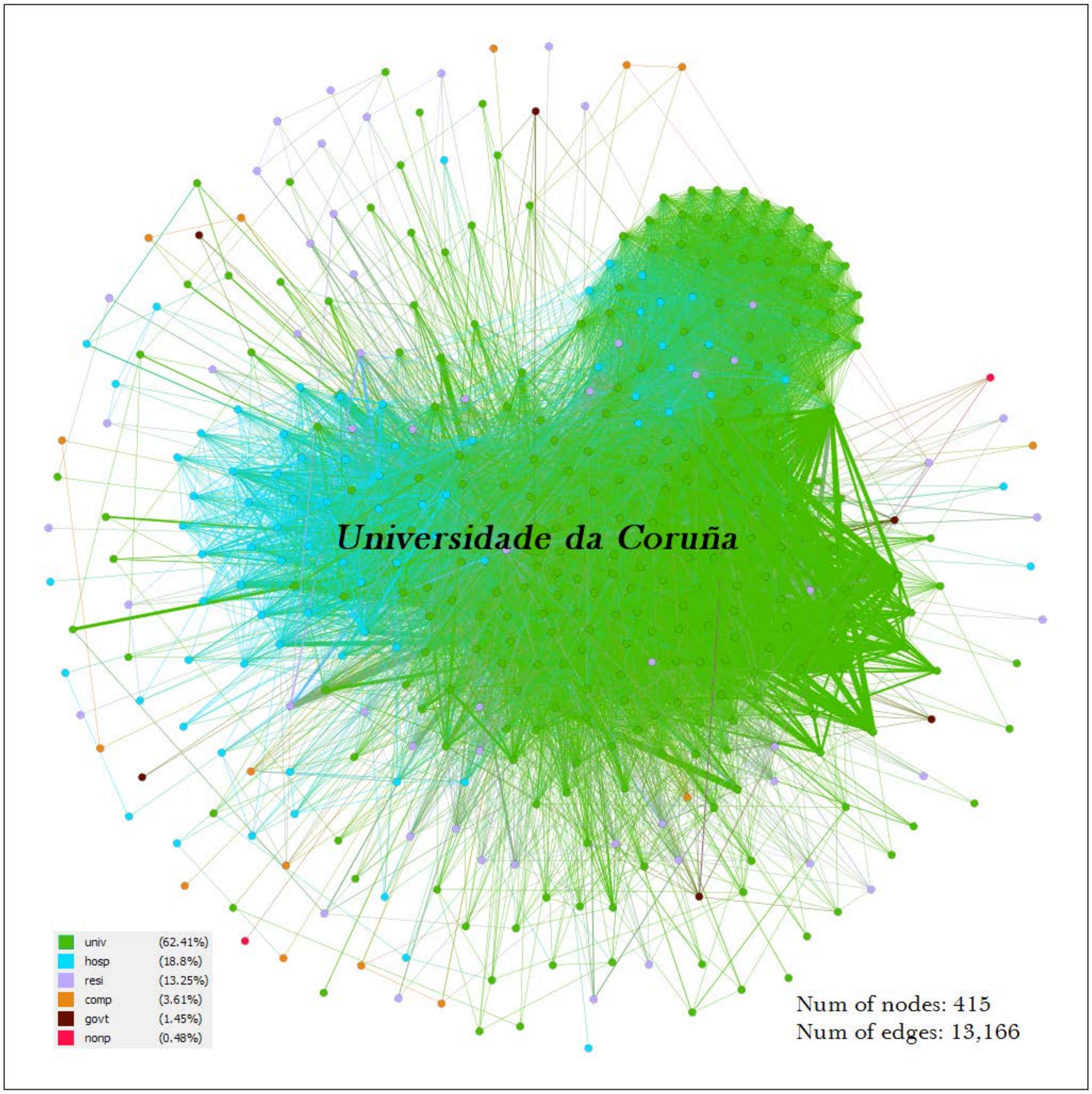


Figure A1.60. Subgraph of the *Universidad de Extremadura*. Fruchterman-Reingold Layout.

Galicia



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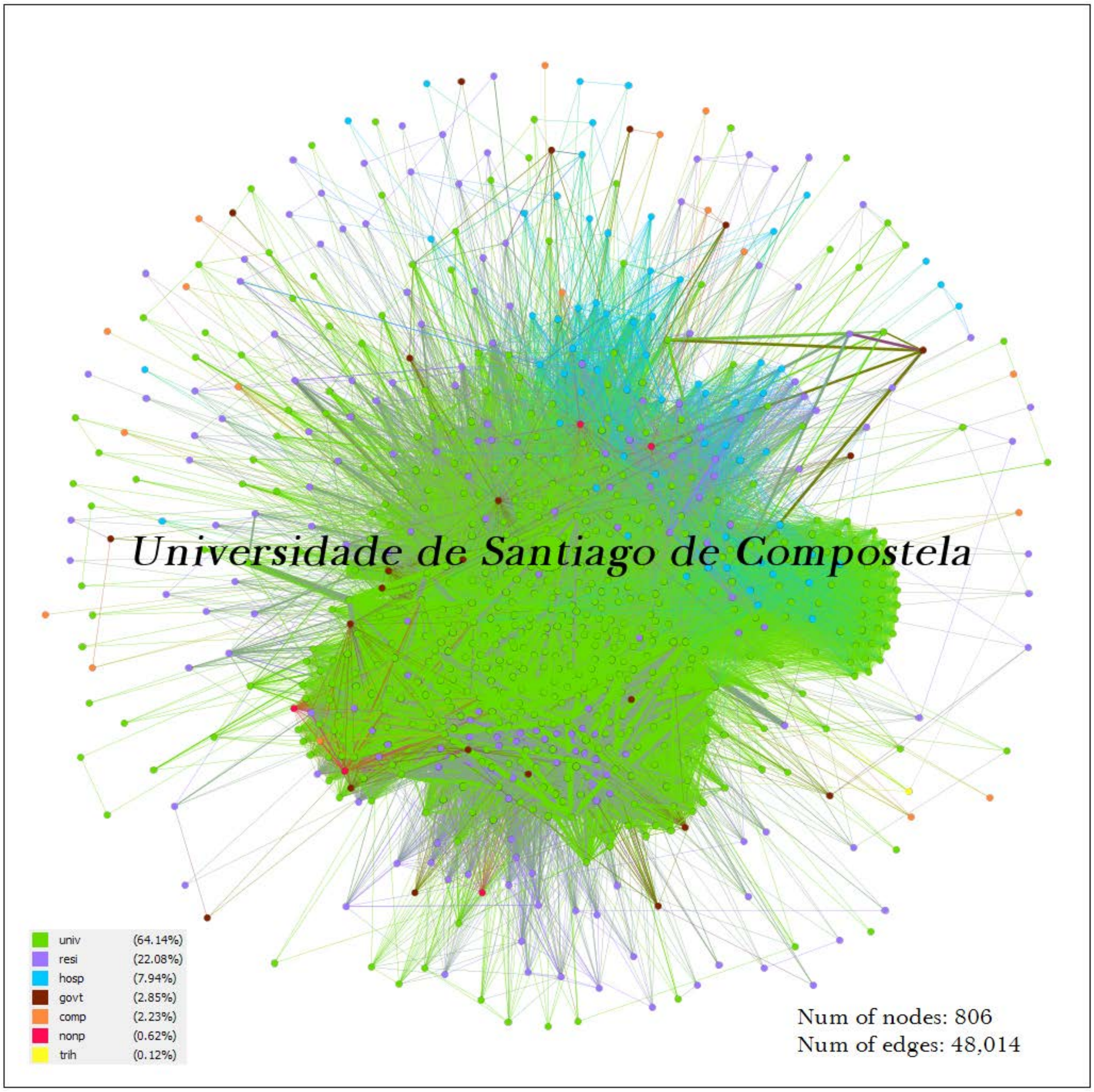

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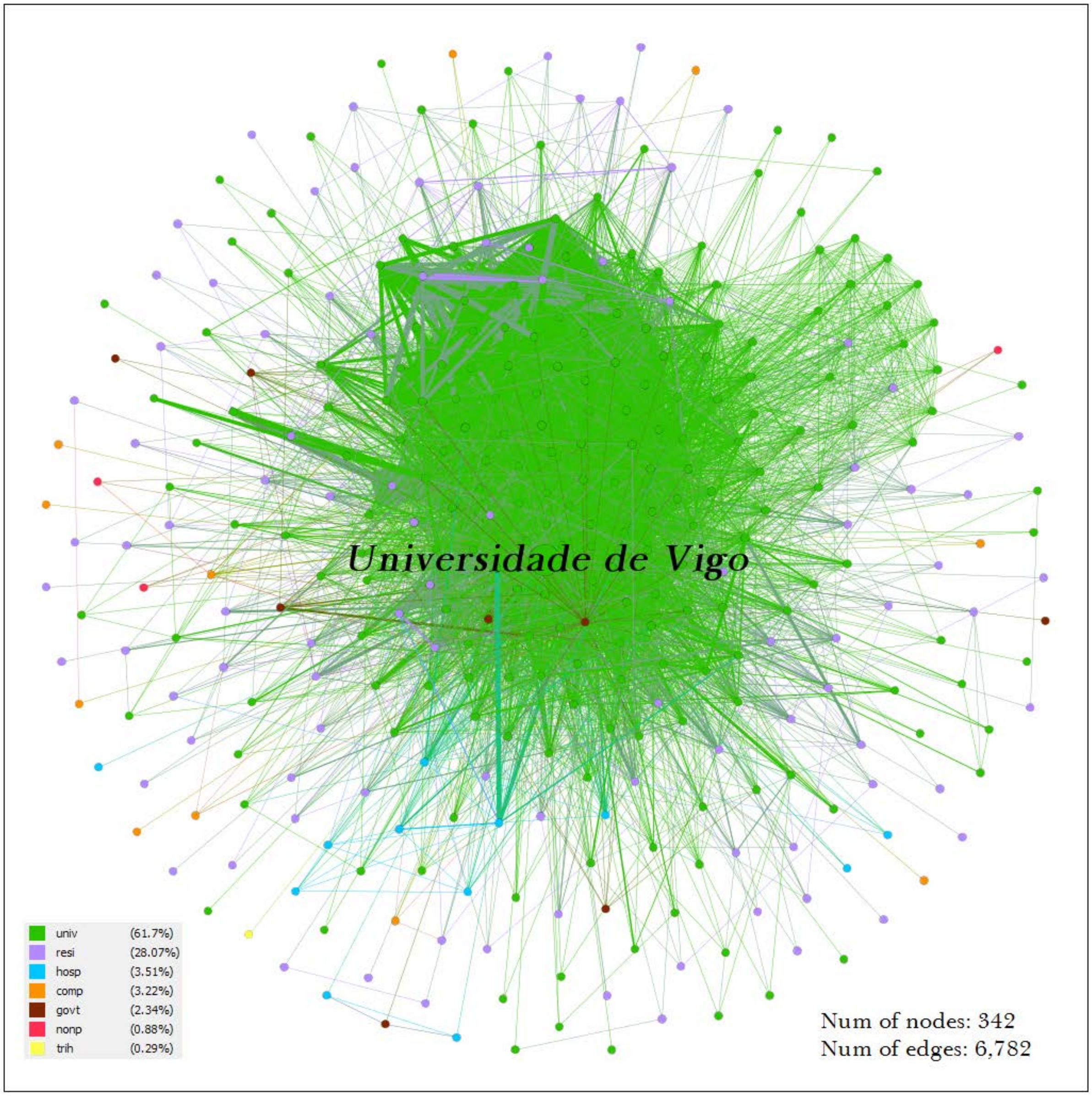

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Islas Baleares

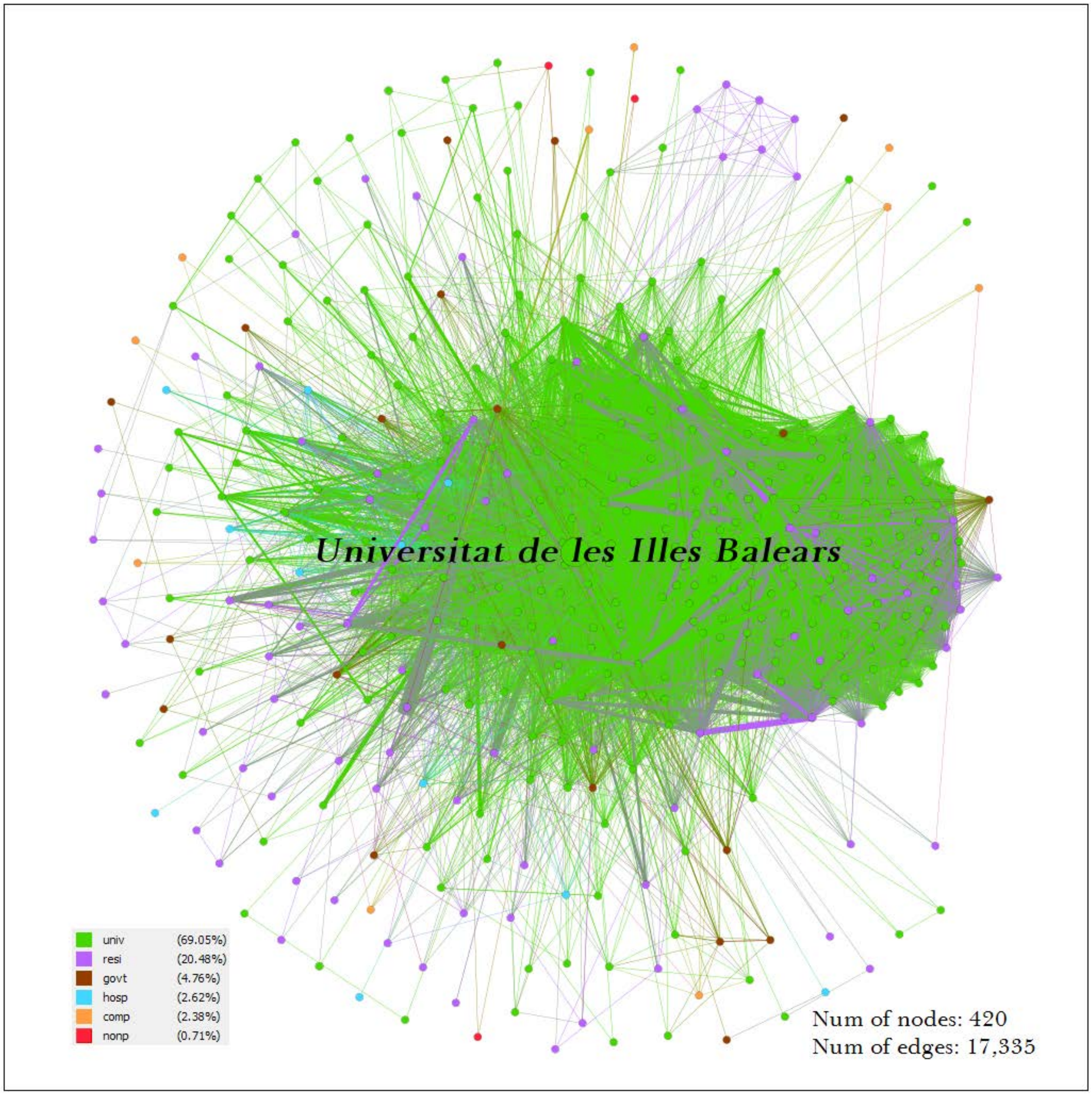


Figure A1.64. Subgraph of the *Universitat de les Illes Balears*. Fruchterman-Reingold Layout.

La Rioja

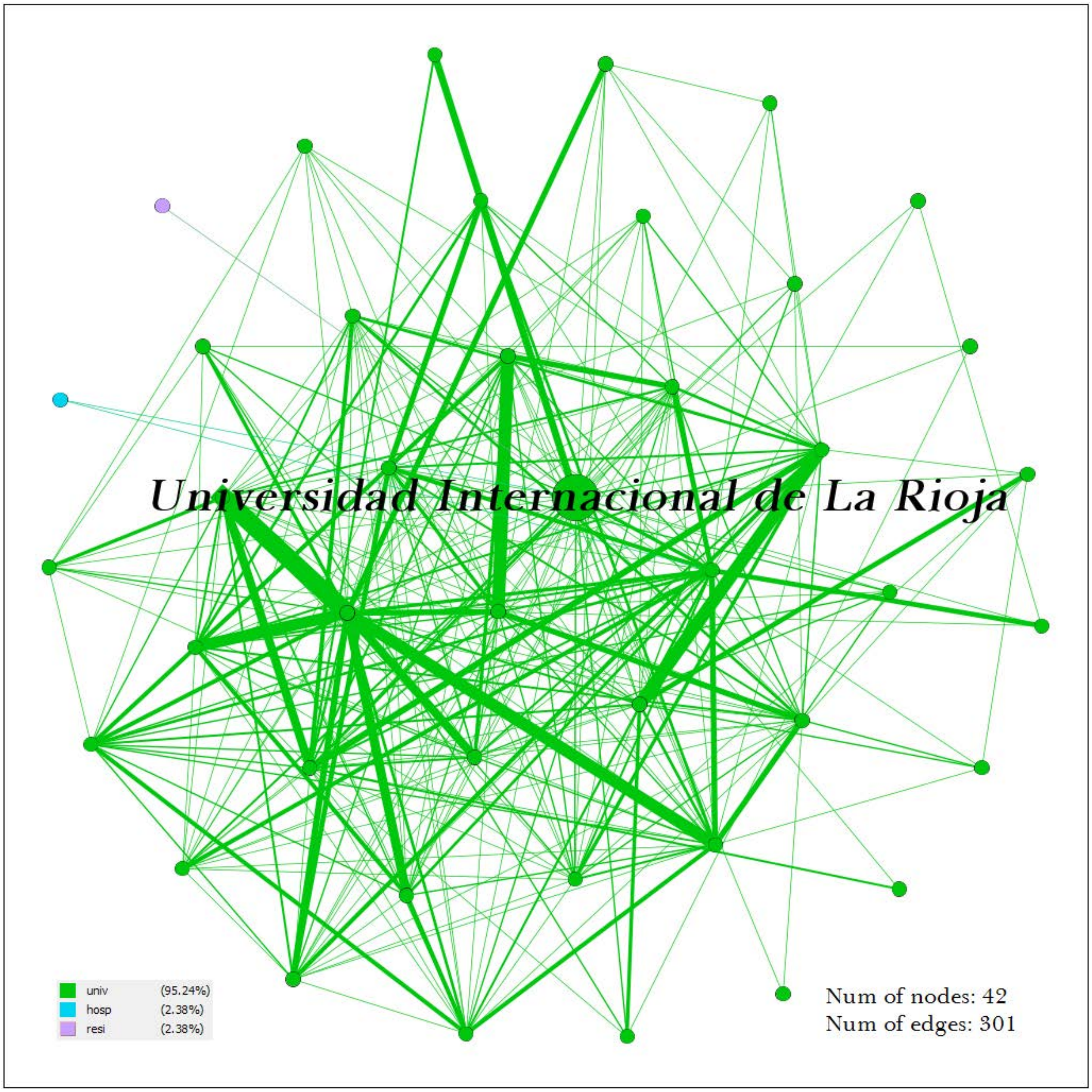
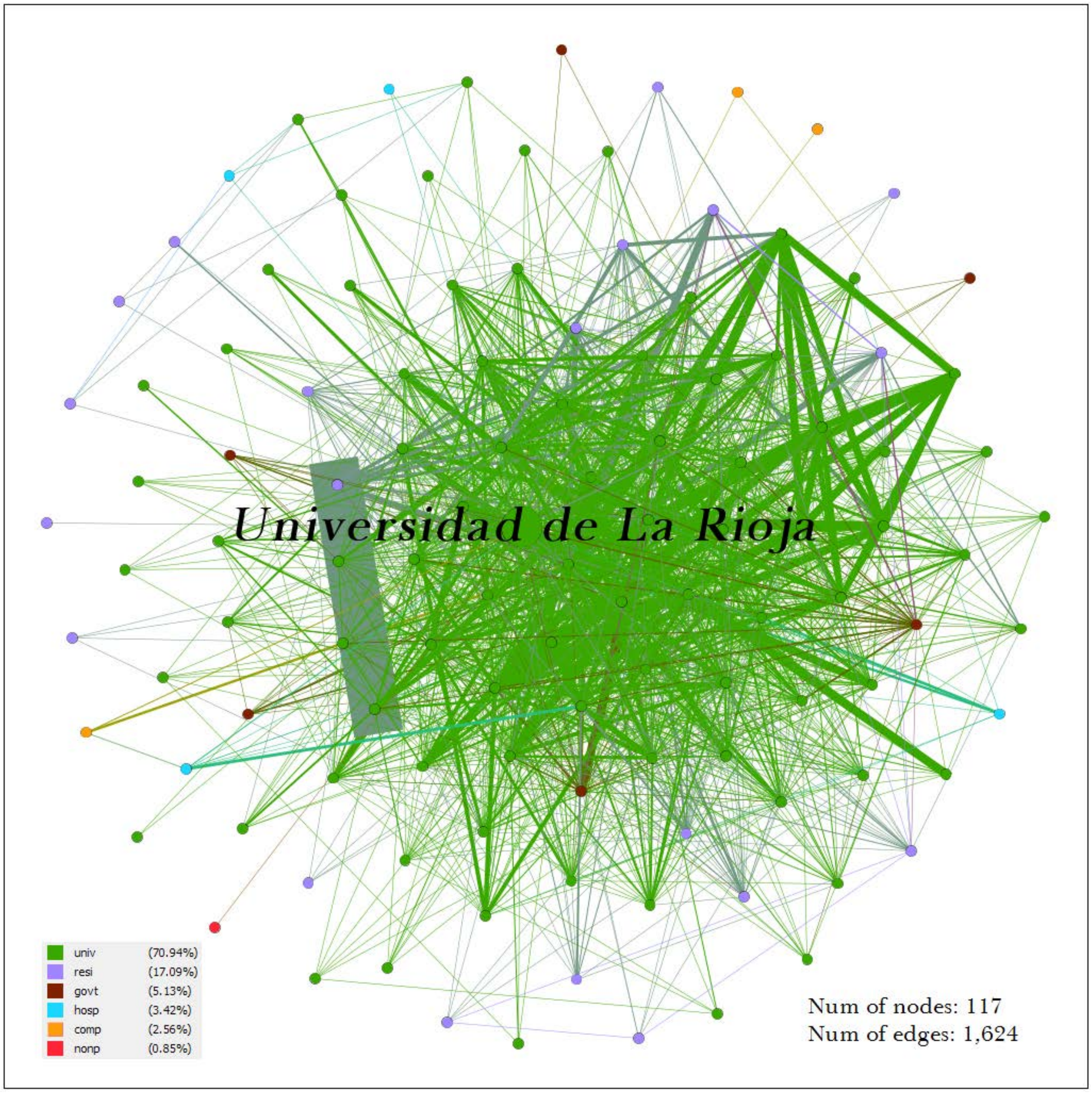


Figure A1.65. Subgraph of the *Universidad Internacional de La Rioja.* Fruchterman-Reingold Layout.



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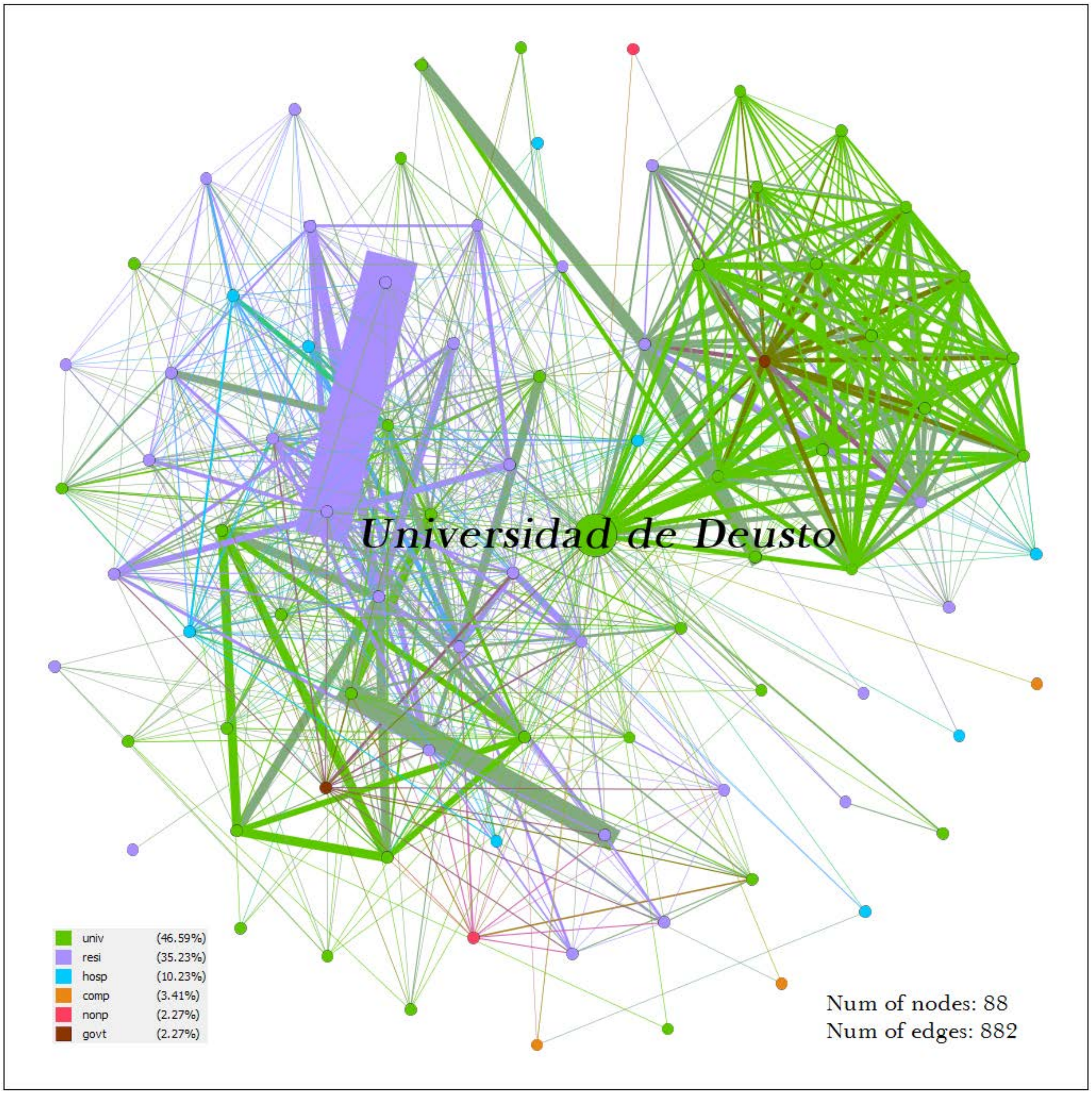
País Vasco



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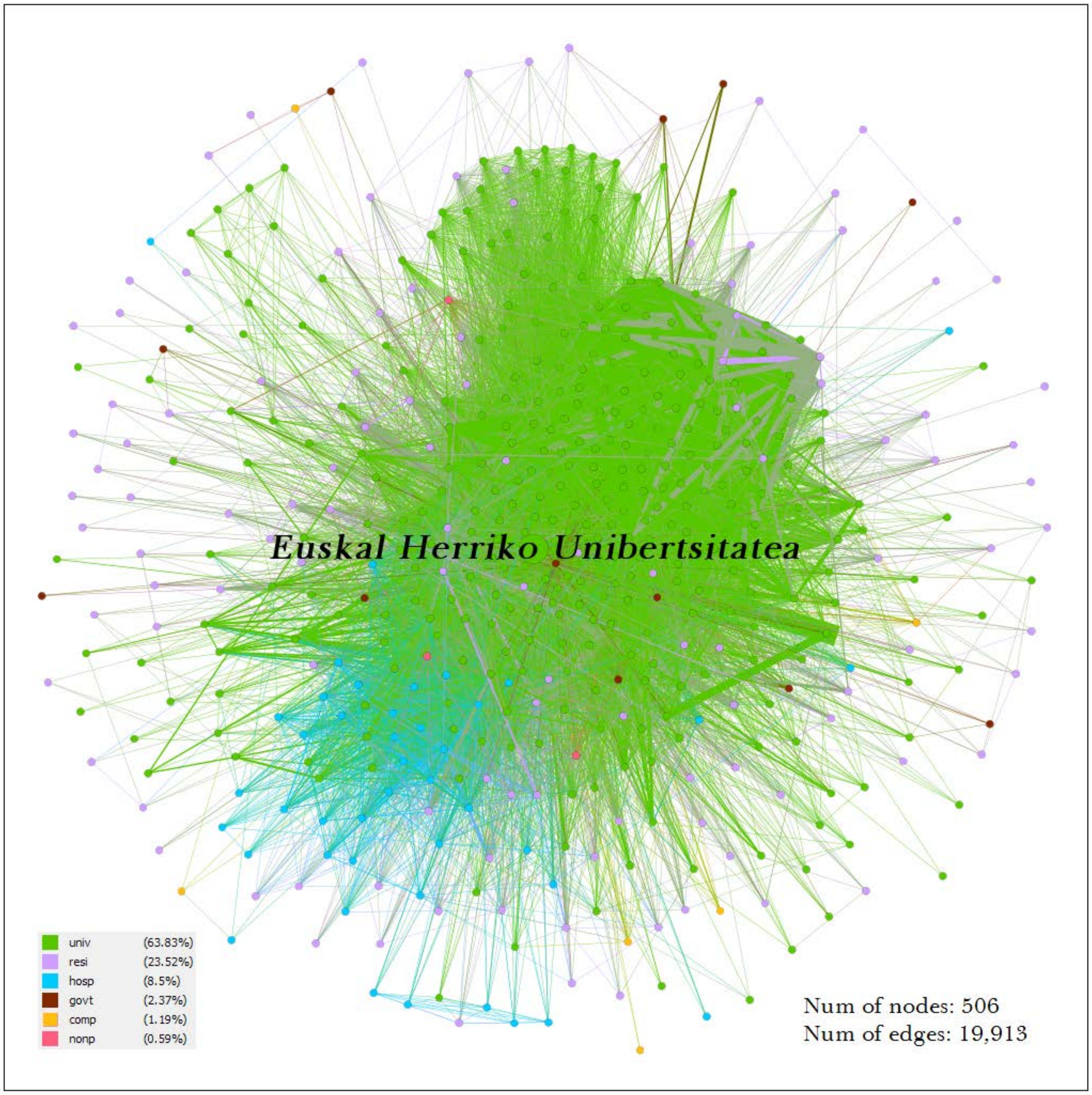

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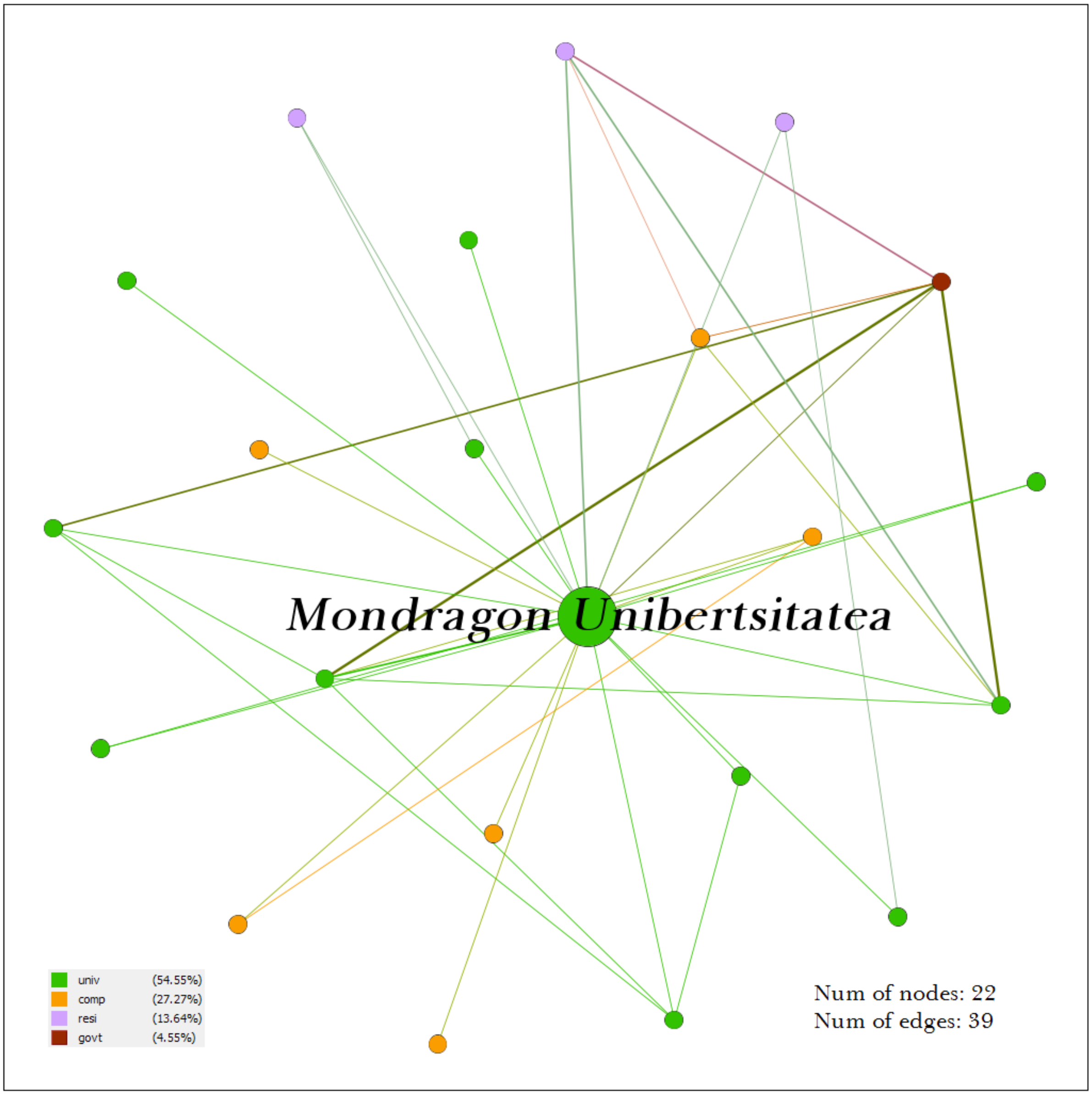

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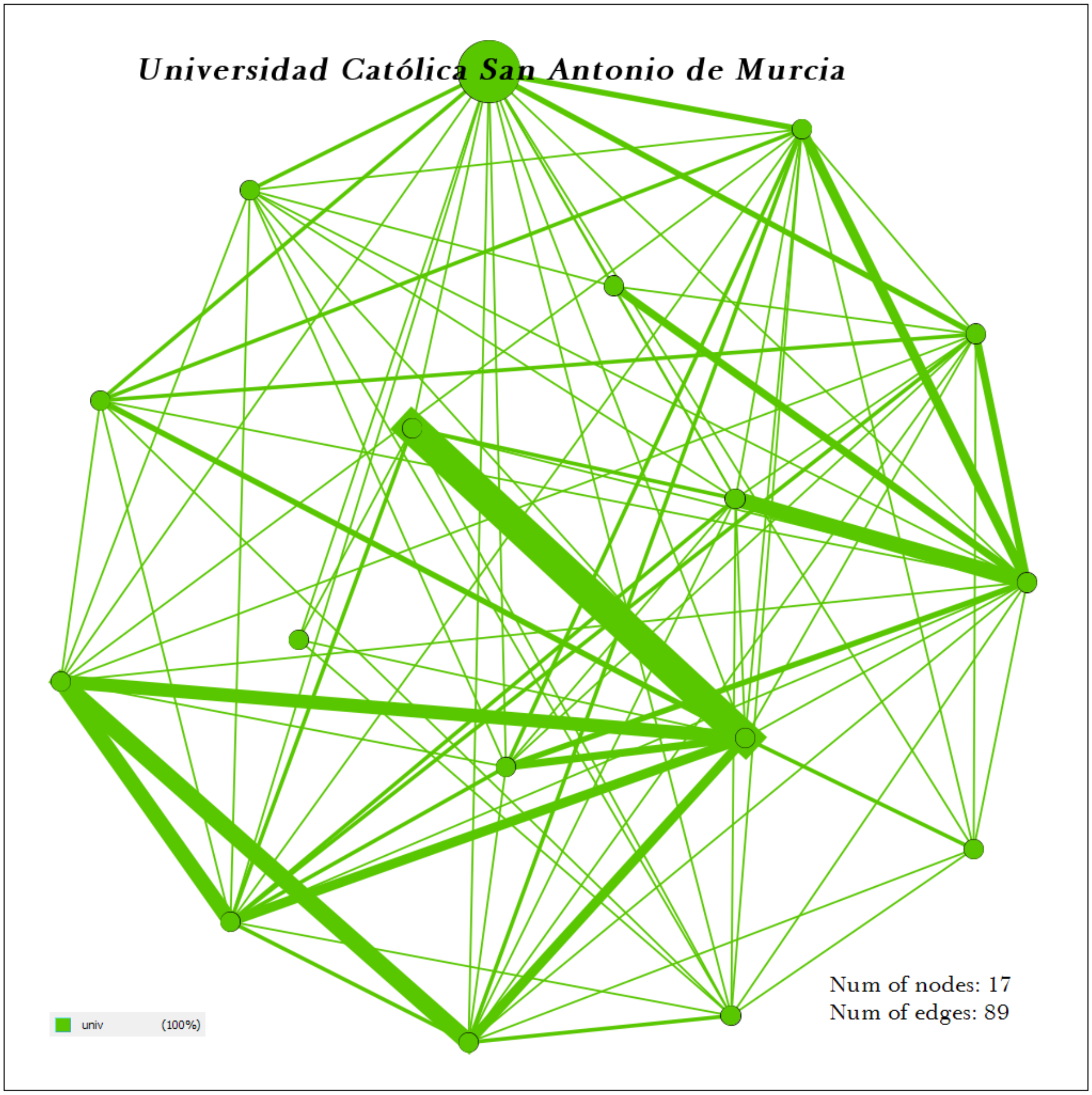
Región de Murcia



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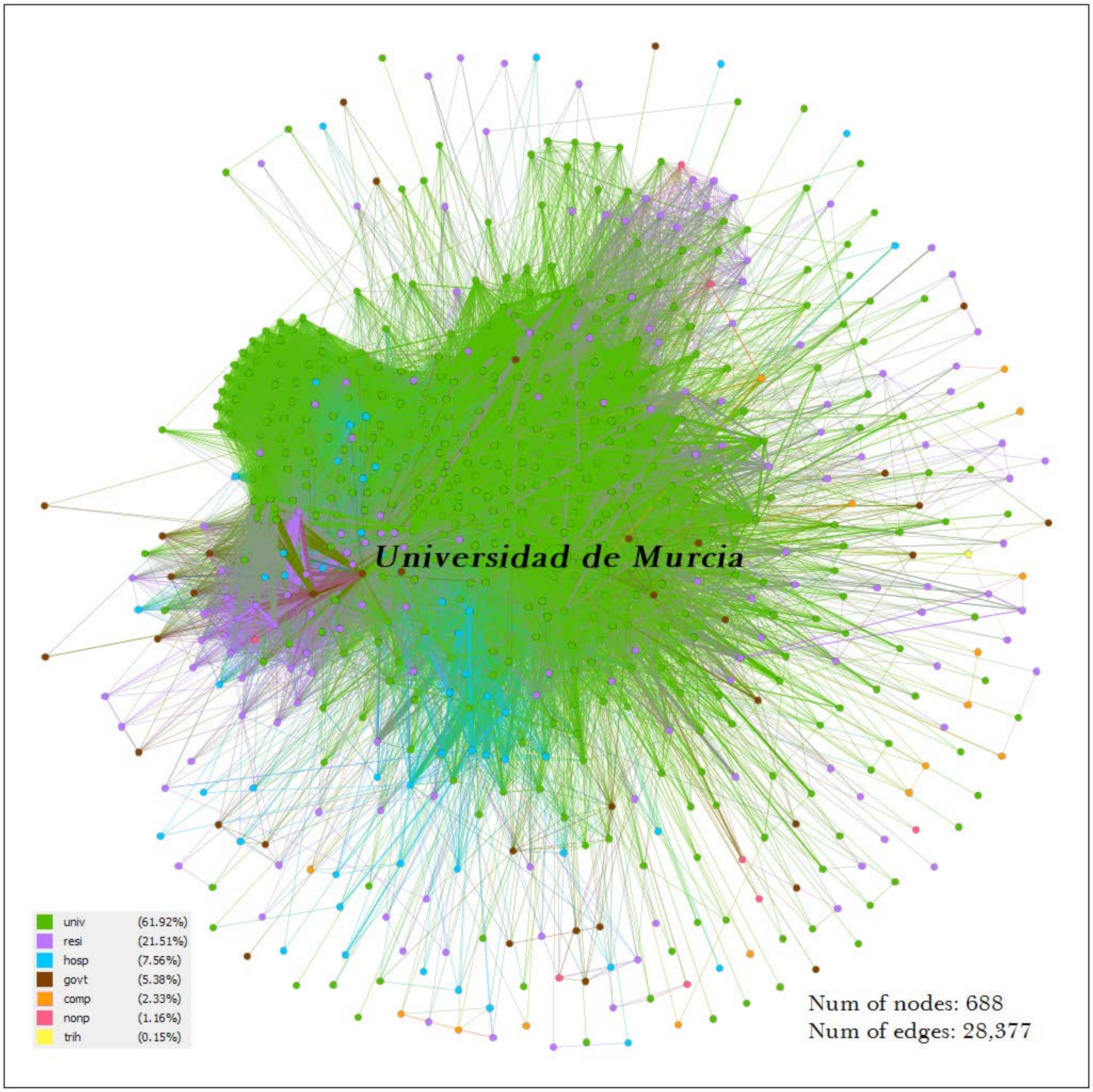

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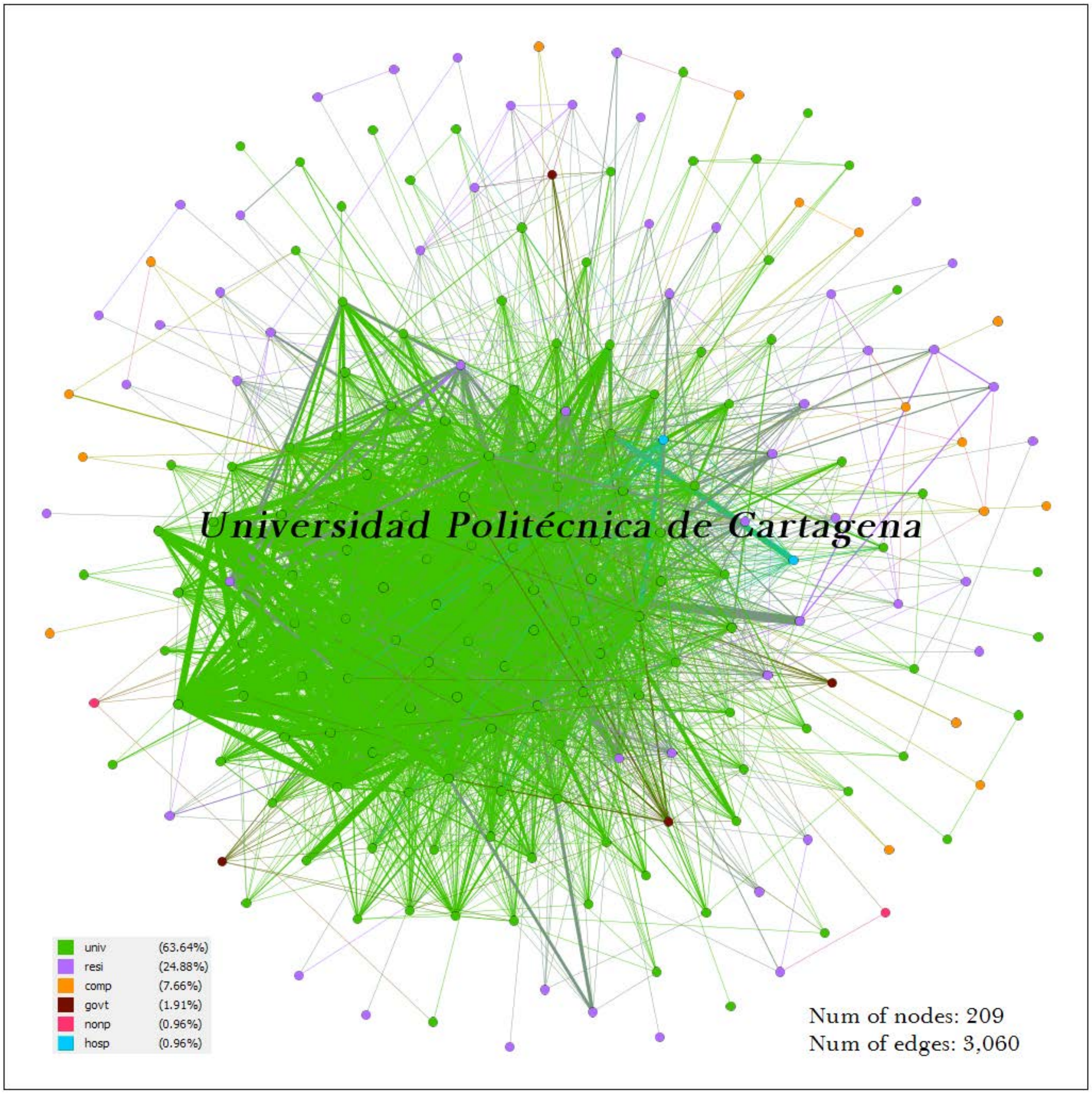

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Nacional

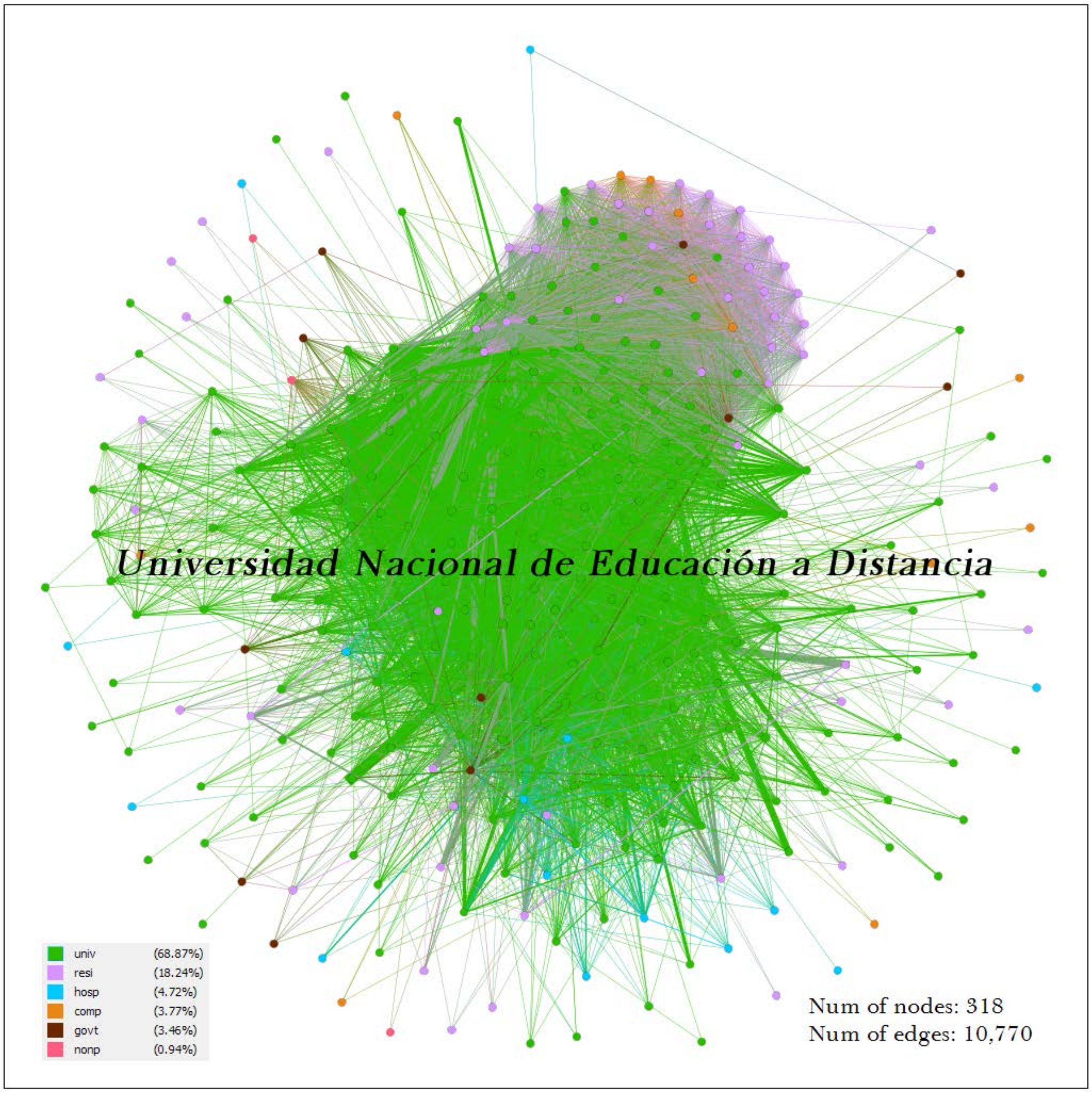


Figure A1.73. Subgraph of the *Universdad Nacional de Educación a Distancia*. Fruchterman-Reingold Layout.

ANNEX II

RECOMMENDATIONS PER UNIVERSITY

LIST OF FIGURES

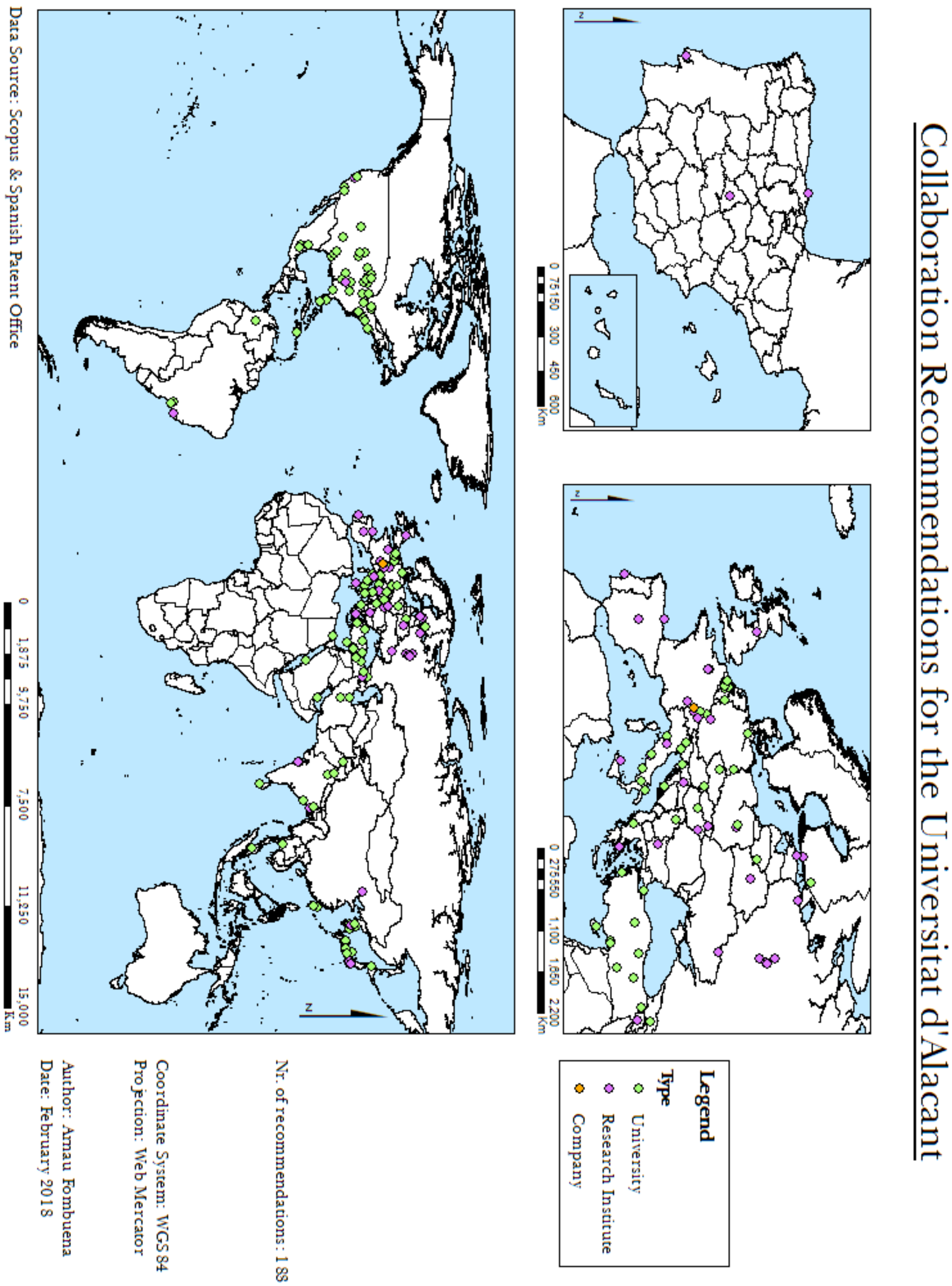
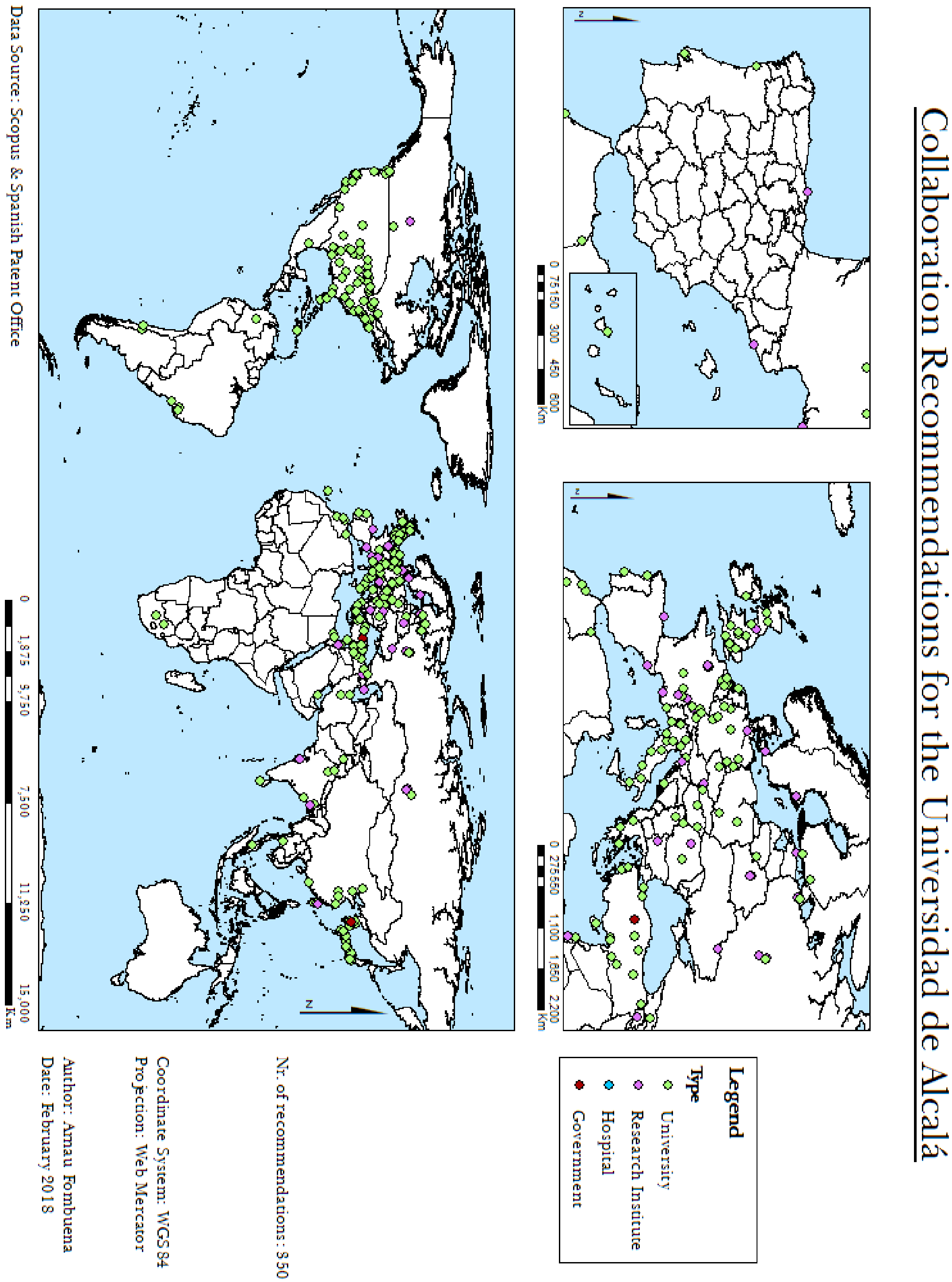


Figure A2.1. Collaboration recommendations for the *Universitat d'Alacant*.



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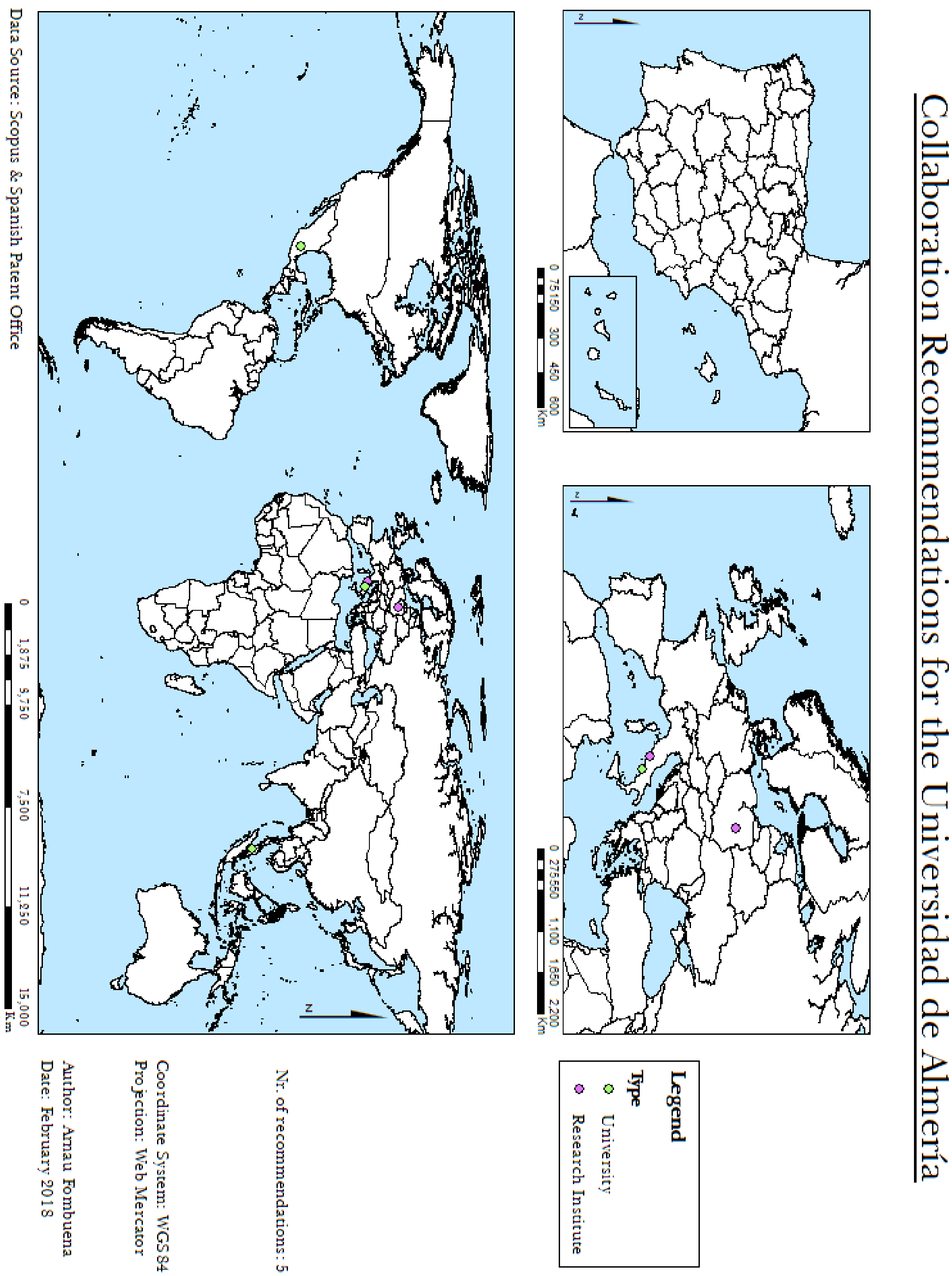

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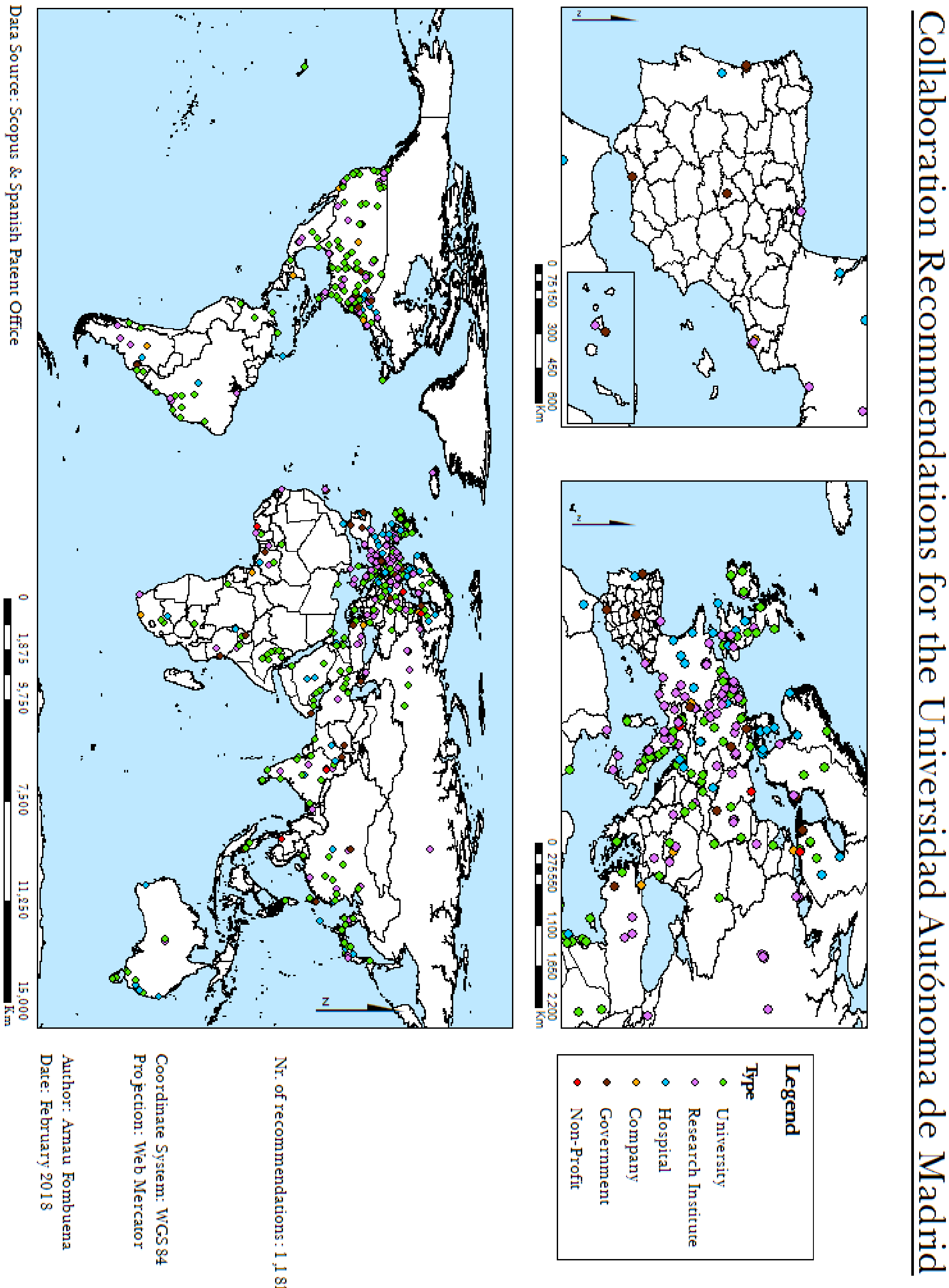

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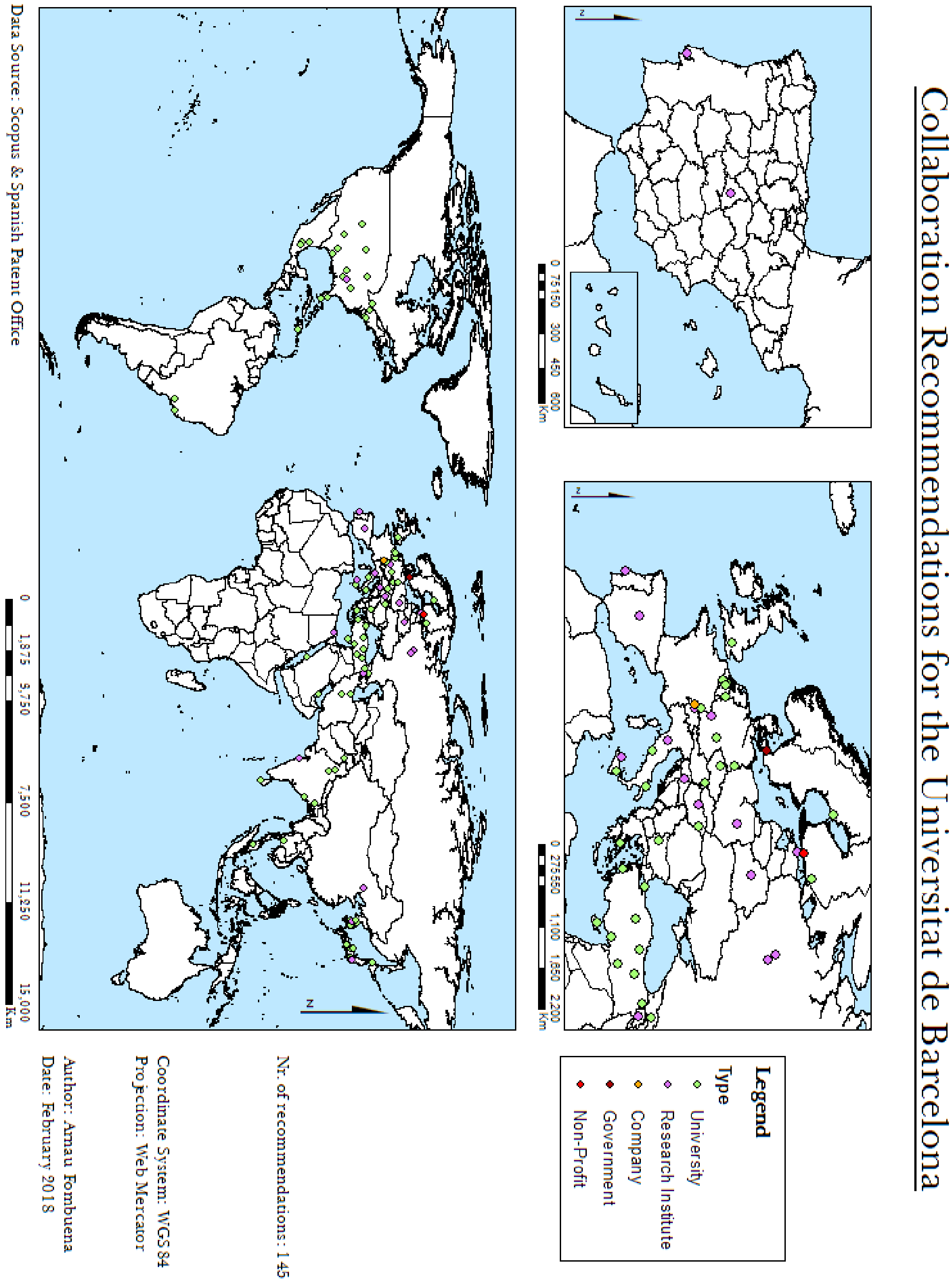

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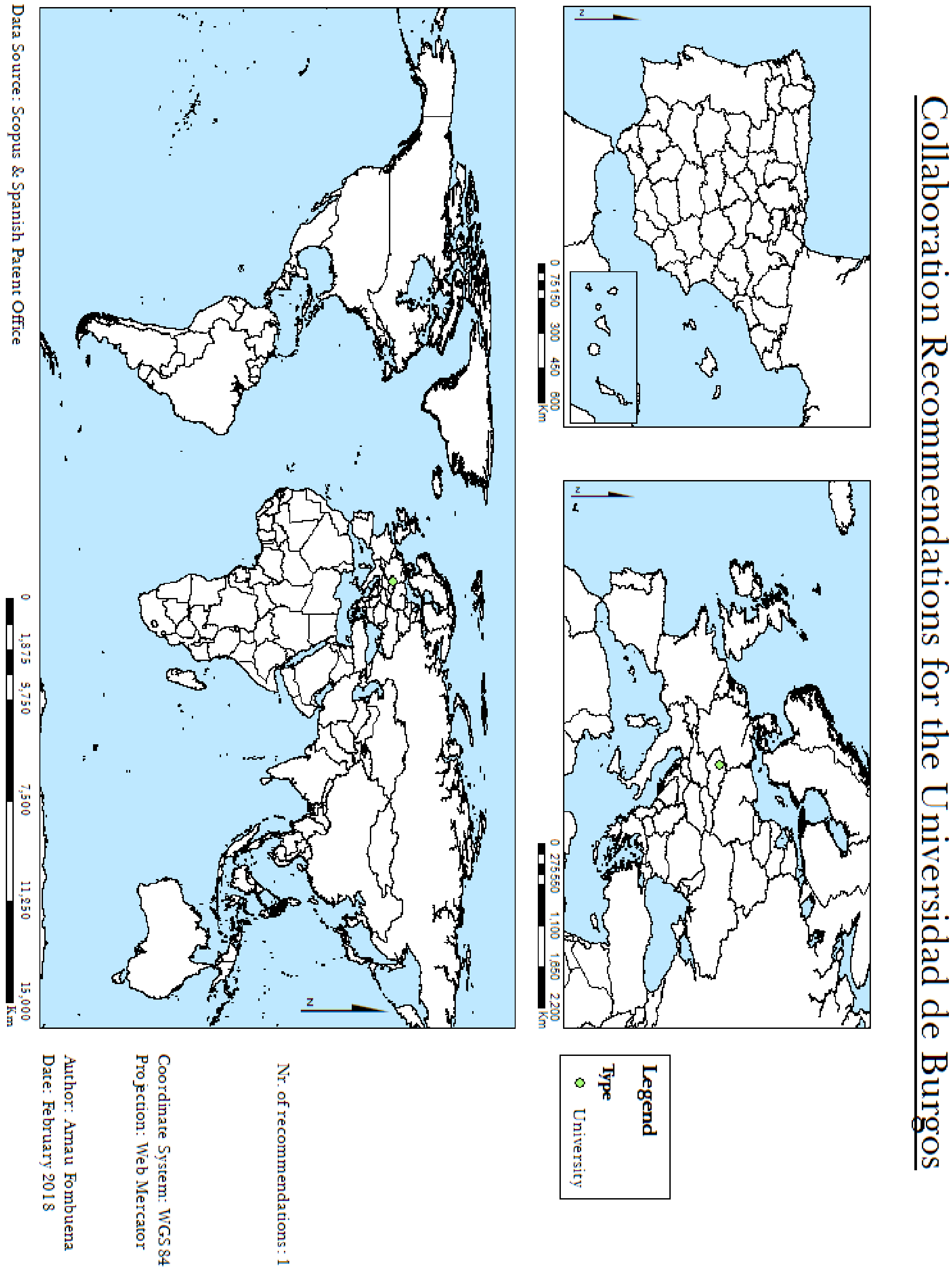

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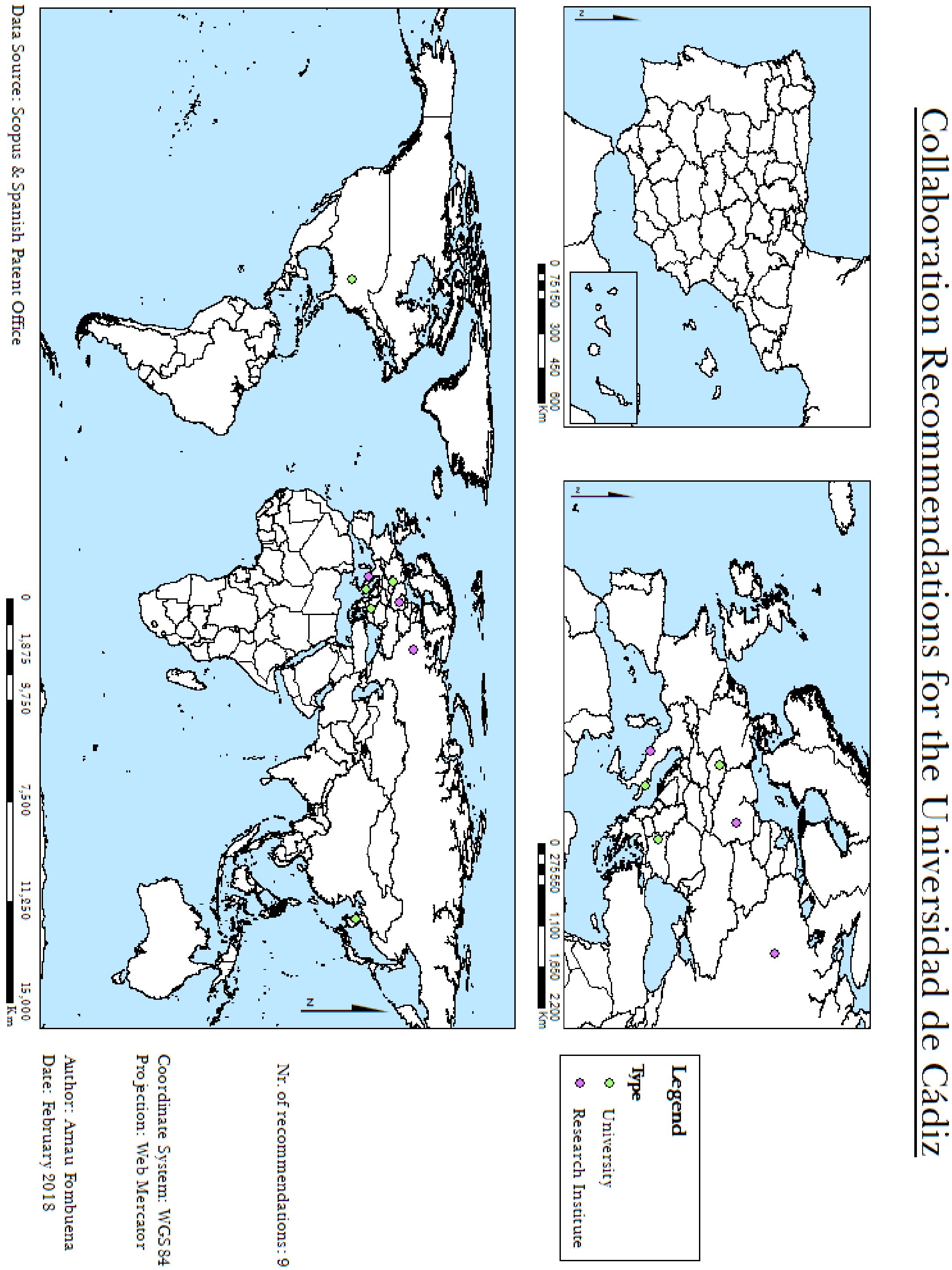

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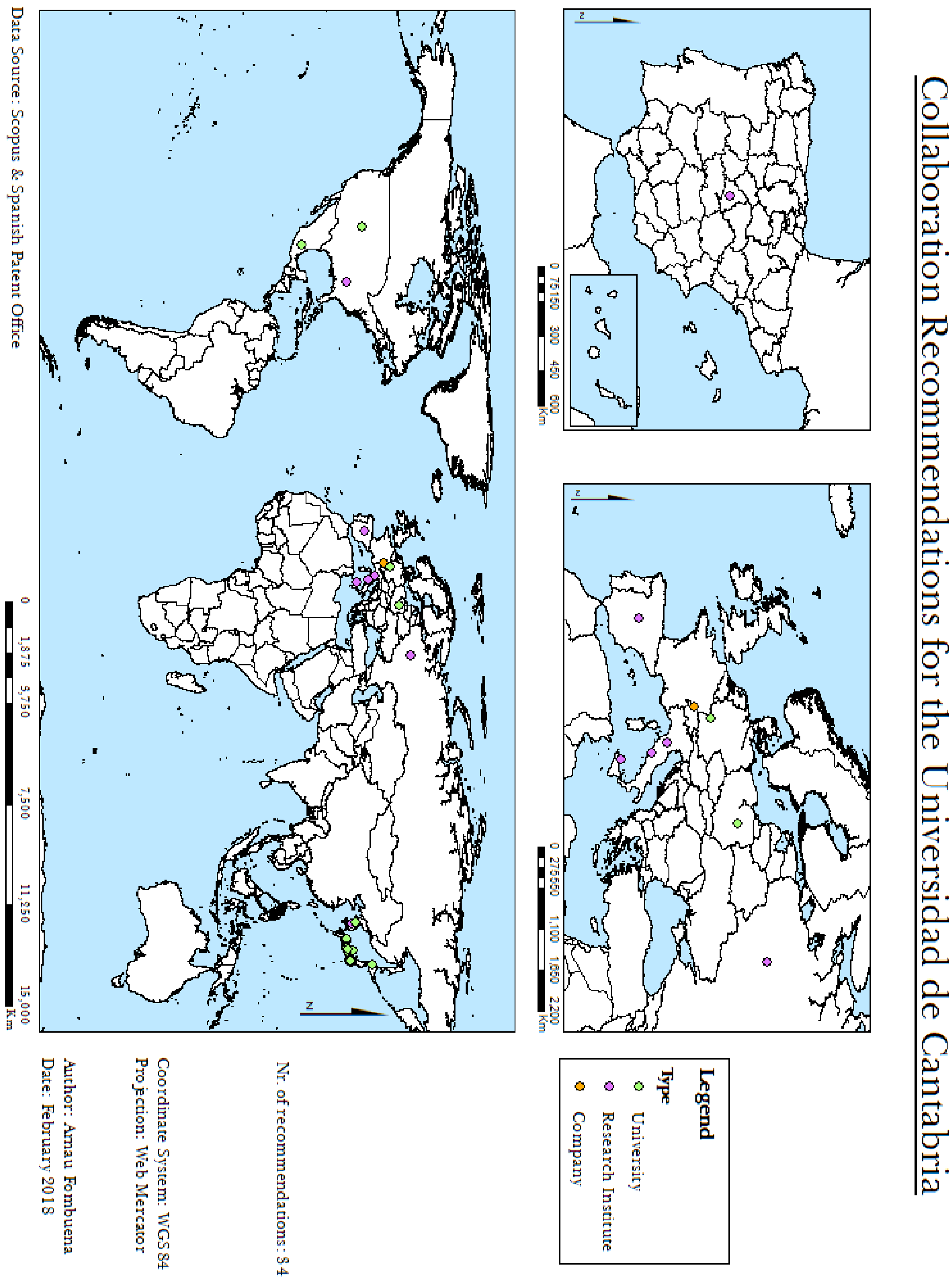

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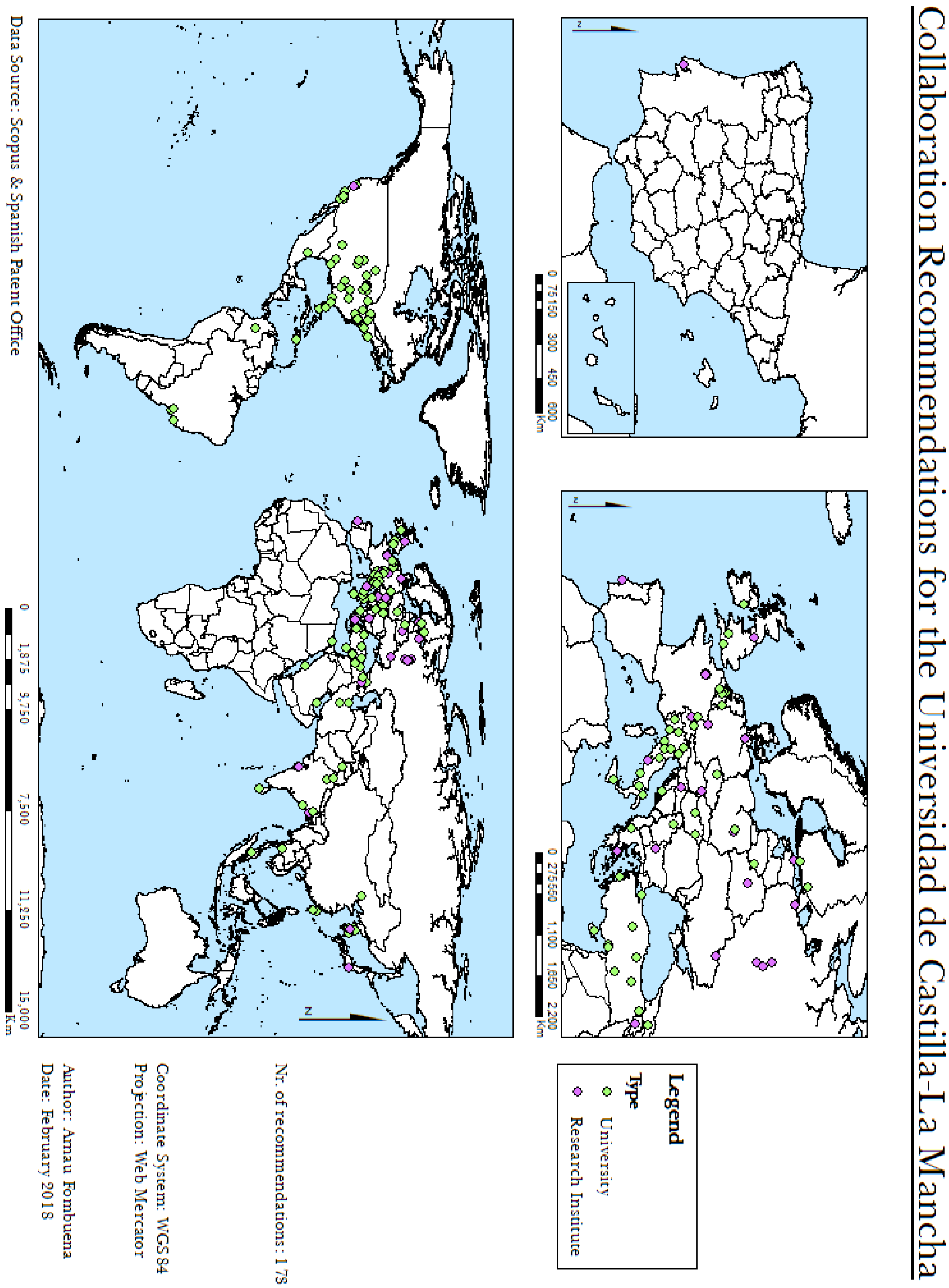


Figure A2.9. Collaboration recommendations for the *Universidad de Castilla-La Mancha.*

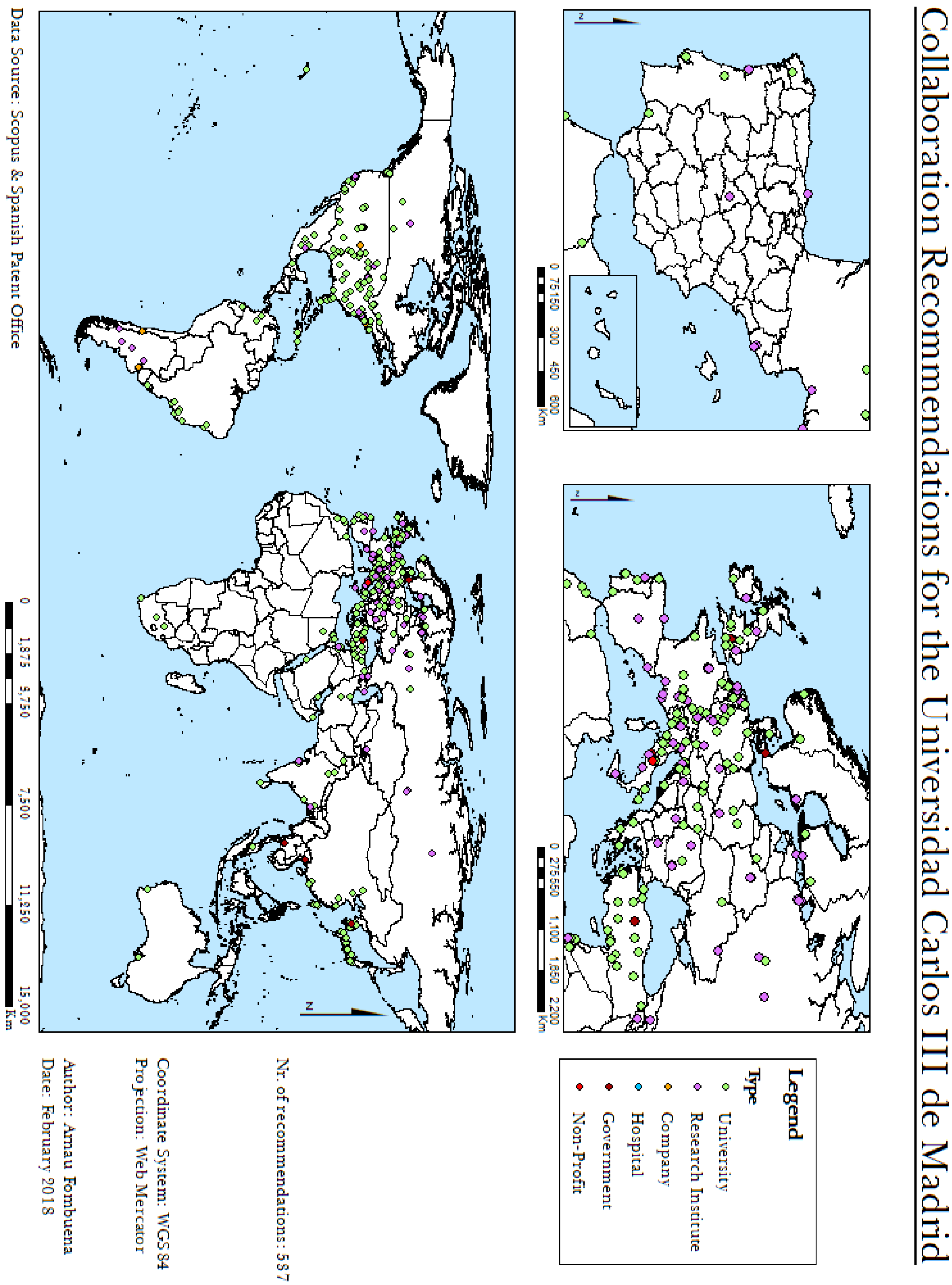
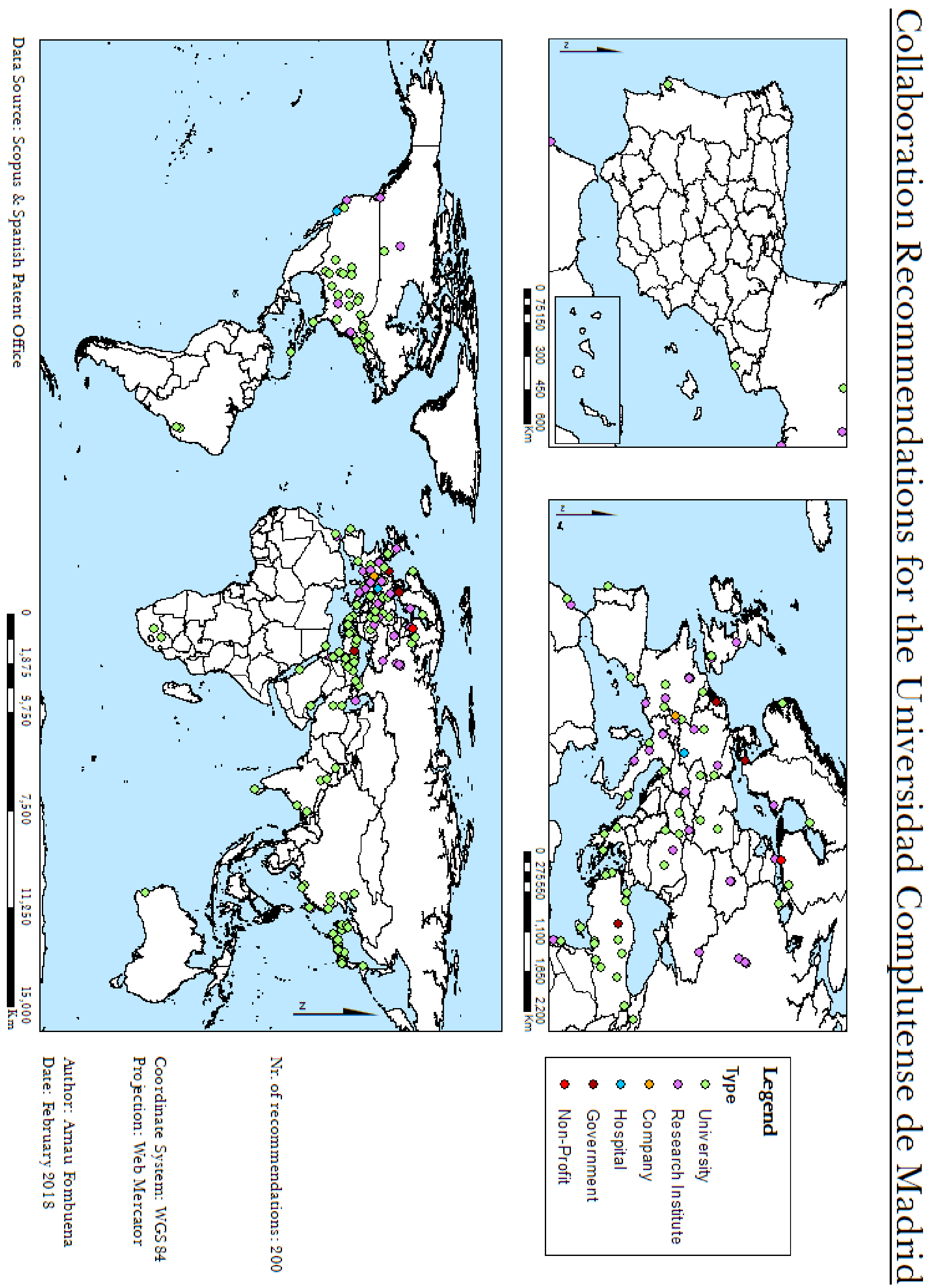


Figure A2.10. Collaboration recommendations for the *Universidad Carlos III de Madrid.*



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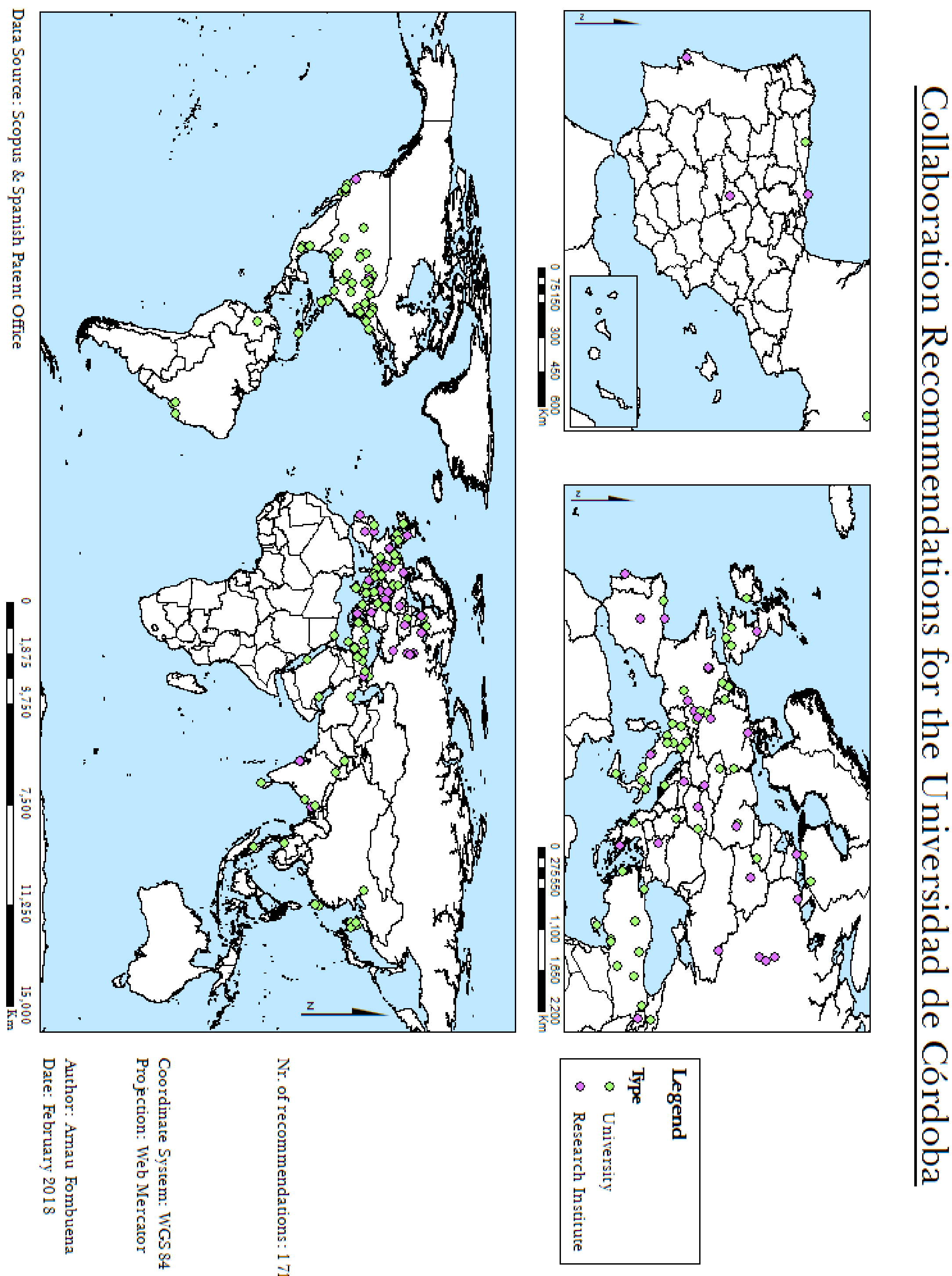

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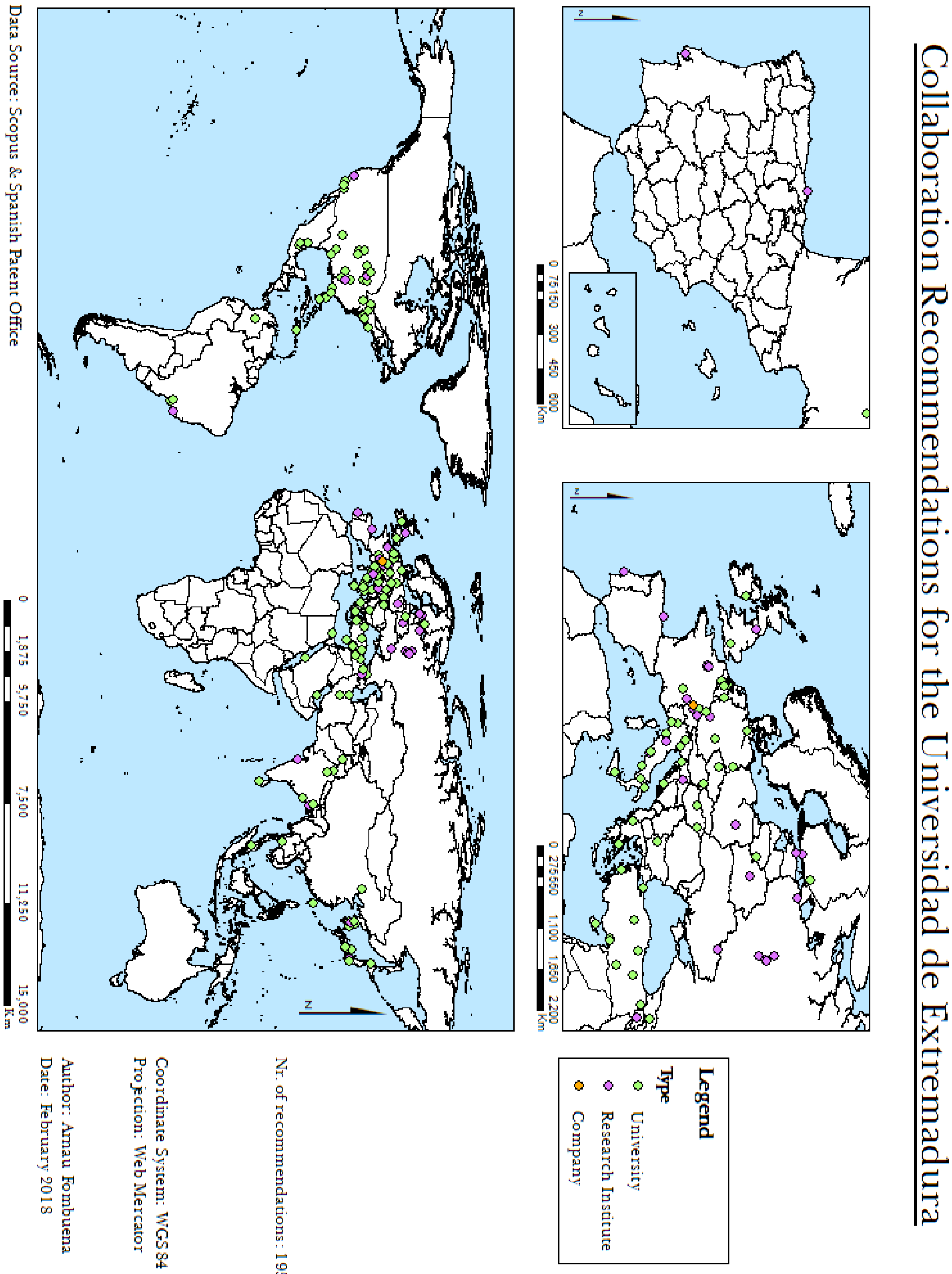

Figure A2.13. Collaboration recommendations for the *Universidad de Extremadura.*

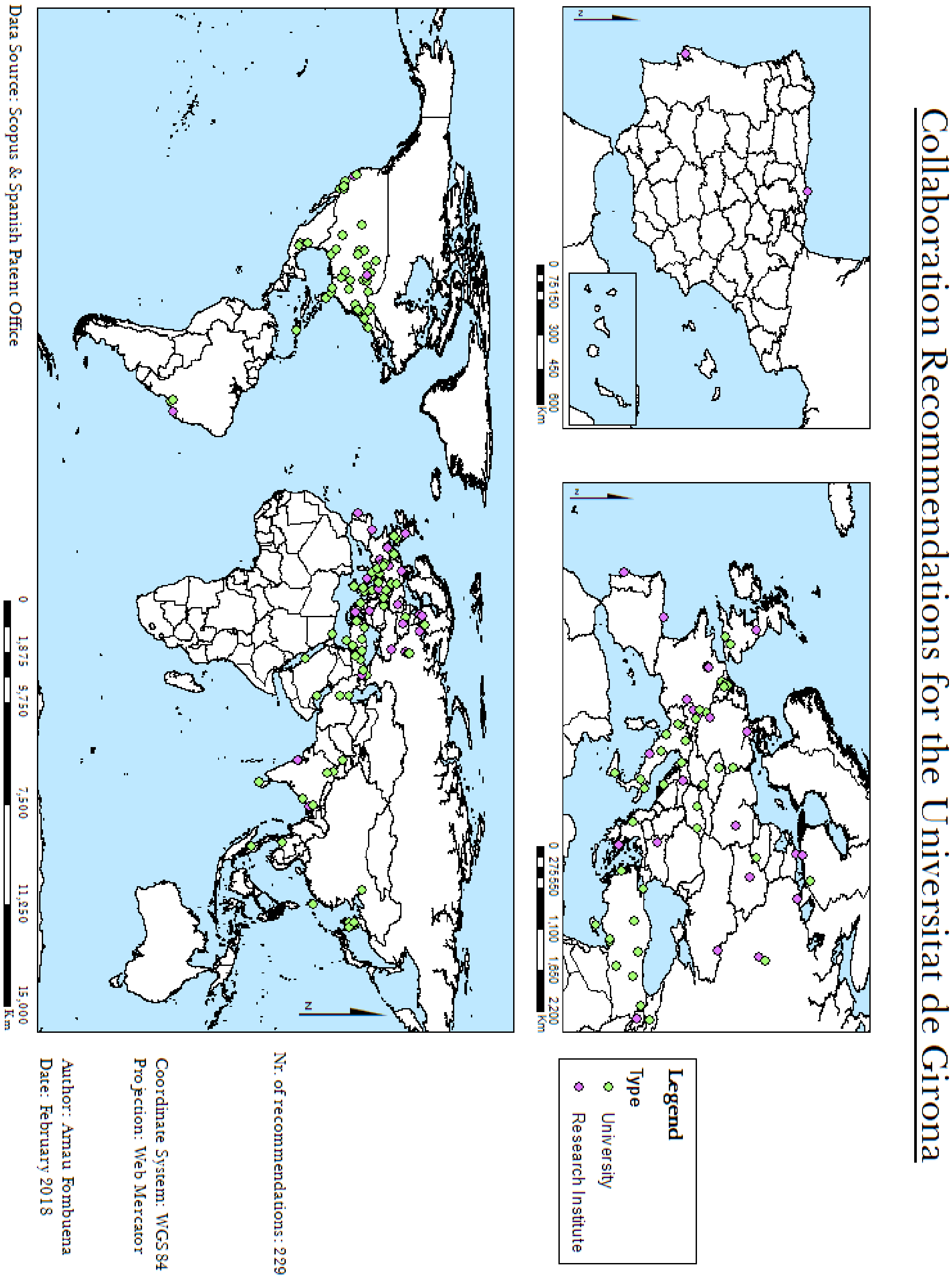

Figure A2.14. Collaboration recommendations for the *Universitat de Girona.*

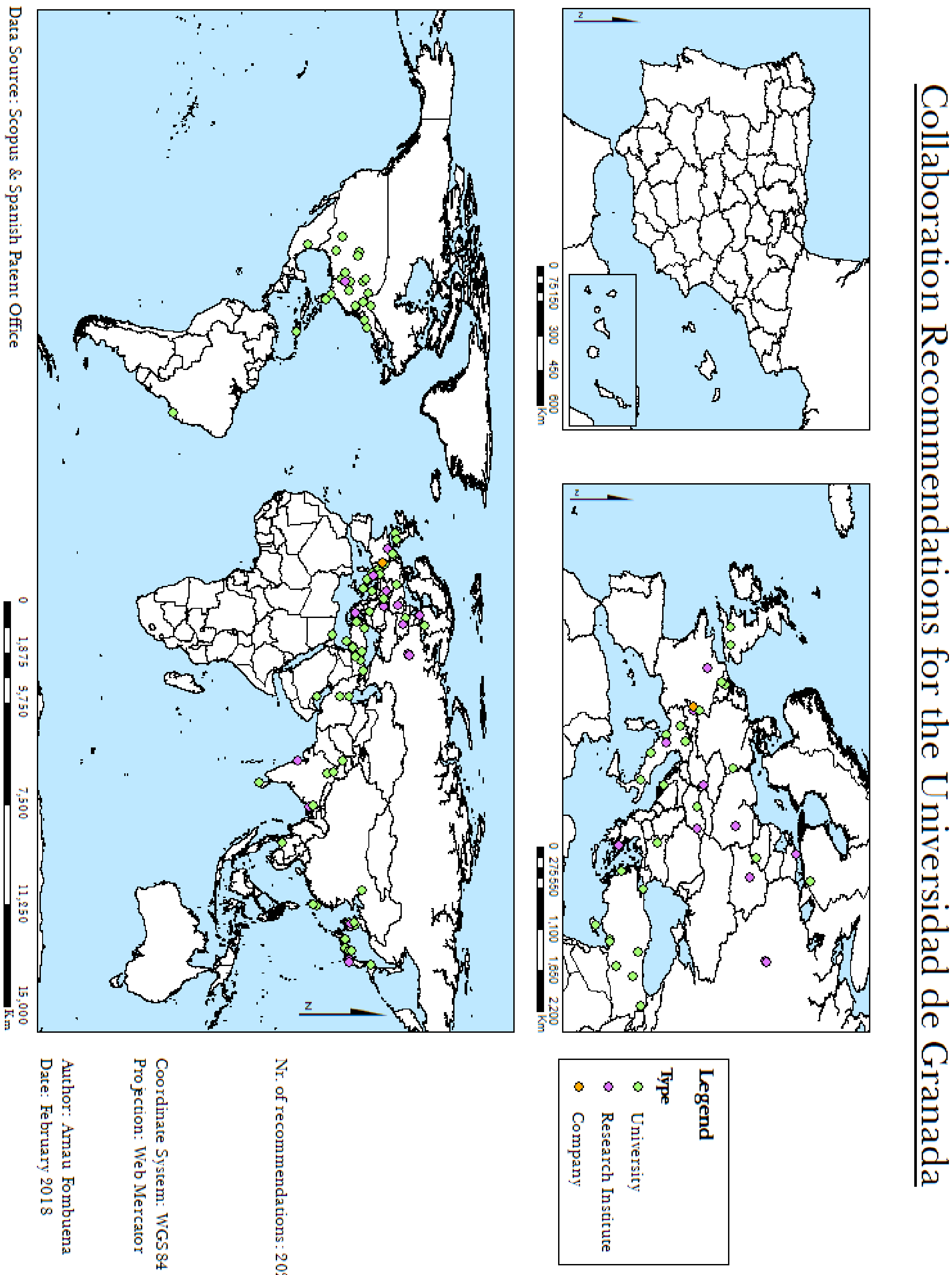

Figure A2.15. Collaboration recommendations for the *Universidad de Granada.*

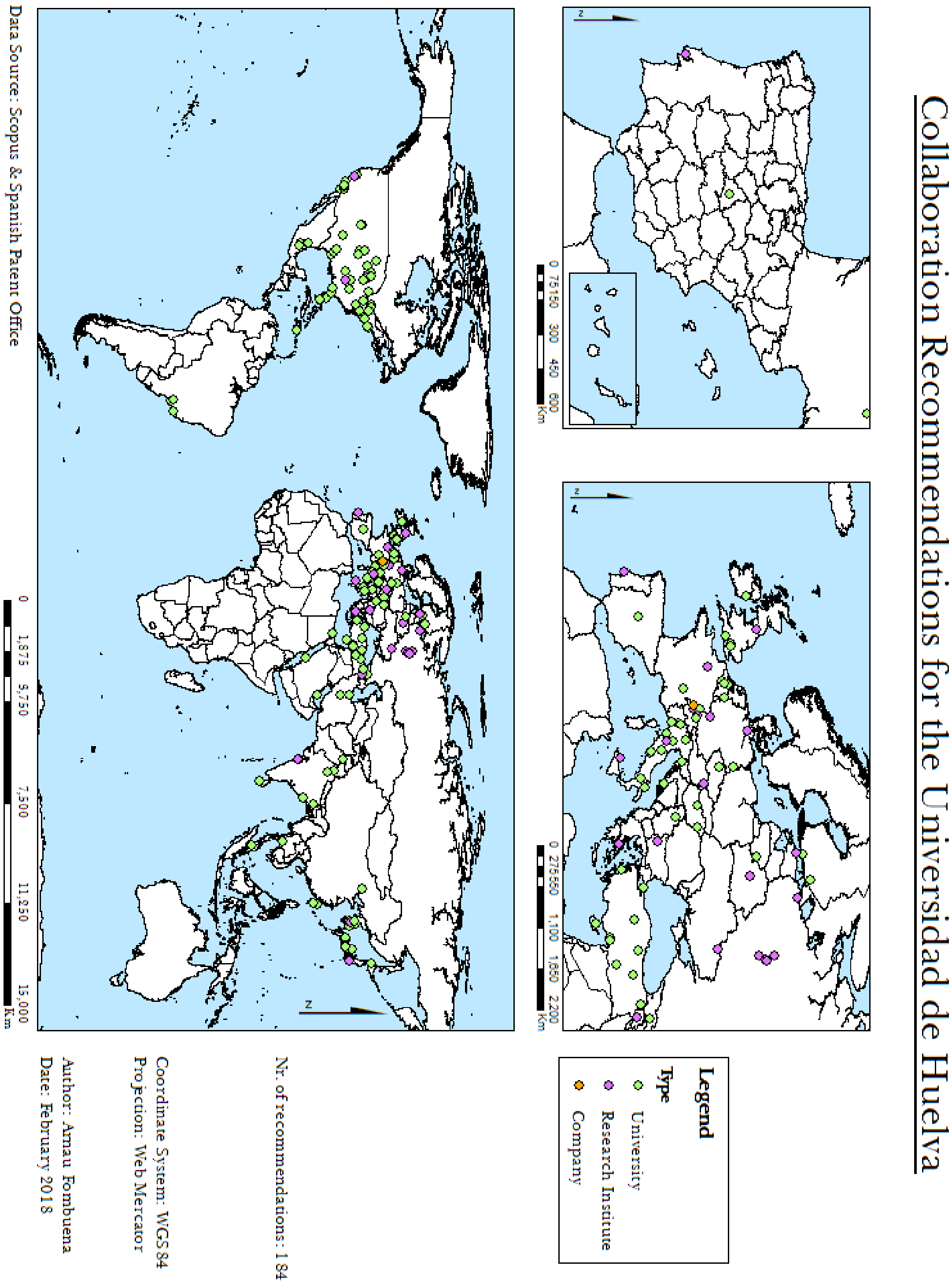

Figure A2.16. Collaboration recommendations for the *Universidad de Huelva.*

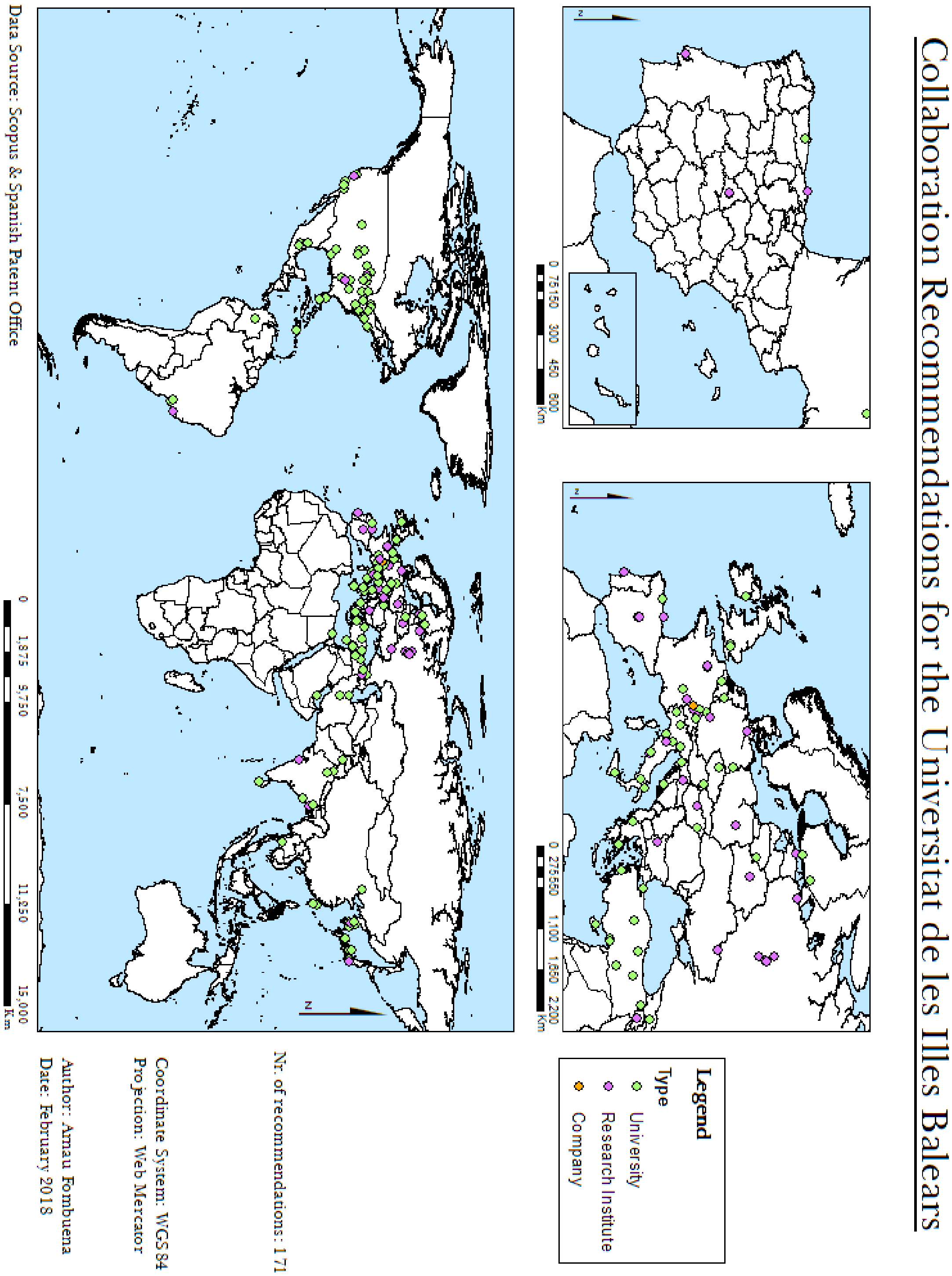

Figure A2.17. Collaboration recommendations for the *Universitat de les Illes Balears.*

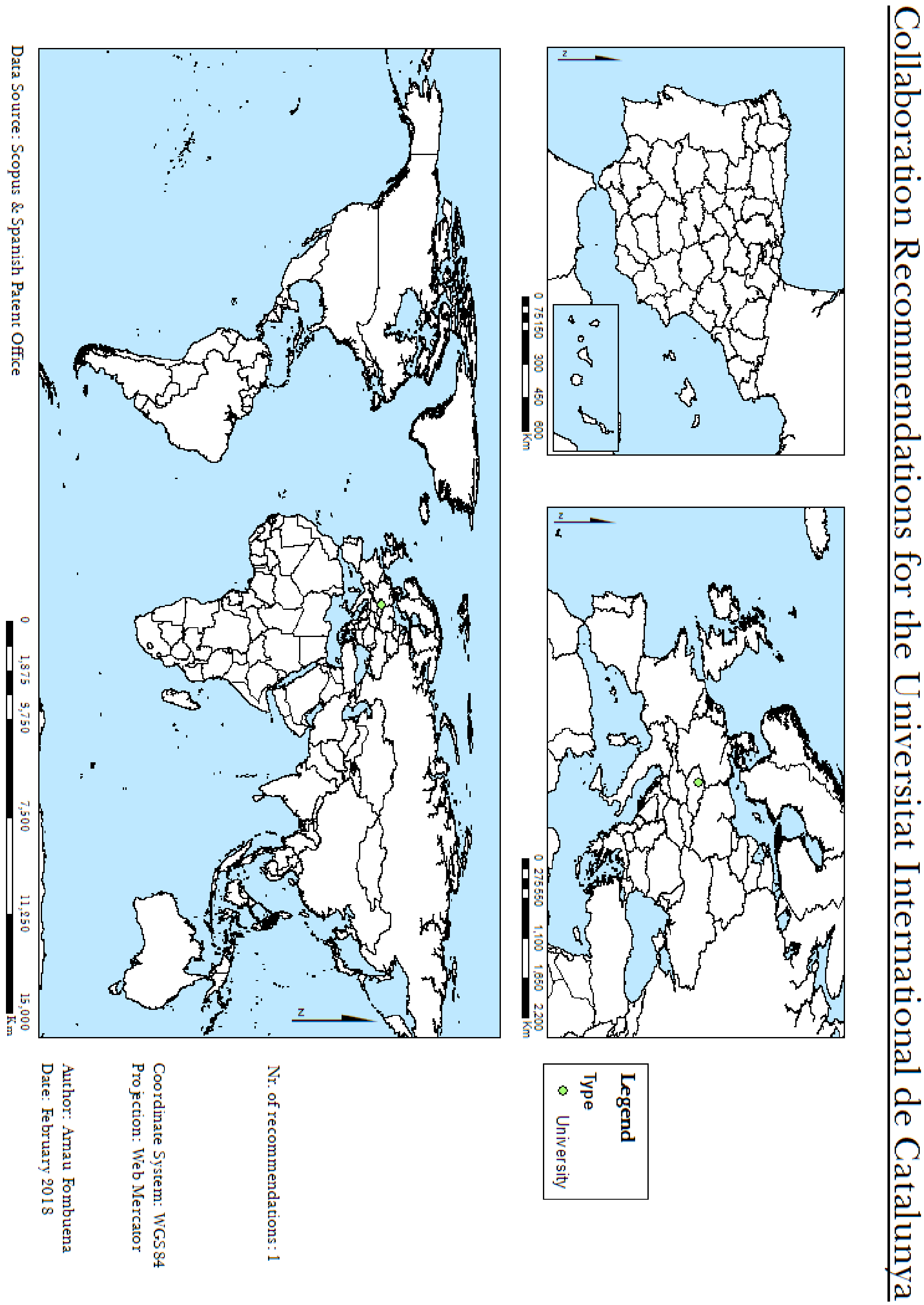

Figure A2.18. Collaboration recommendations for the *Universitat Internacional de Catalunya.*

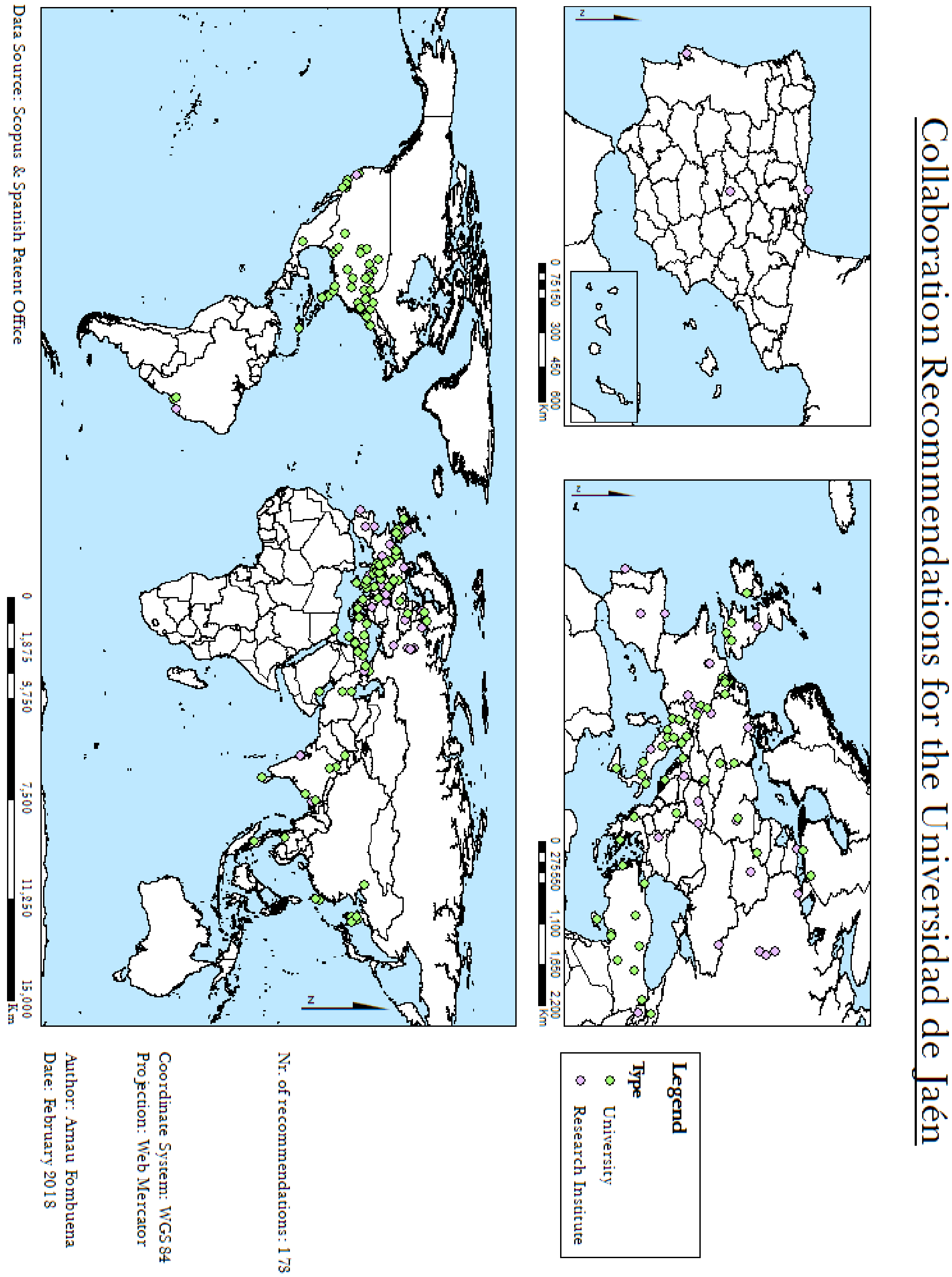

Figure A2.19. Collaboration recommendations for the *Universidad de Jaén.*

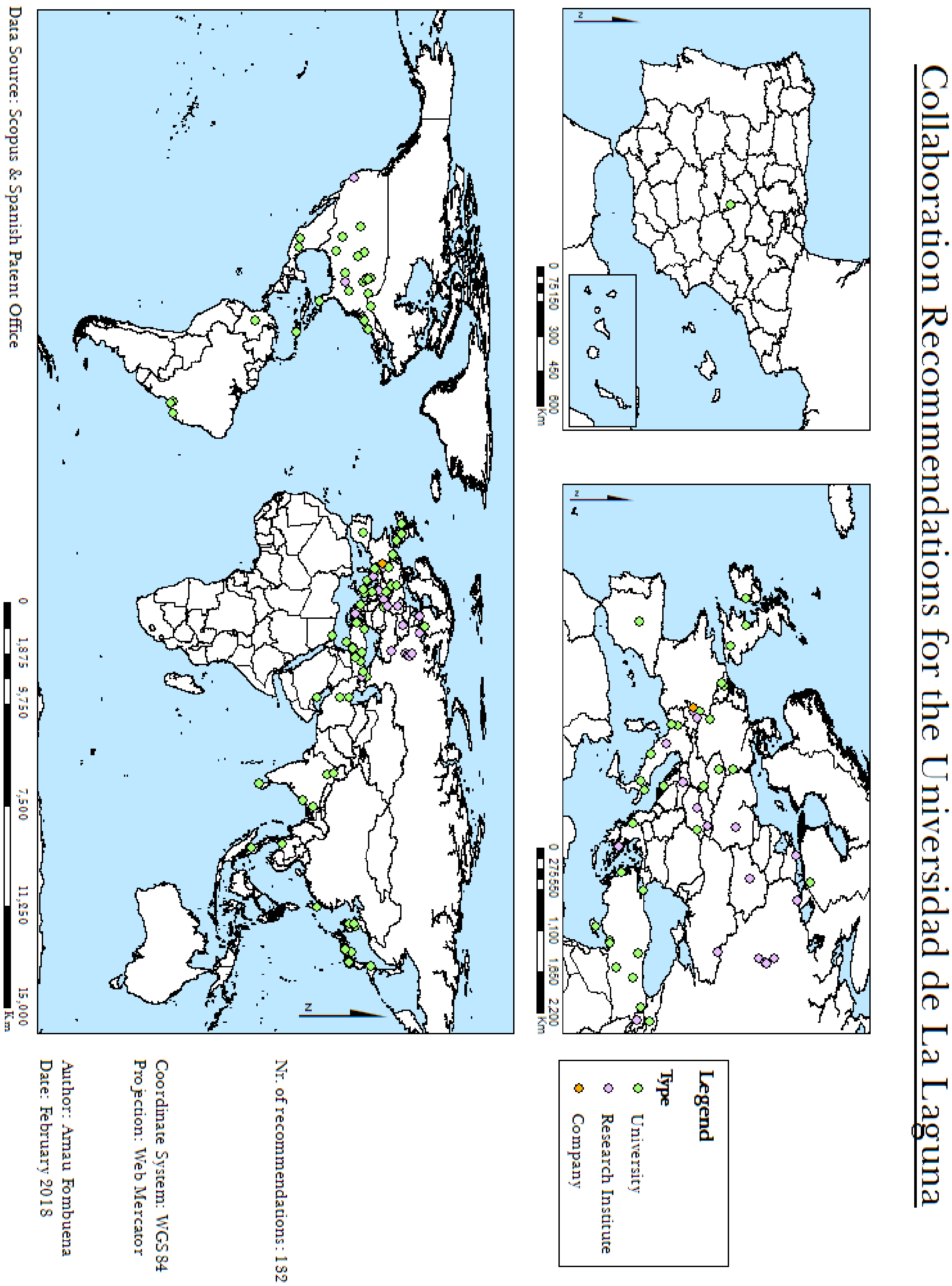

Figure A2.20. Collaboration recommendations for the *Universidad de La Laguna.*

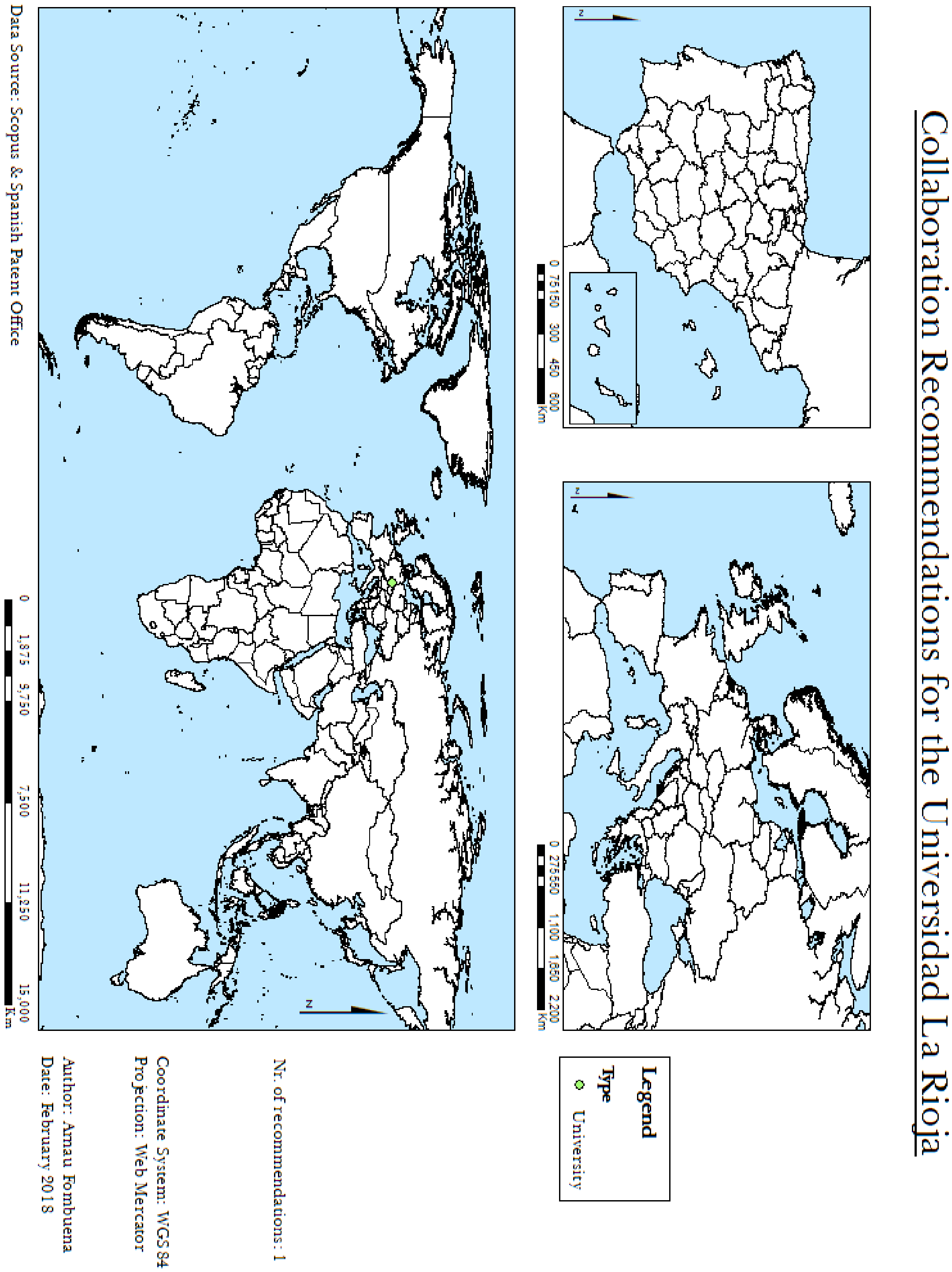

Figure A2.21. Collaboration recommendations for the *Universidad de La Rioja.*

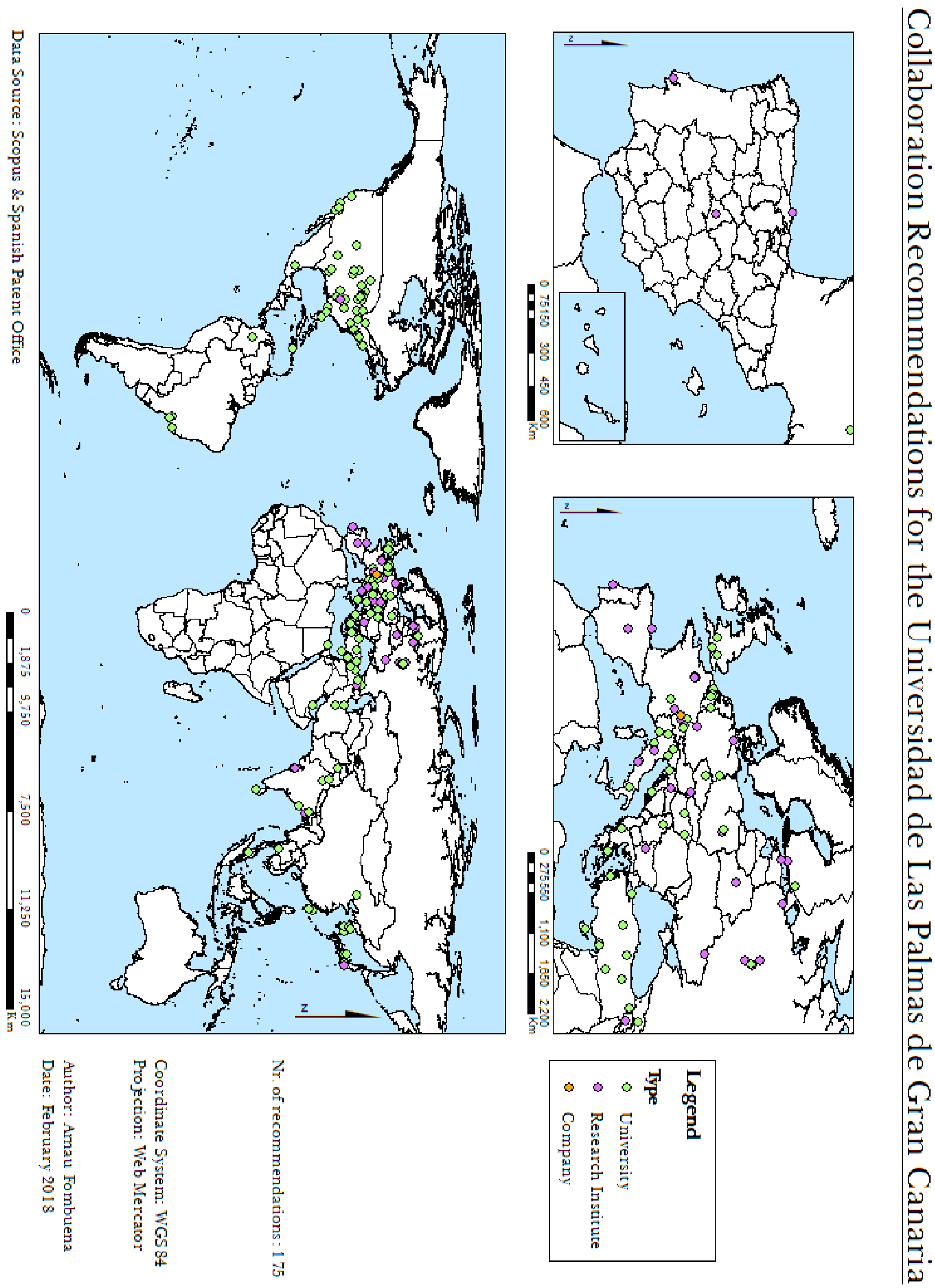

Figure A2.22. Collaboration recommendations for the *Universidad de Las Palmas de Gran Canaria.*

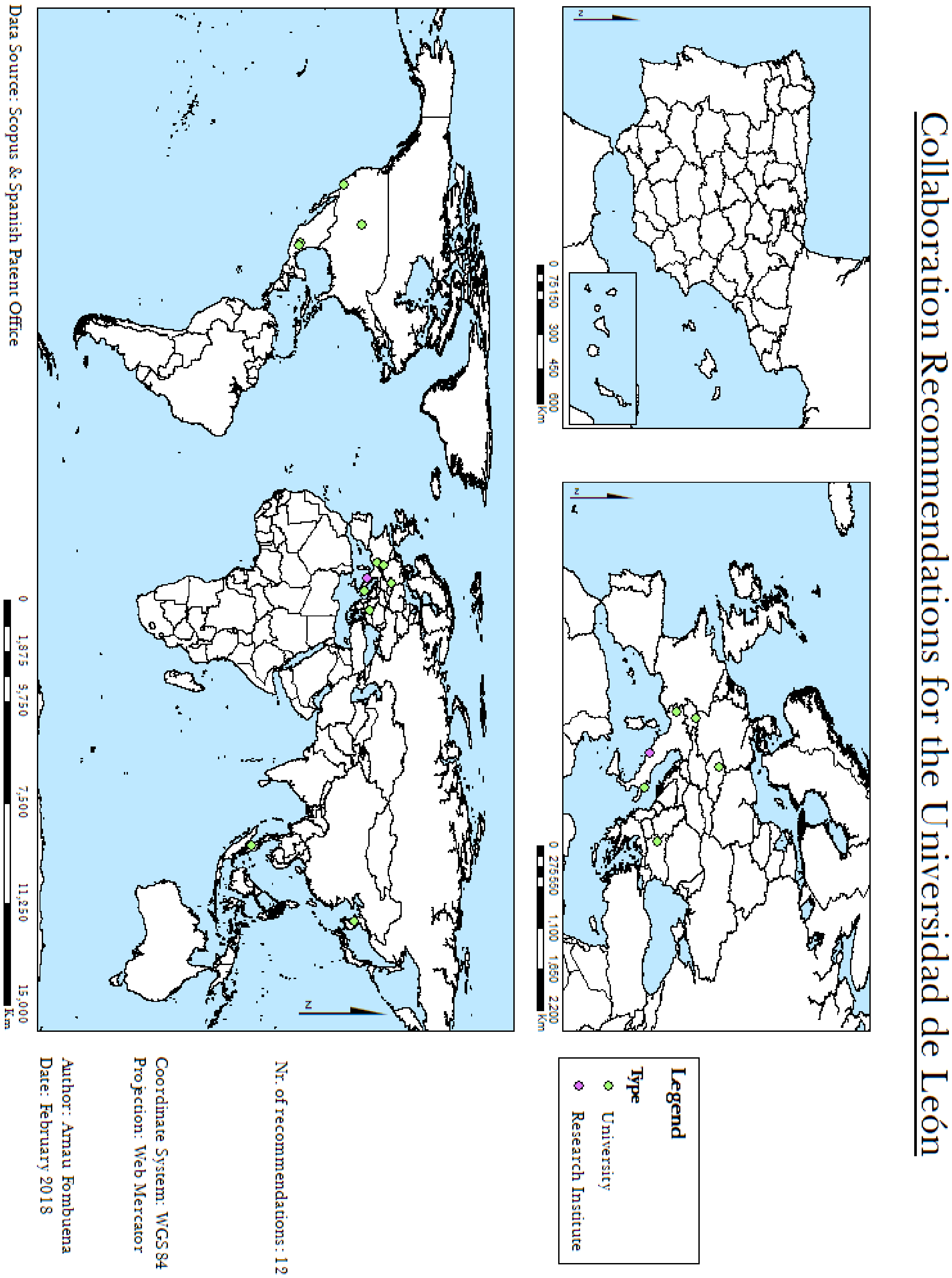

Figure A2.23. Collaboration recommendations for the *Universidad de León.*

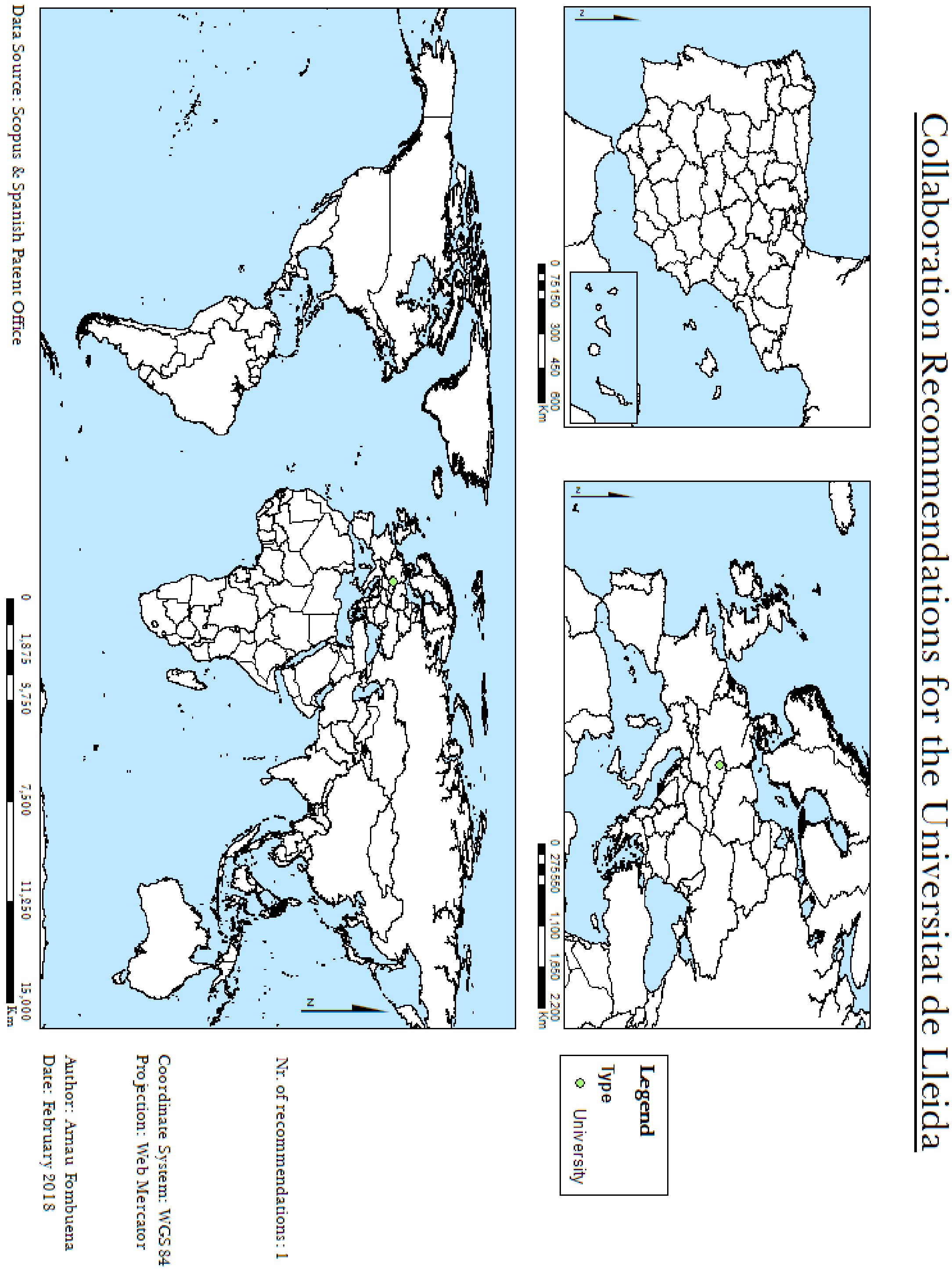

Figure A2.24. Collaboration recommendations for the *Universitat de Lleida.*

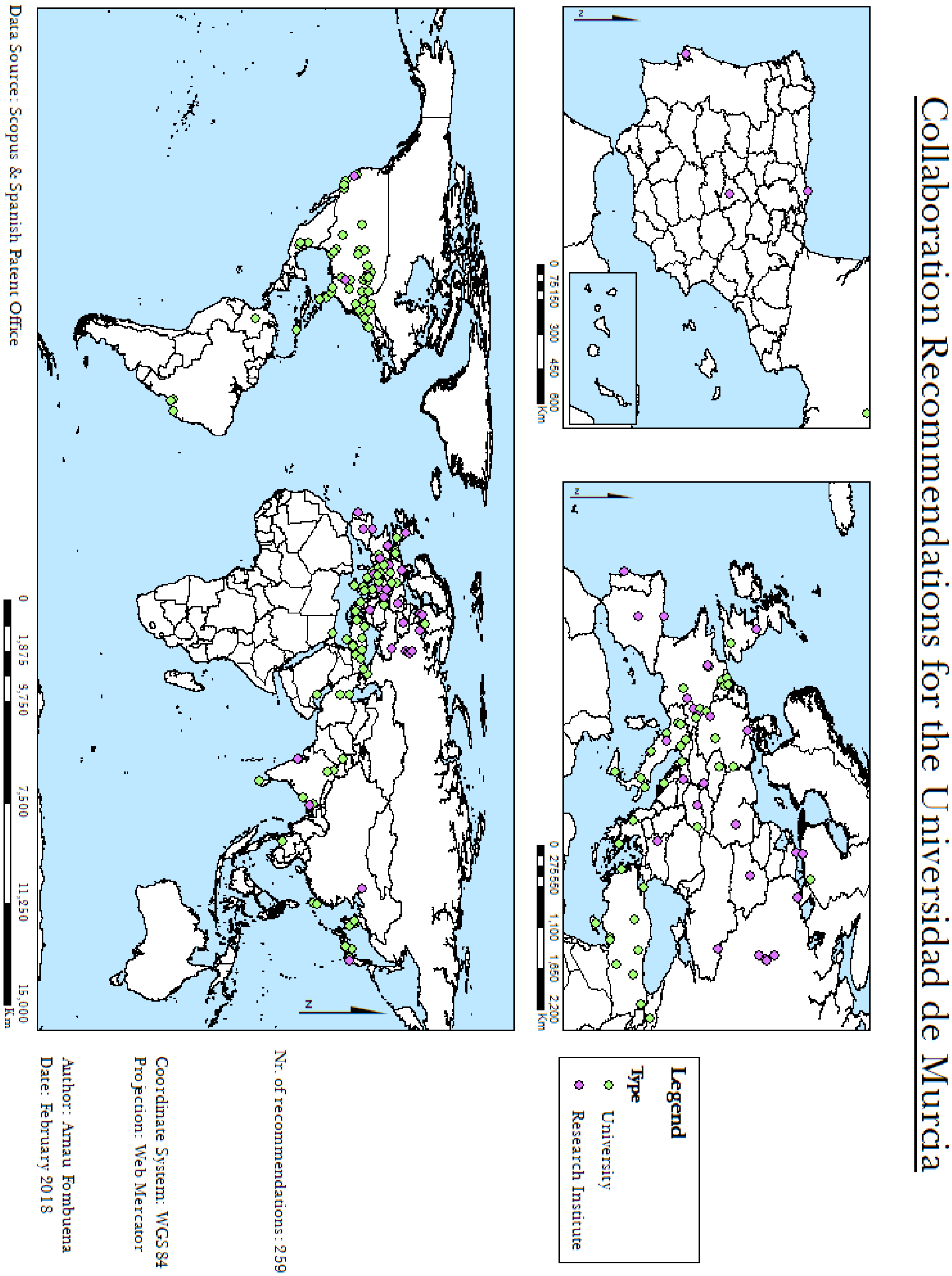

Figure A2.25. Collaboration recommendations for the *Universidad de Málaga.*

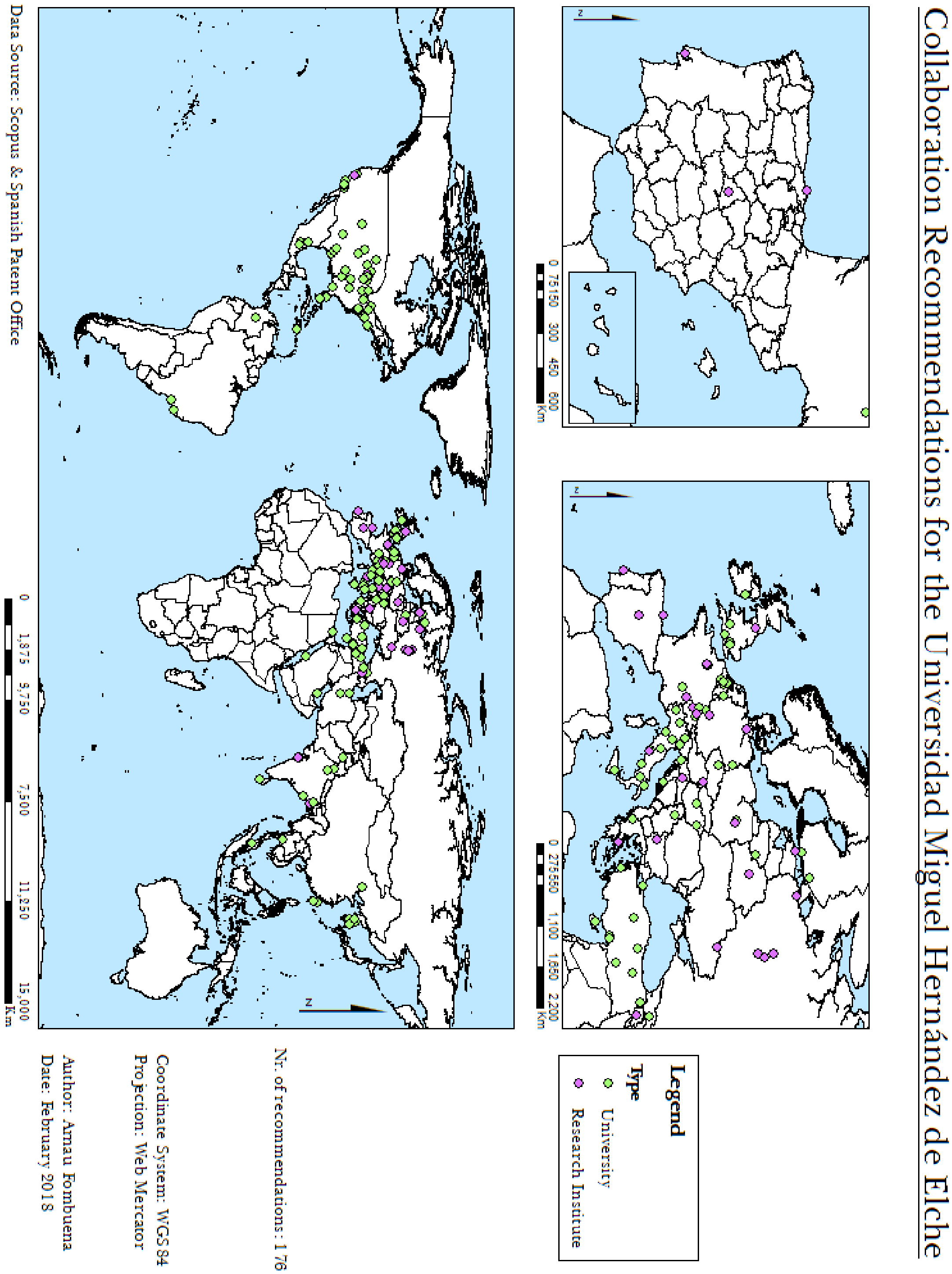

Figure A2.26. Collaboration recommendations for *Universidad Miguel Hernández de Elche.*

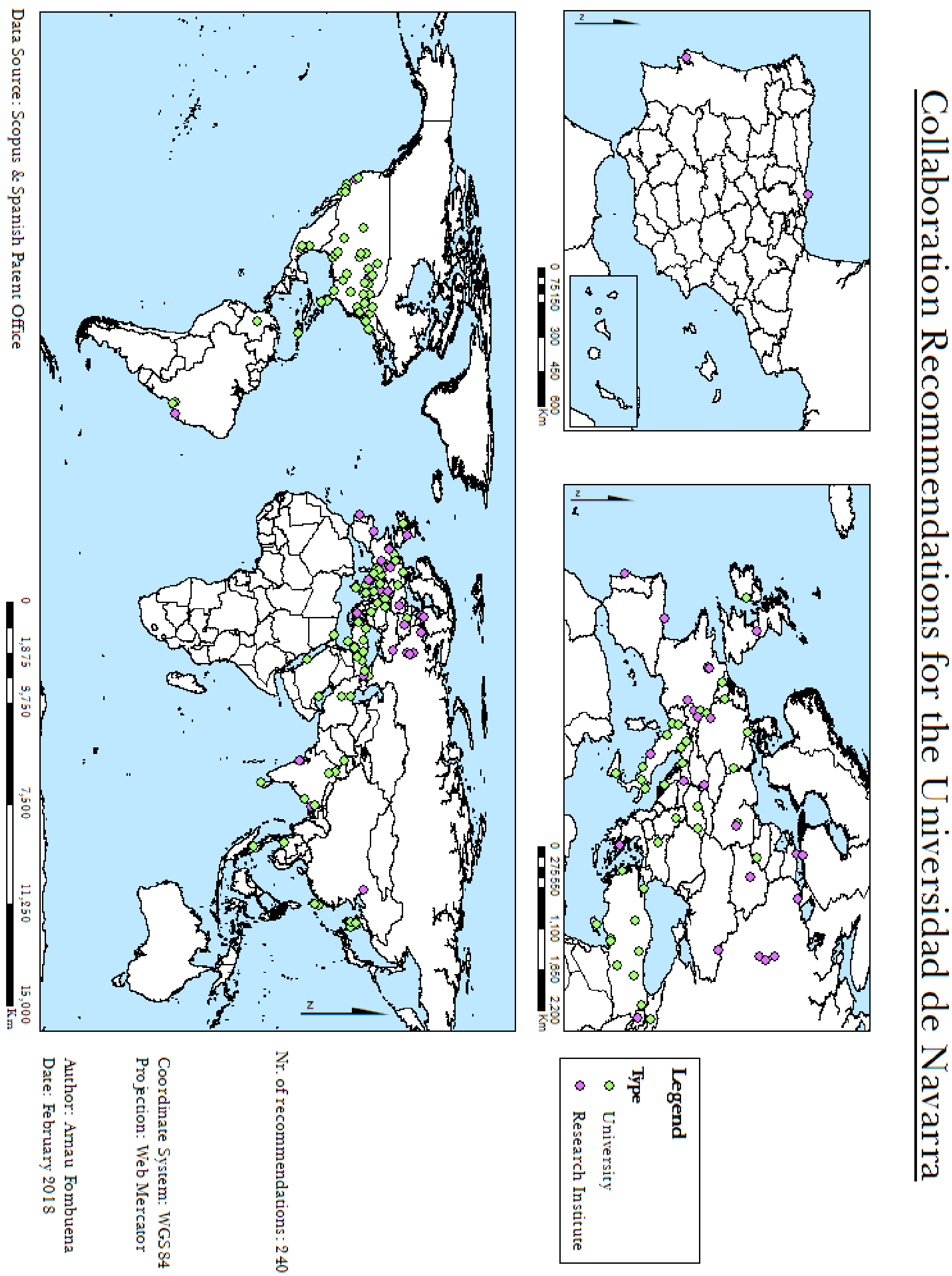

Figure A2.27. Collaboration recommendations for the *Universidad de Navarra.*

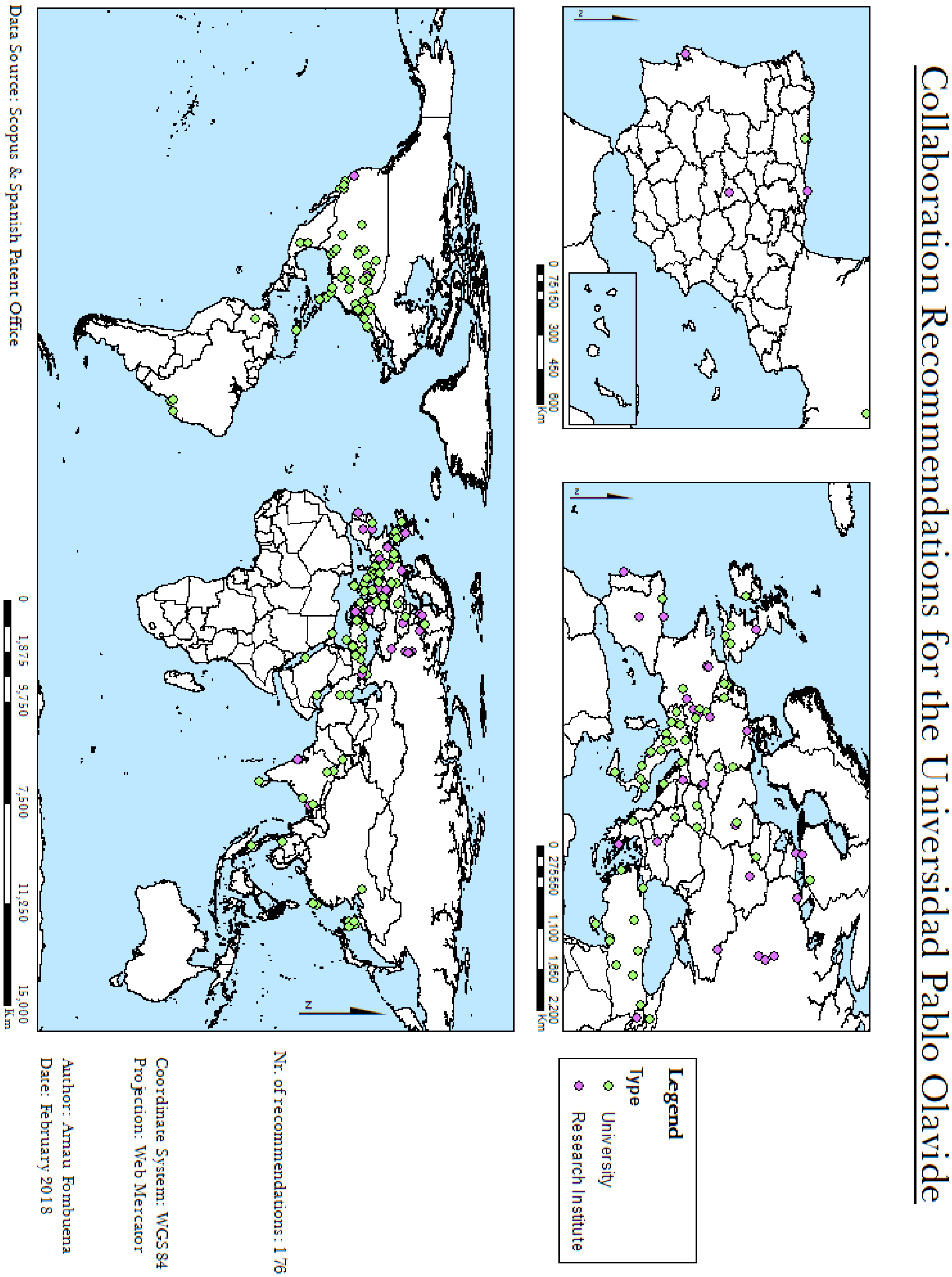

Figure A2.28. Collaboration recommendations for the *Universidad Pablo Olavide.*

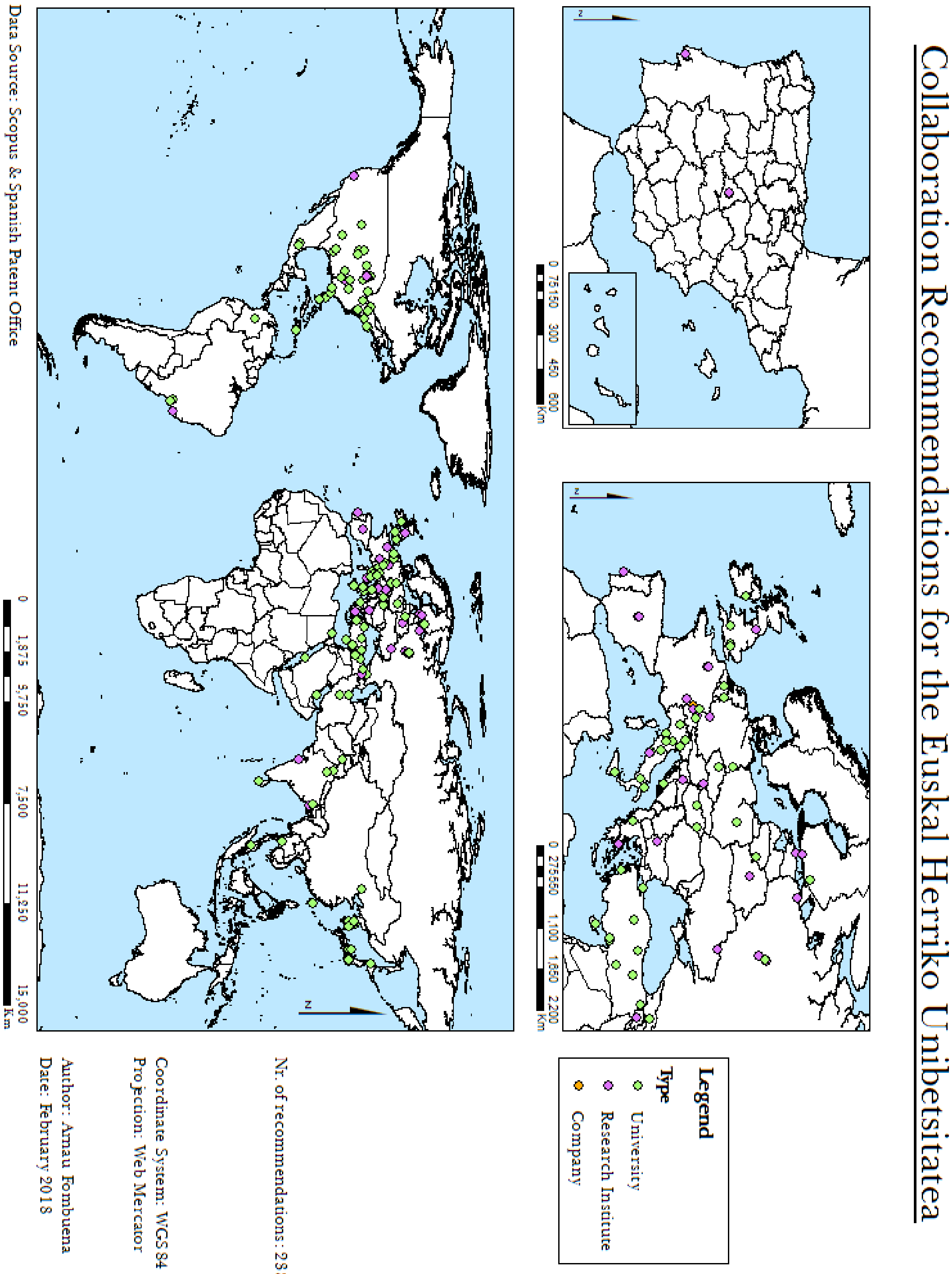

Figure A2.29. Collaboration recommendations for the *Euskal Herriko Unibertsitatea.*

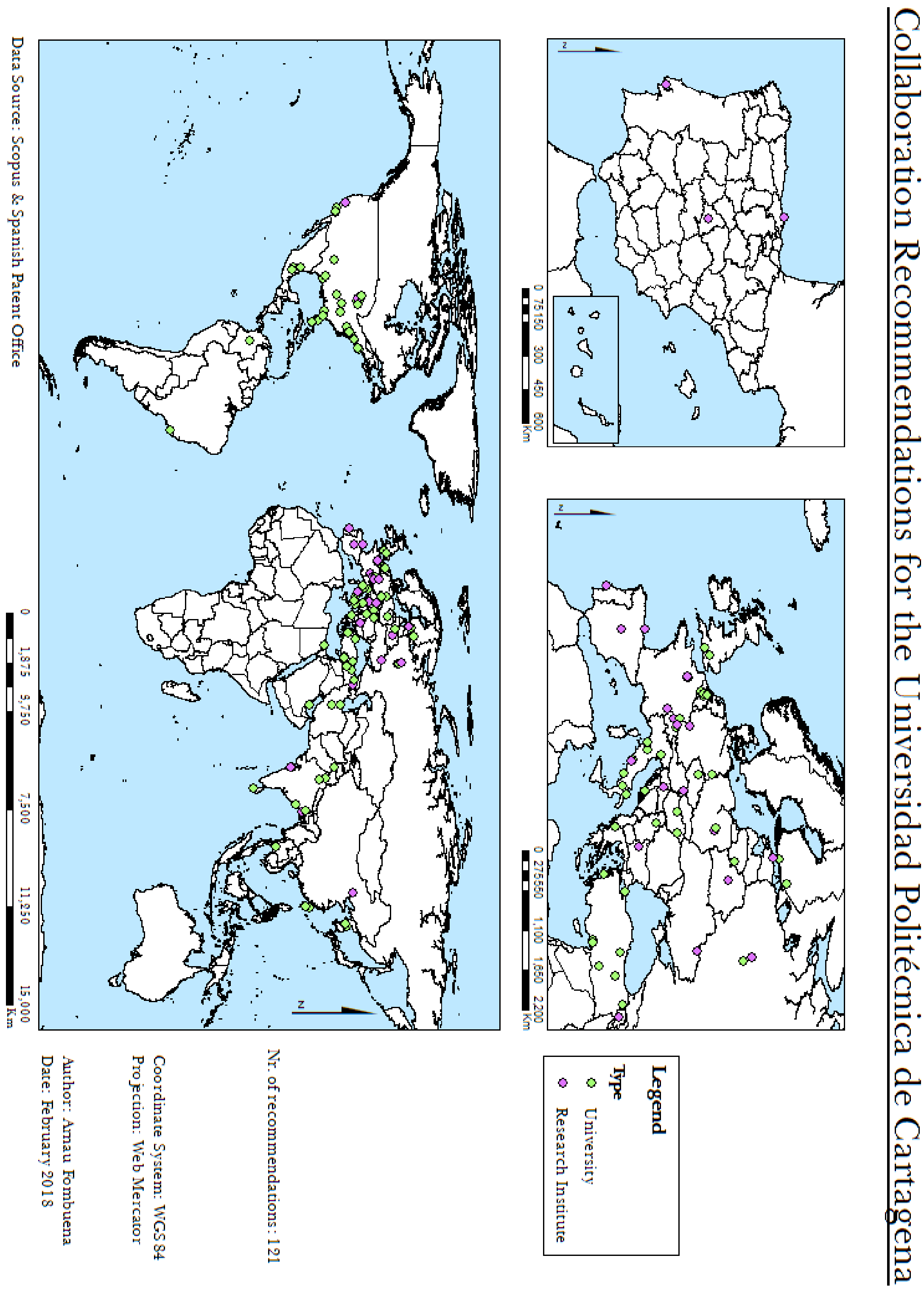

Figure A2.30. Collaboration recommendations for the *Universidad Politécnica de Cartagena.*

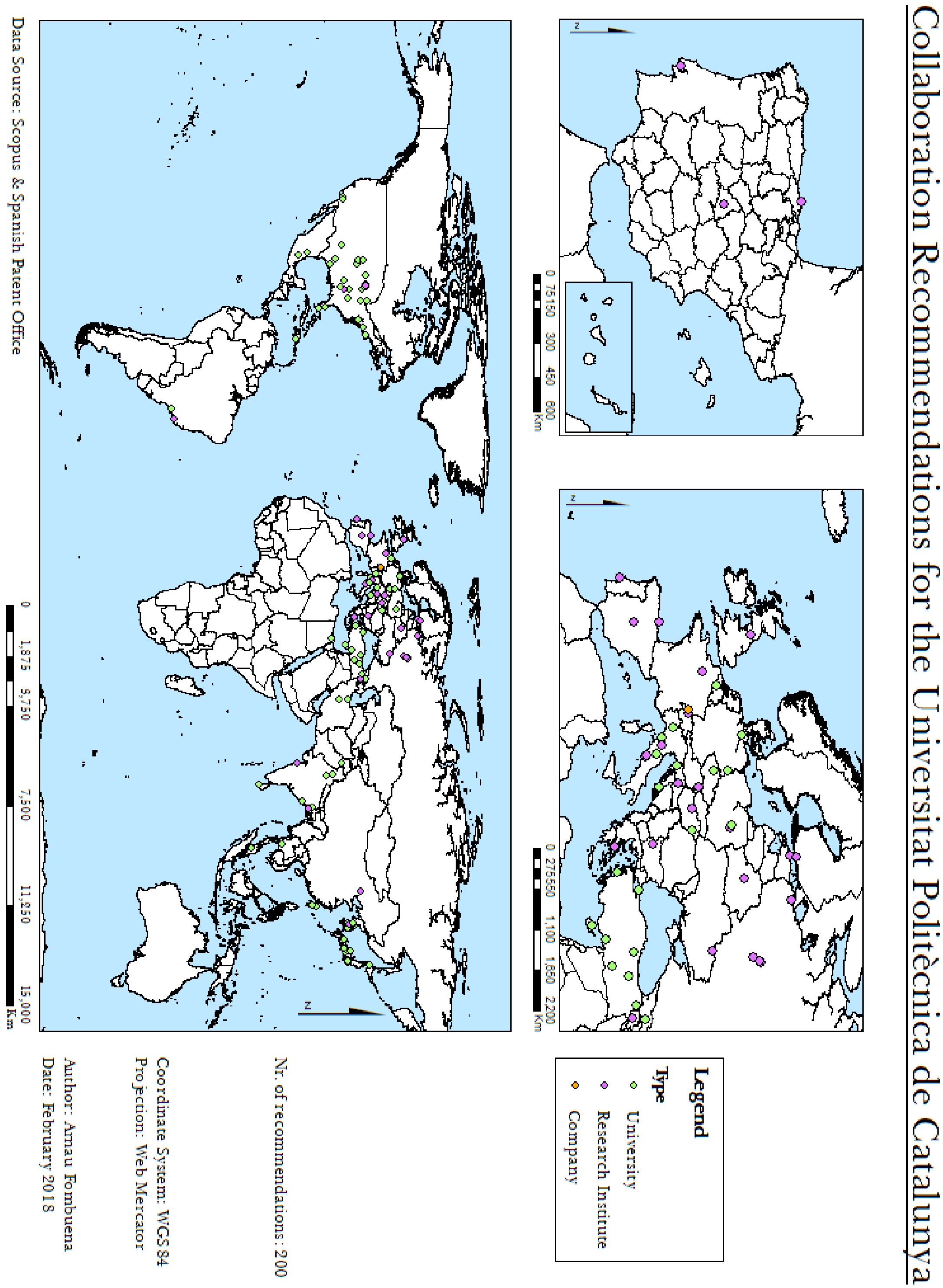

Figure A2.31. Collaboration recommendations for the *Universitat Politècnica de Catalunya.*

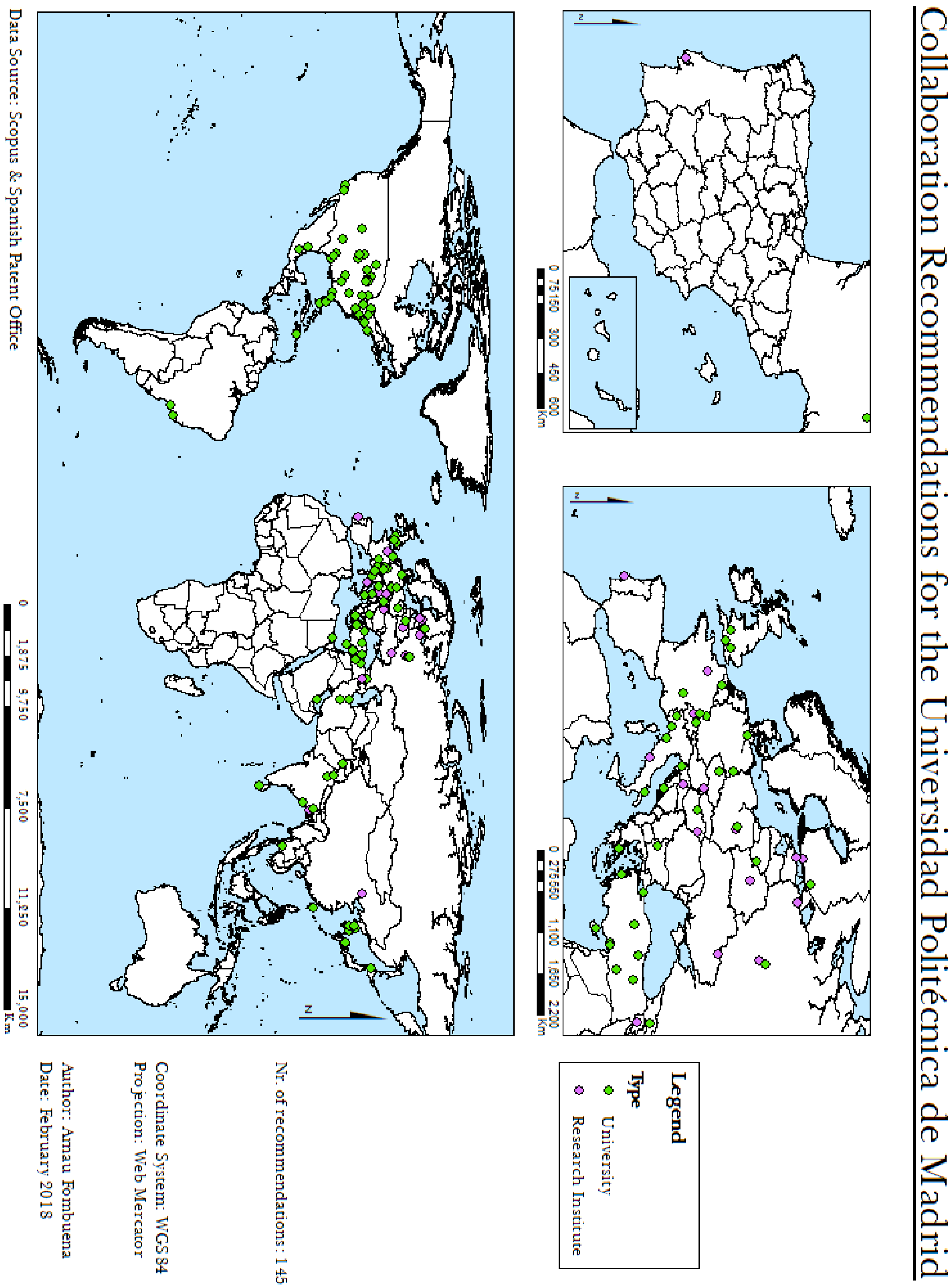

Figure A2.32. Collaboration recommendations for the *Universidad Politécnica de Madrid.*

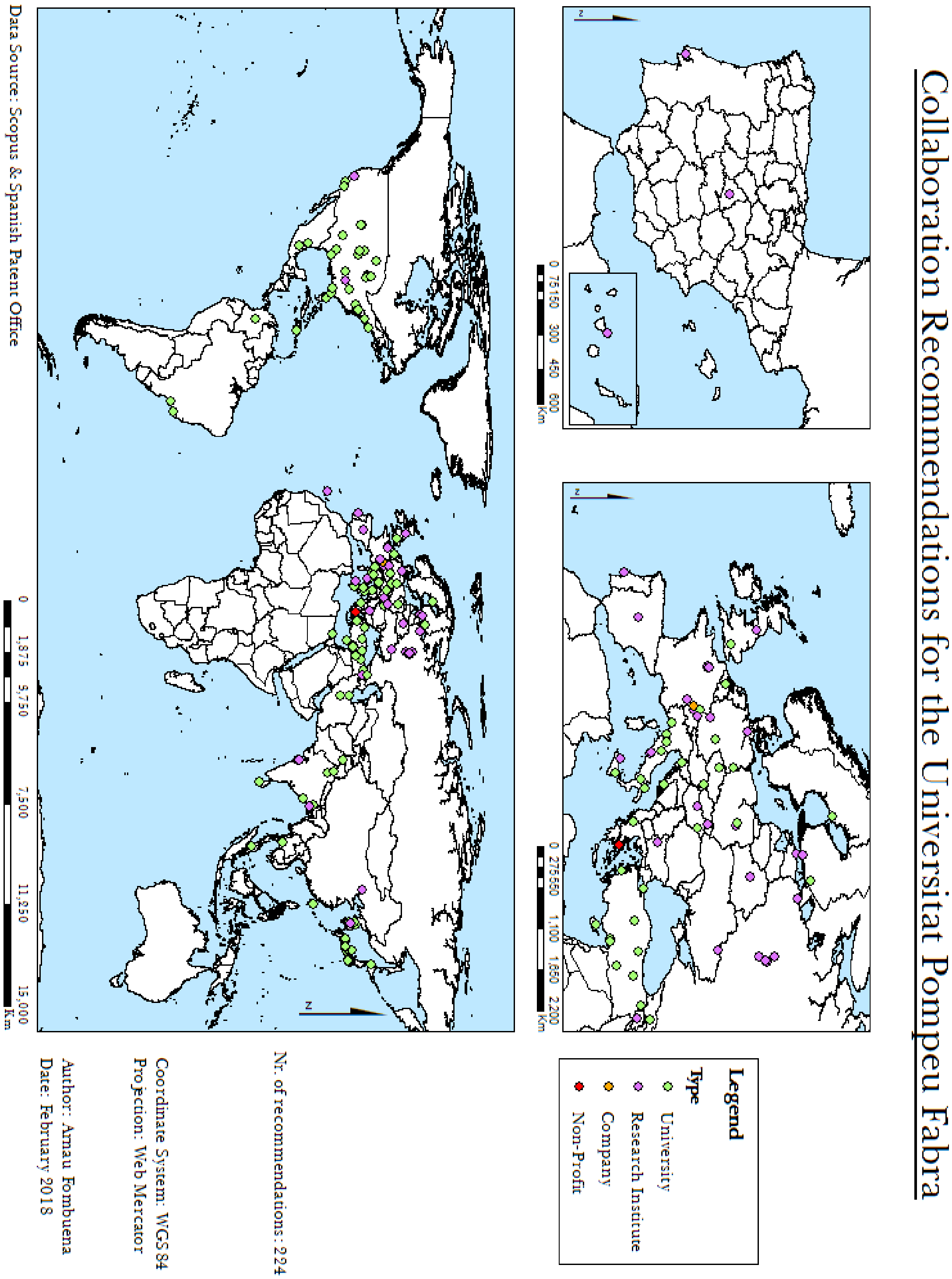

Figure A2.33. Collaboration recommendations for the *Universitat Pompeu Fabra.*

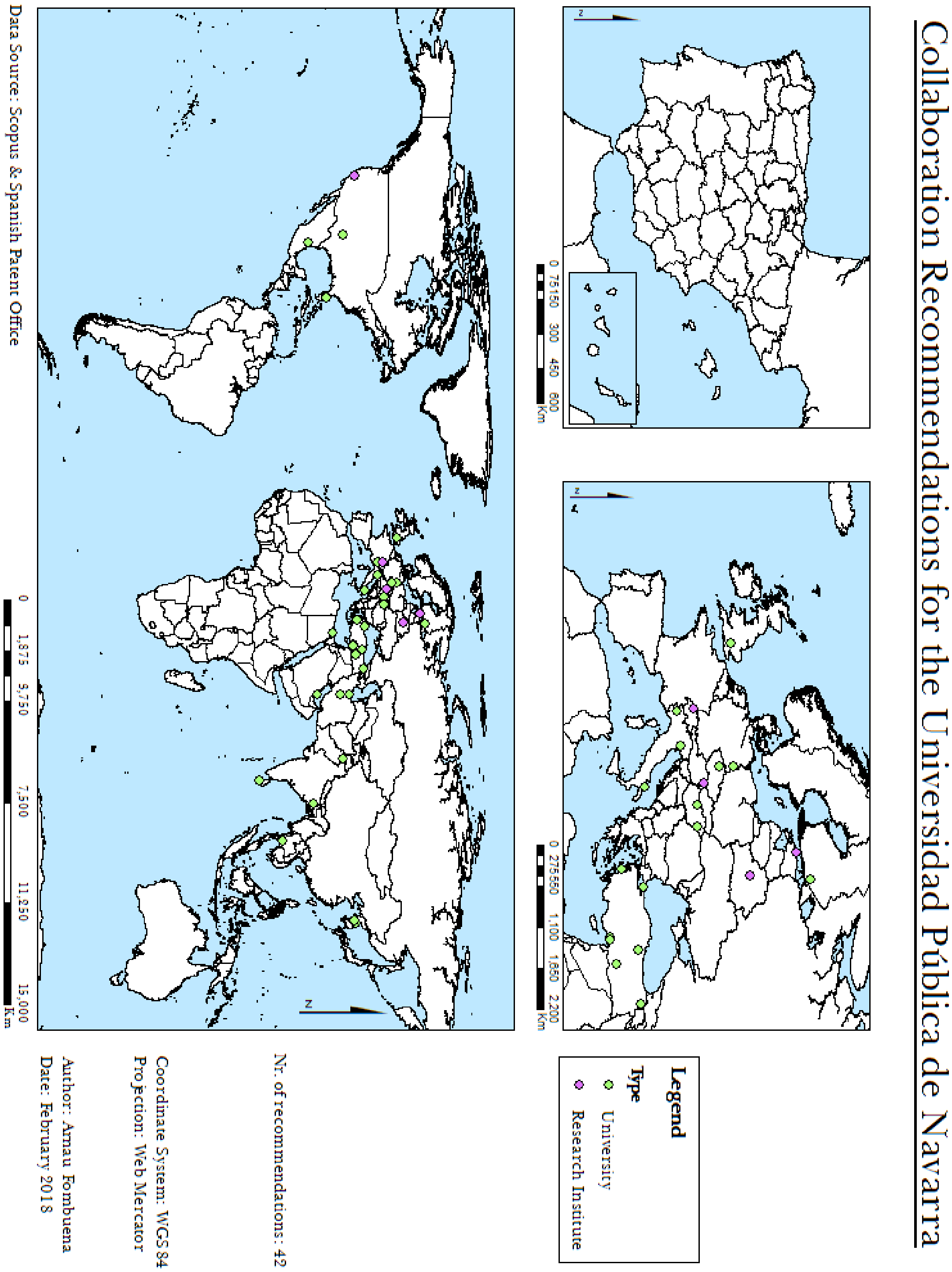

Figure A2.34. Collaboration recommendations for the *Universidad Pública de Navarra.*

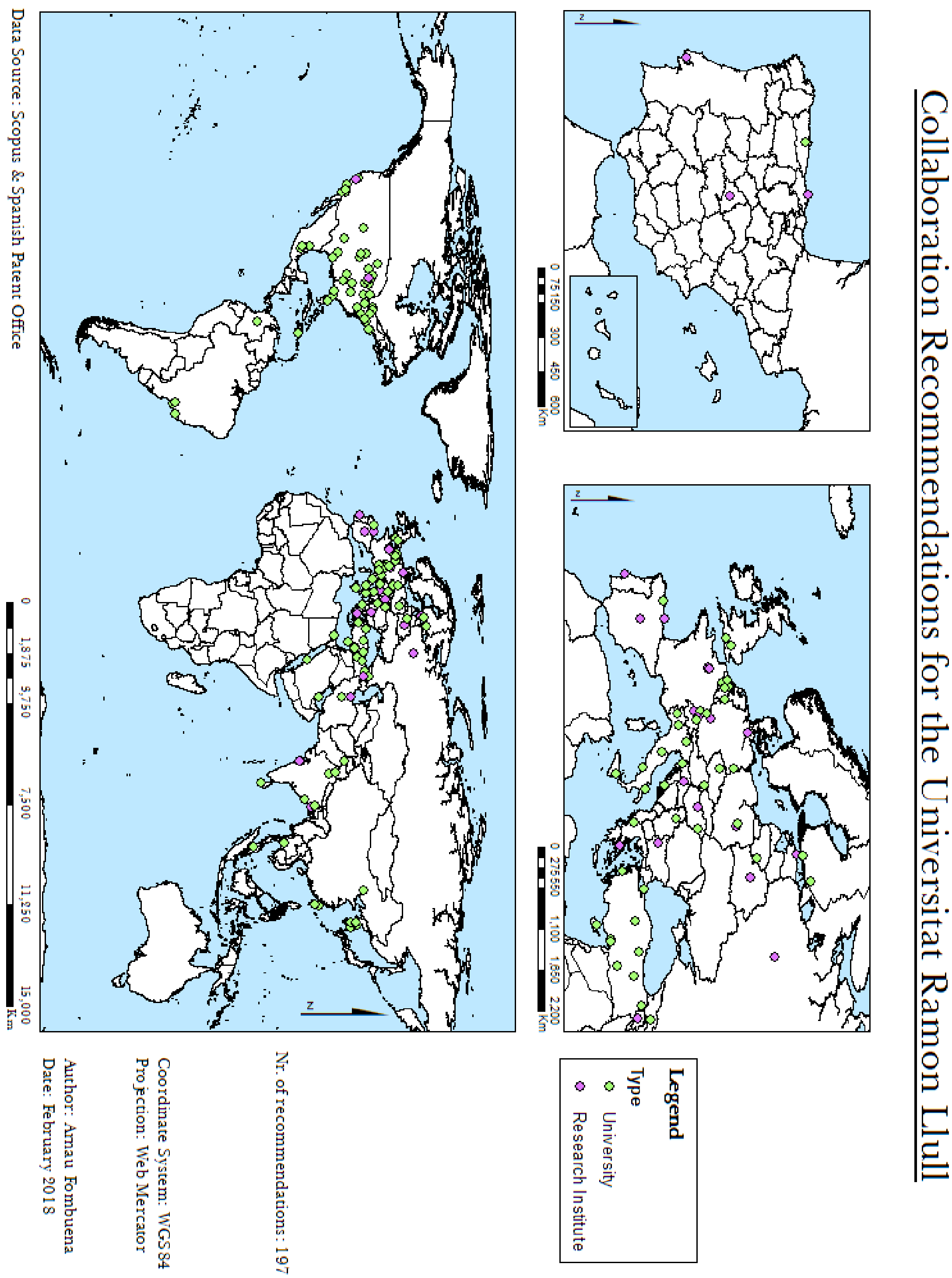

Figure A2.35. Collaboration recommendations for the *Universitat Ramon Llull.*

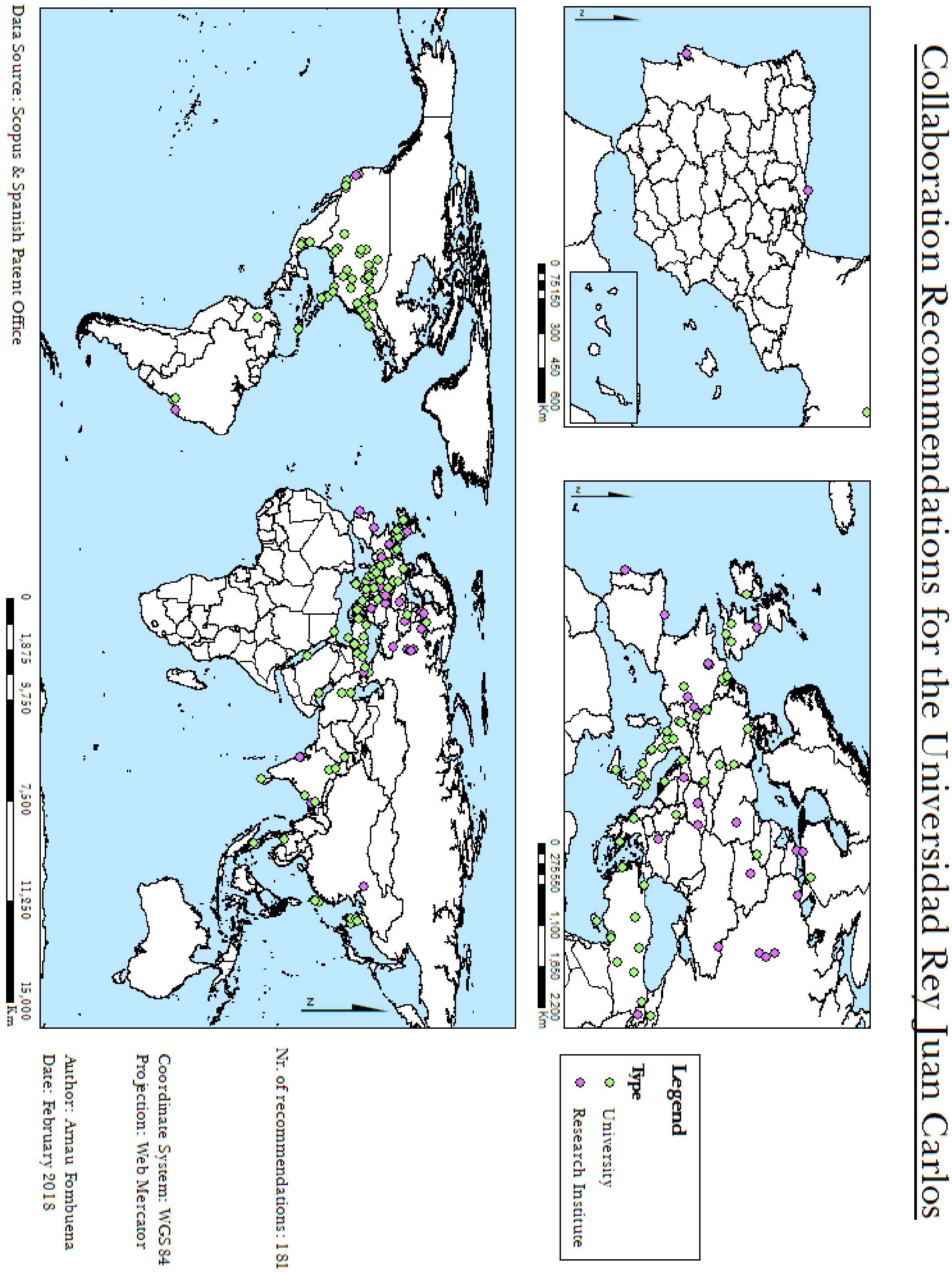

Figure A2.36. Collaboration recommendations for the *Universidad Rey Juan Carlos.*

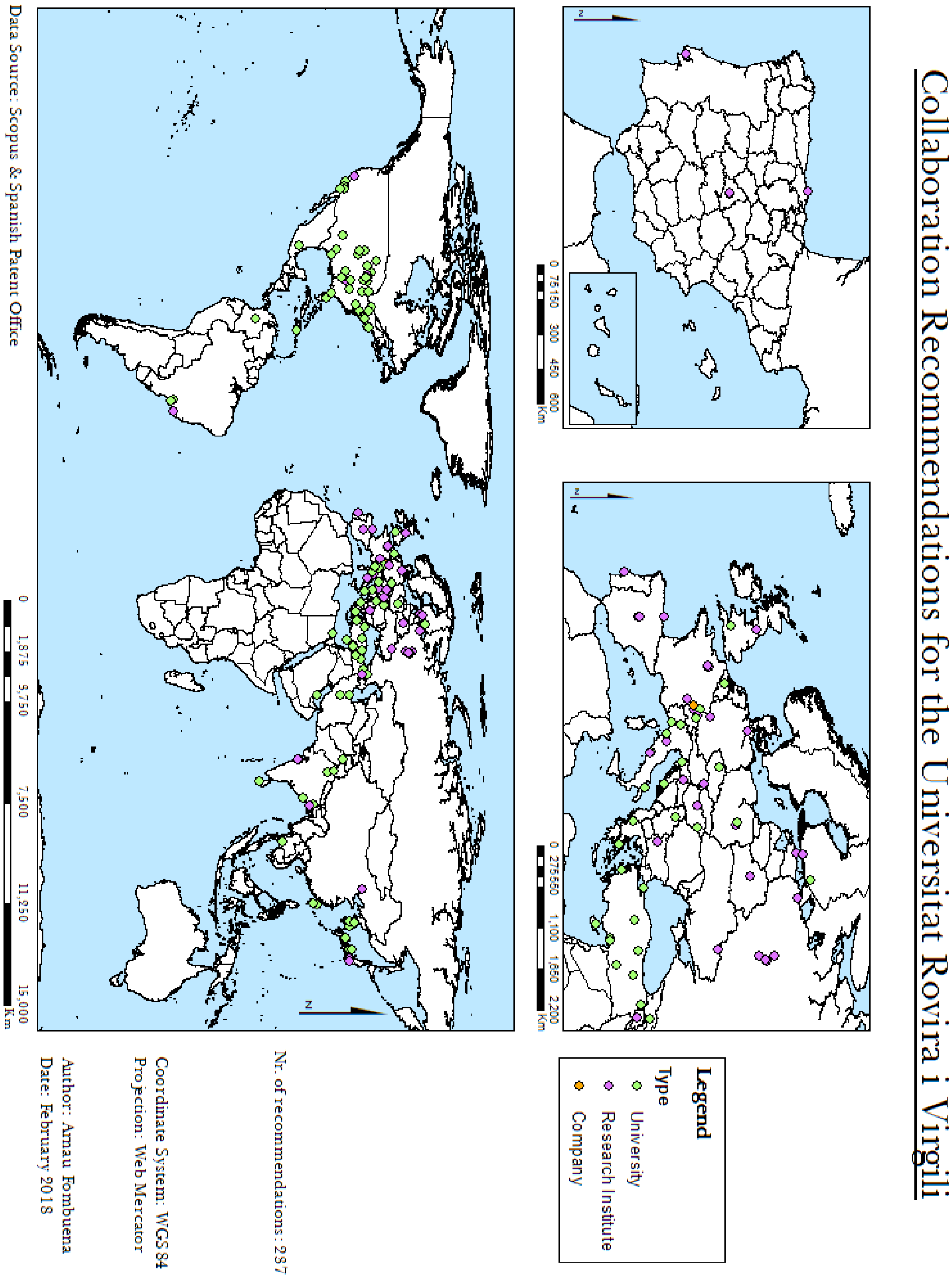

Figure A2.37. Collaboration recommendations for the *Universitat Rovira i Virgili.*

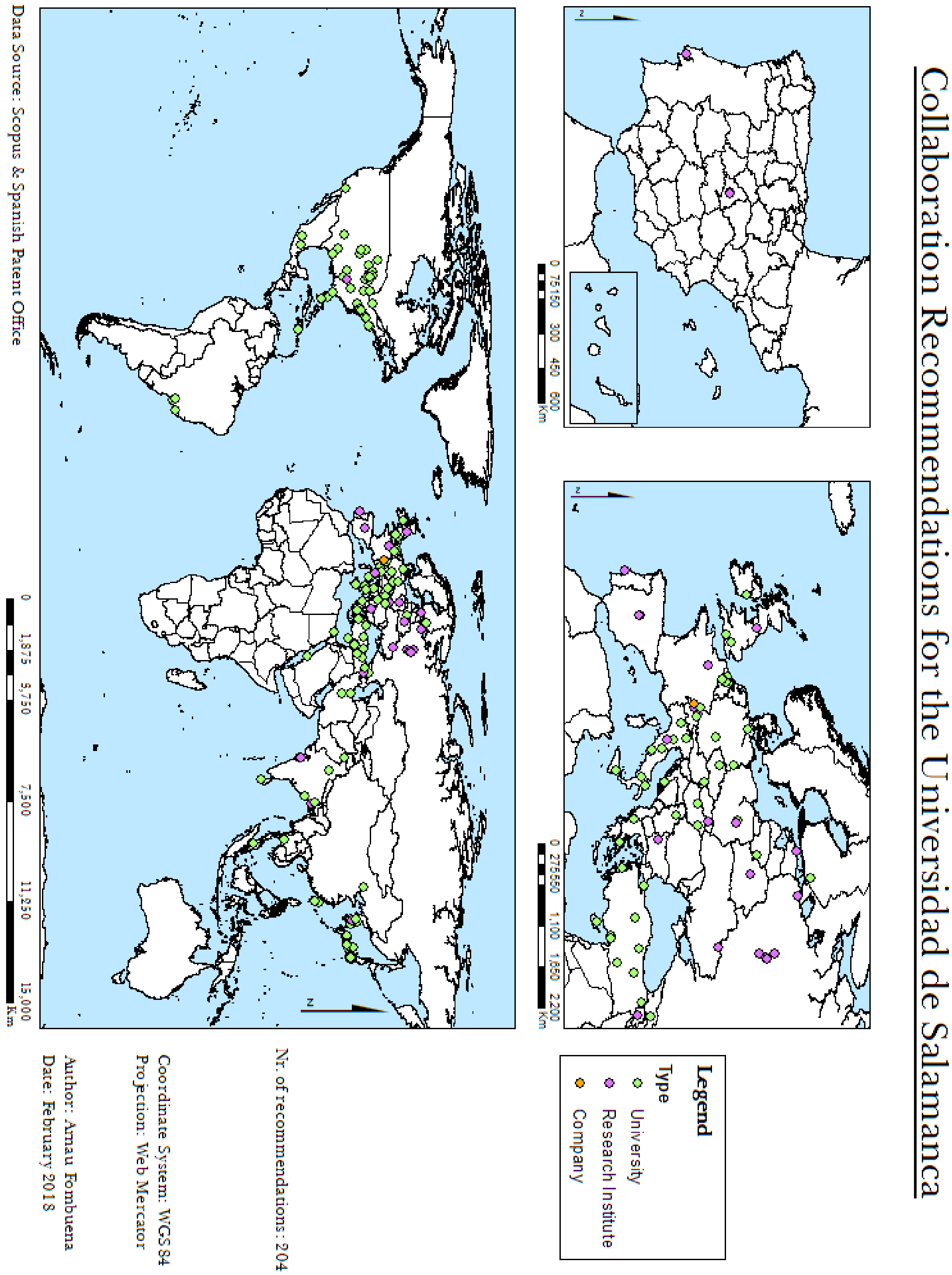

Figure A2.38. Collaboration recommendations for the *Universidad de Salamanca.*

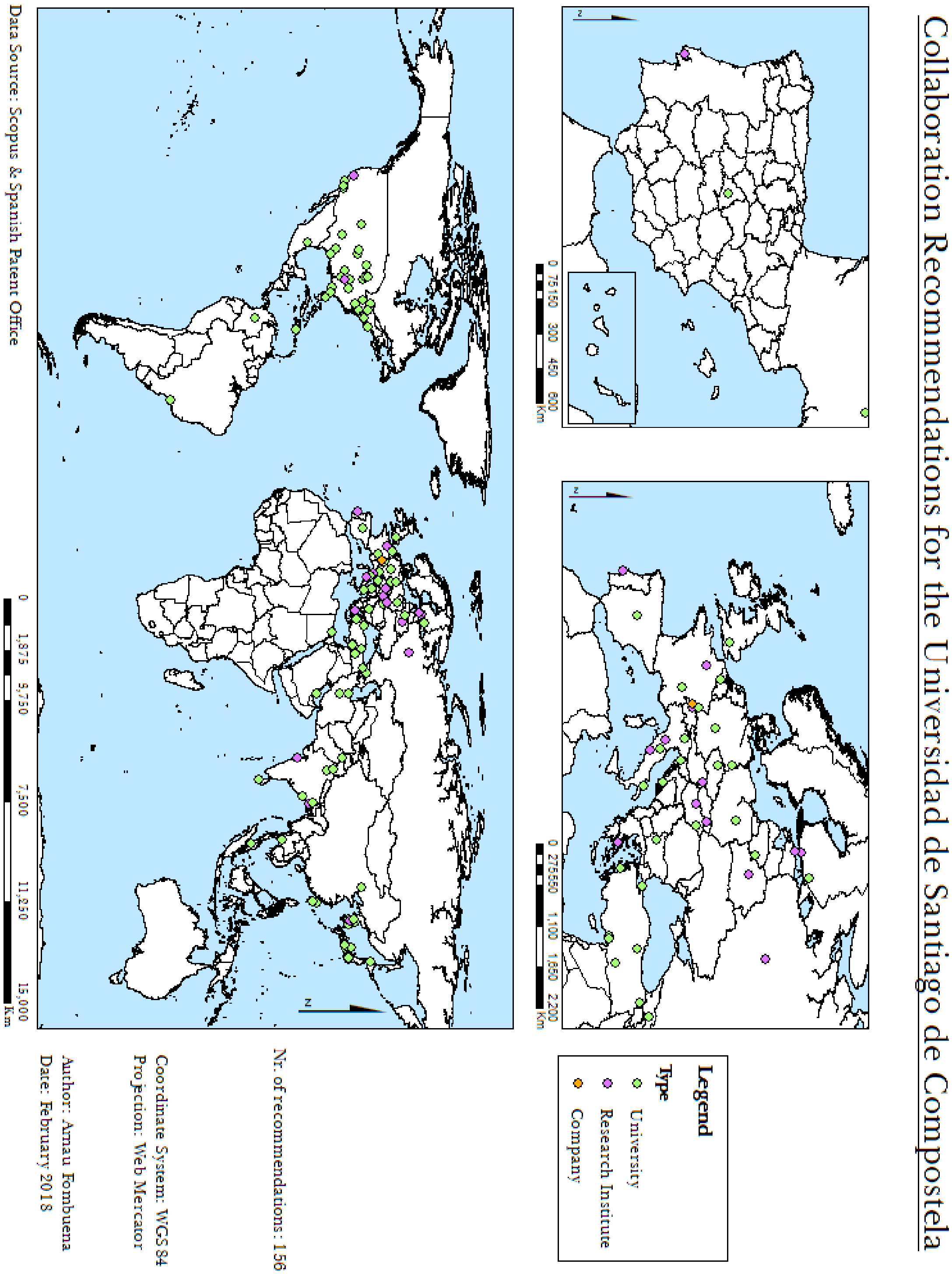

Figure A2.39. Collaboration recommendations for *Universidad de Santiago de Compostela.*

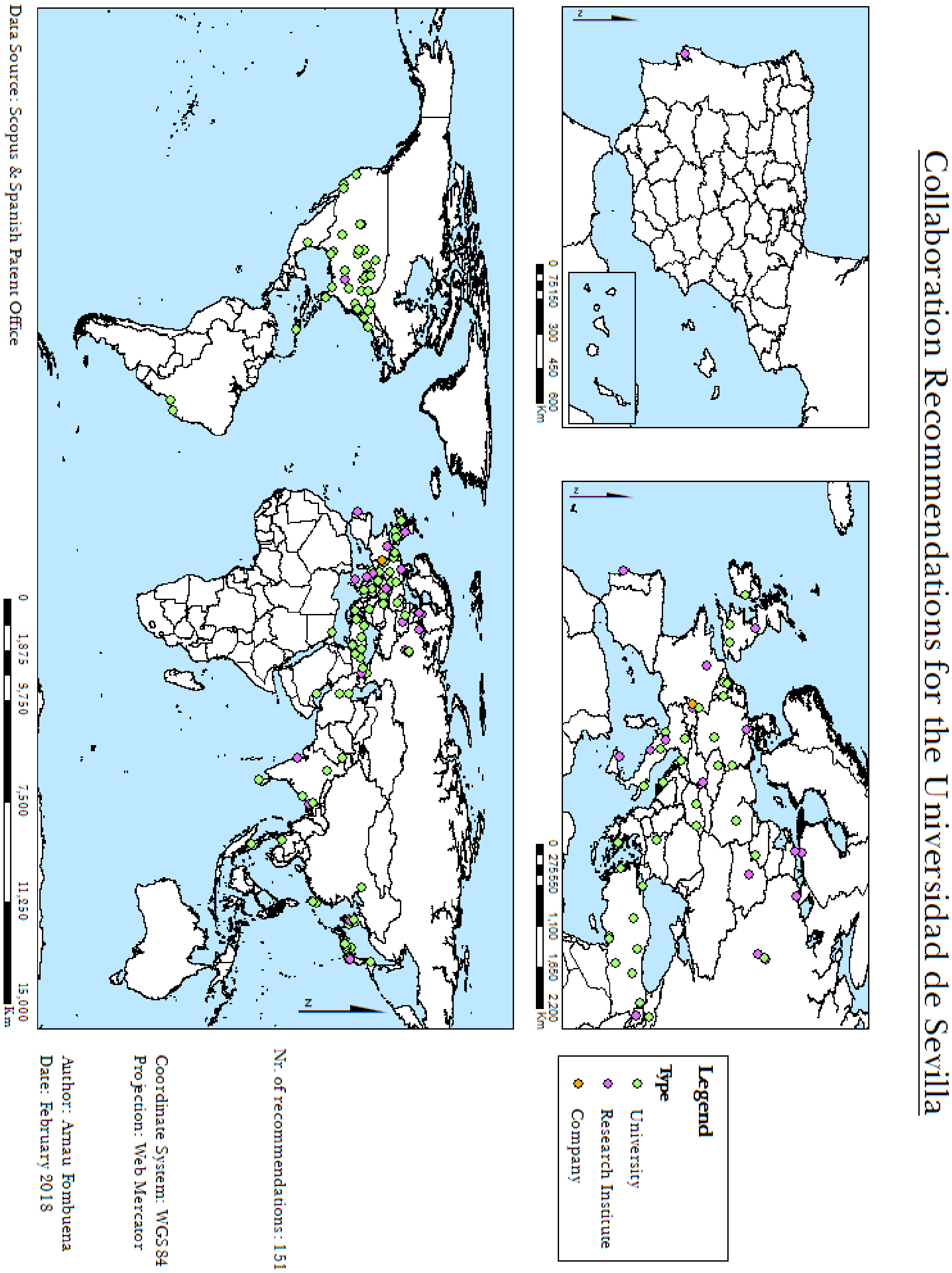

Figure A2.40. Collaboration recommendations for the *Universidad de Sevilla.*

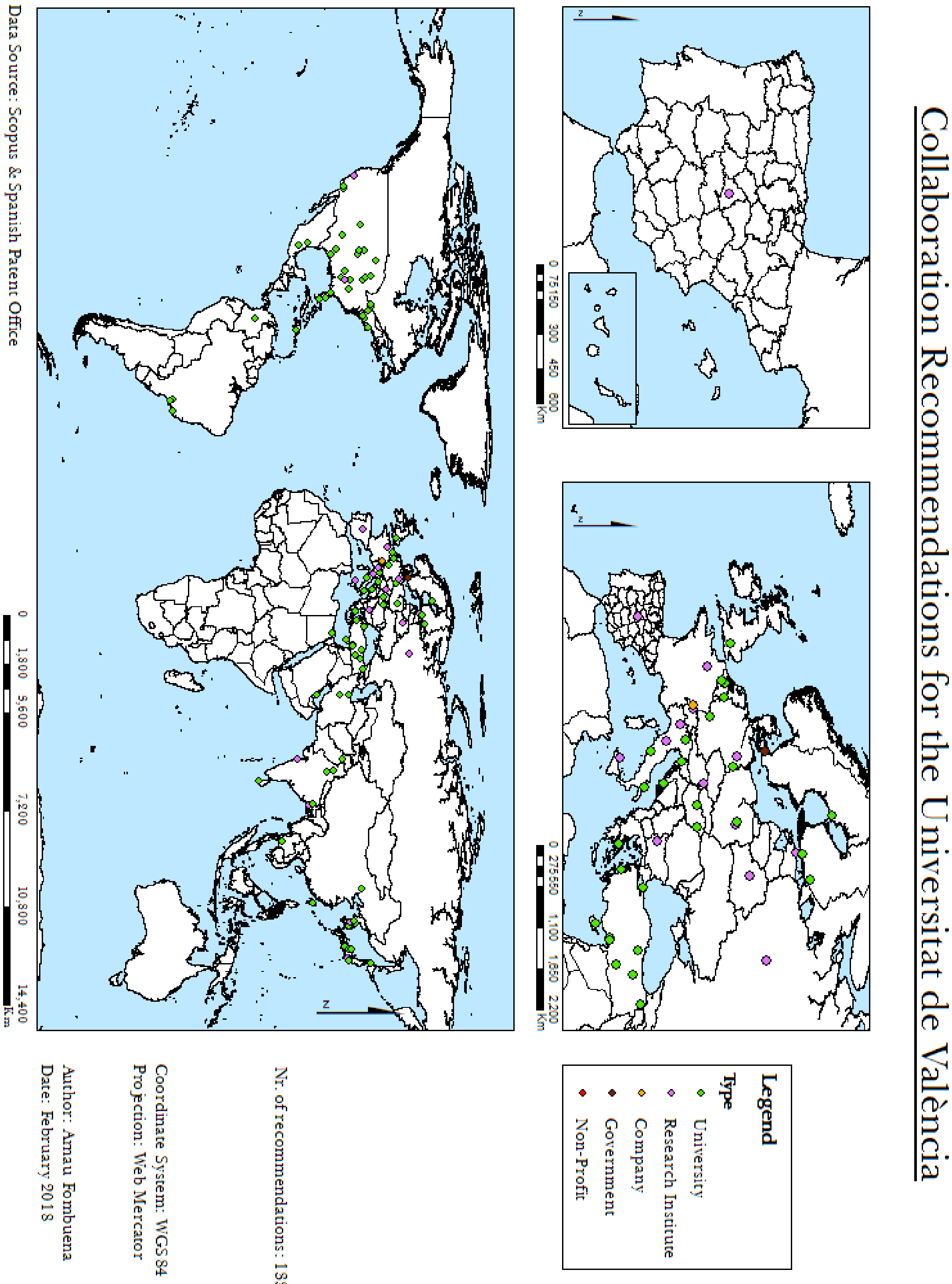

Figure A2.41. Collaboration recommendations for the *Universitat de València.*

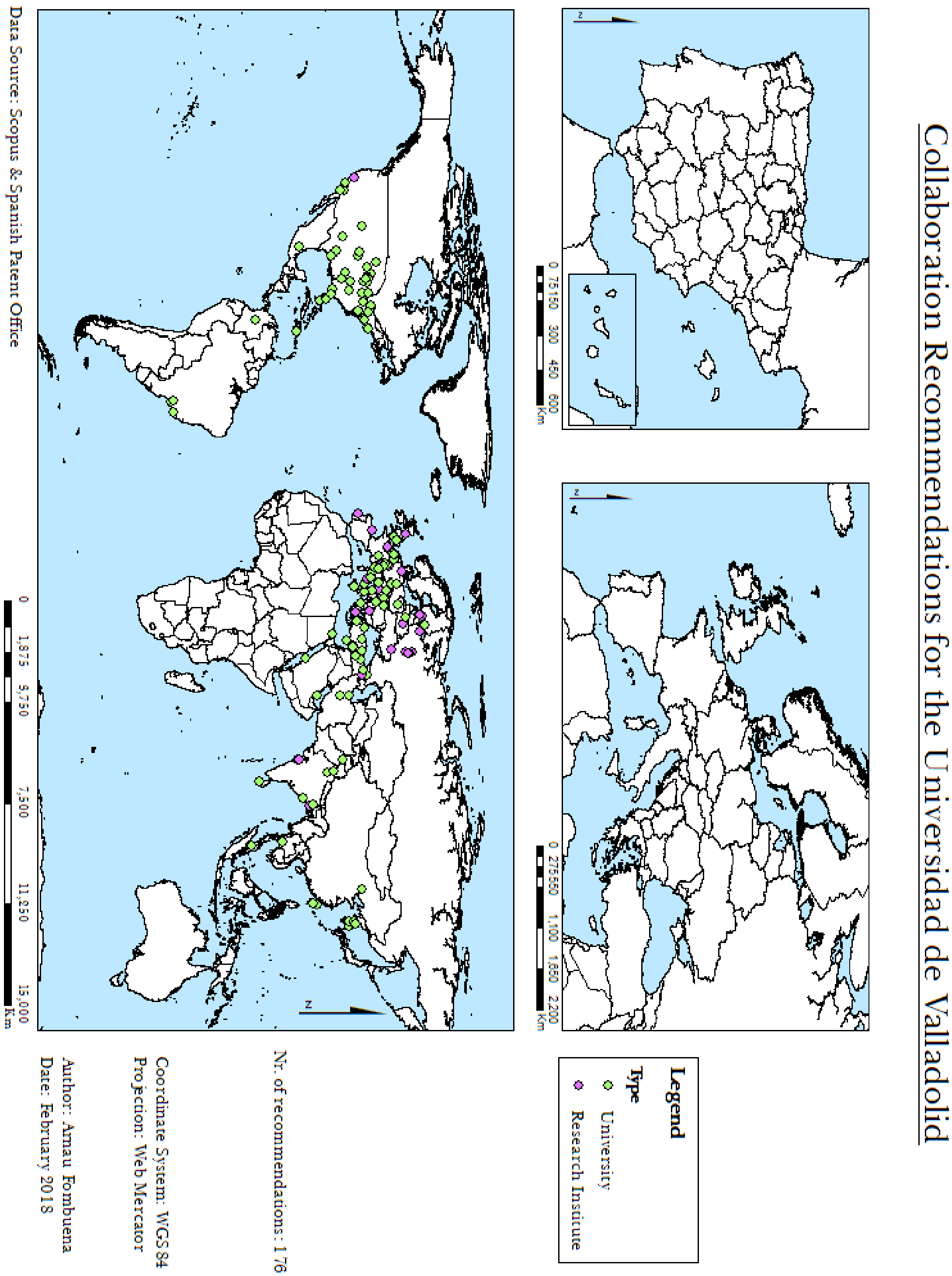

Figure A2.42. Collaboration recommendations for the *Universidad de Valladolid.*

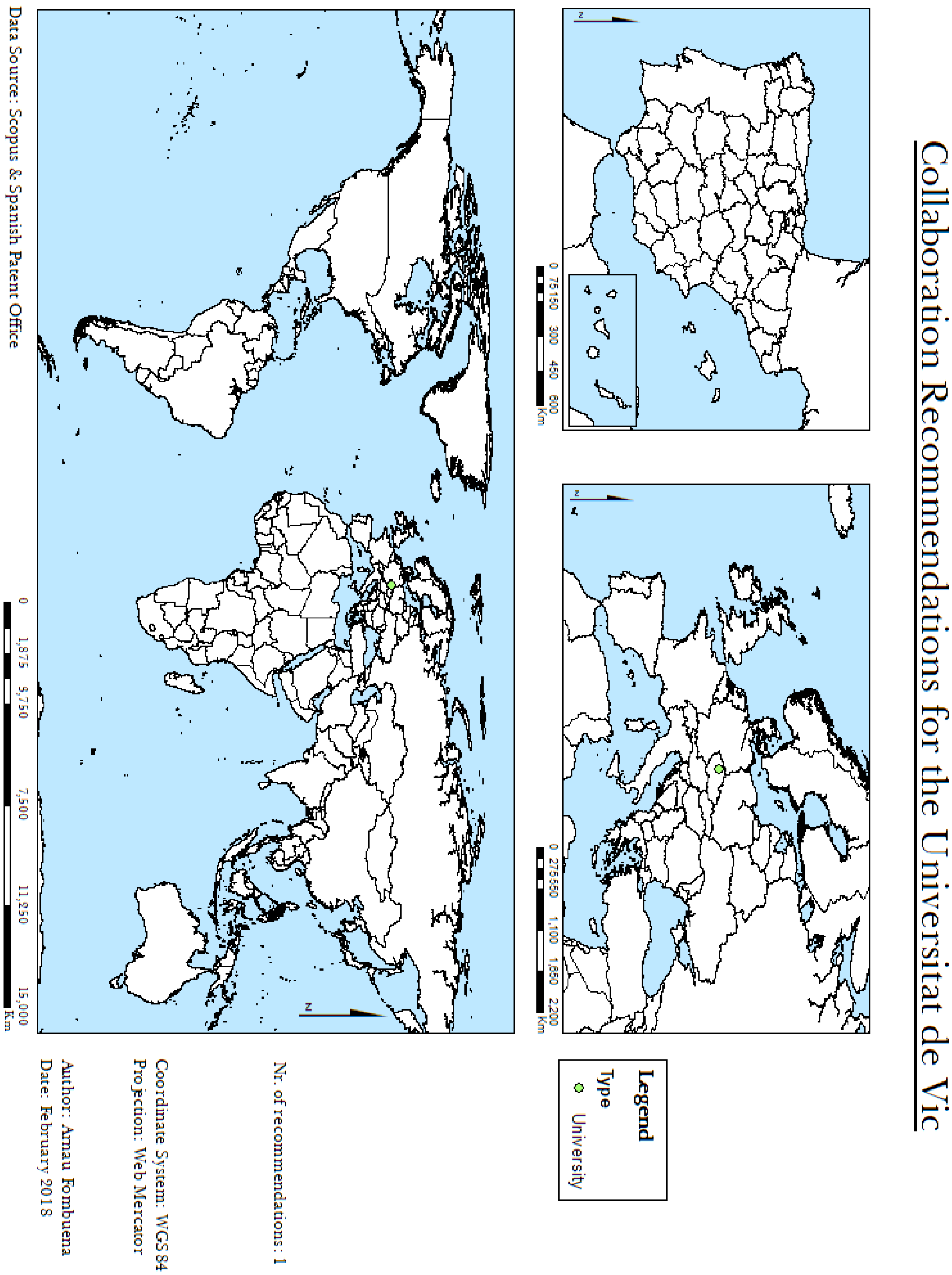

Figure A2.43. Collaboration recommendations for the *Universitat de Vic.*

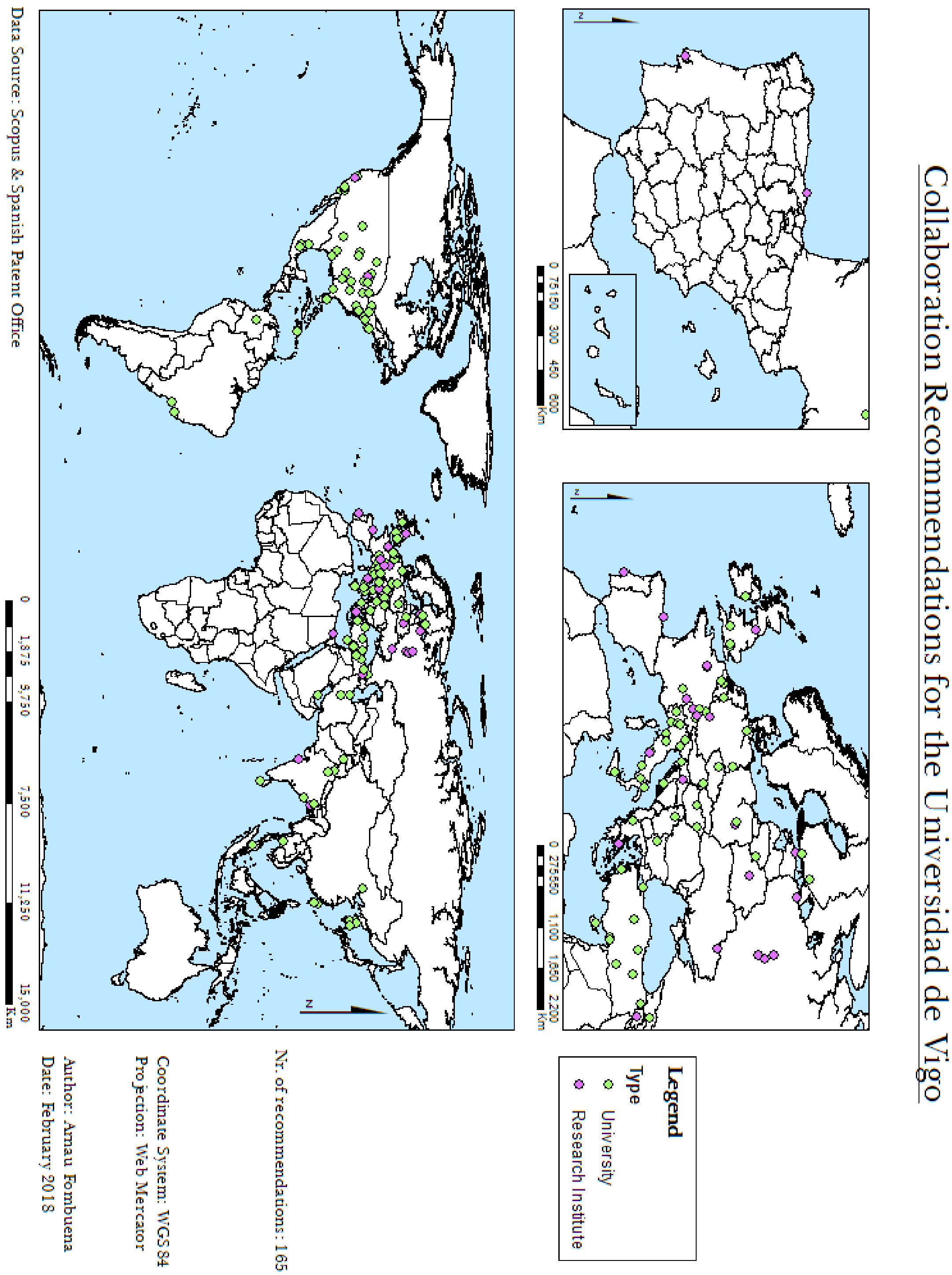

Figure A2.44. Collaboration recommendations for the *Universidad de* Vigo.