

Georeferencing networks and social network analysis: an exploratory study about the research and development projects of the Brazilian Electricity Regulatory Agency (ANEEL)

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ABSTRACT

The aim of this article is to investigate research and development (R&D) networks created under the scope of the R&D Programme implemented by the Brazilian Electricity Regulatory Agency (2006-2008). The main contribution of this article is its empirical analysis, drawing upon social network analysis and georeferencing to support the visualisation of the networks, as well as identify the location of actors and interactions in the Brazilian territory. We identified the features of the interactions with regards to their geographical location and distribution in the territory, as well as the main actors and their roles in the creation and circulation of knowledge based on R&D activities, and whether geographical proximity was present in the interactions. The results show that the networks are hierarchical, and electricity companies show a leading role in the governance of knowledge creation and circulation over external

research organizations and project coordinators. Such companies interacted mainly with researchers based in regions where the capacity of research infrastructure has been consolidated.

KEYWORDS | ANEEL R&D; Social Networks Analysis; Georeferencing; Geographical Proximity

JEL CODES | L14; O30; O310

Georreferenciamento de redes e análise de redes sociais: um estudo exploratório dos projetos de P&D Aneel

RESUMO

O objetivo deste estudo é investigar as redes de P&D formadas no escopo do Programa de Pesquisa e Desenvolvimento da Agência Nacional de Energia Elétrica (Aneel) para o triênio de 2006 a 2008. A principal contribuição do artigo é empírica. São utilizadas métricas de análise de redes sociais e georreferenciamento para visualização da rede e mapeamento das interações no território nacional. Apresenta-se o perfil das interações quanto à sua localidade geográfica e distribuição no território e identificam-se os principais atores na criação e circulação do conhecimento a partir das atividades de P&D e quando a proximidade geográfica estava presente na criação de tais interações. Os resultados mostram que as redes são hierarquizadas e as concessionárias de energia elétrica exercem liderança na governança da criação e circulação de conhecimento sobre organizações de pesquisa extramuro e sobre os coordenadores de projetos. Estas criaram interações com pesquisadores baseados nas regiões do país que oferecem infraestrutura de pesquisa consolidada.

PALAVRAS-CHAVE | P&D Aneel; Análise de Redes Sociais, Georreferenciamento; Proximidade; Geografia da Inovação

CÓDIGOS-JEL: L14; O30; O310

1. Introduction

The Brazilian energy matrix presents a high percentage of renewable energy sources (41.2% in 2015) compared to other countries (e.g., 9.4% in OECD countries) (BRASIL, 2016). Considering renewable sources, sugar cane derivatives present the main share of internal energy supply (16.9%) followed by hydropower (11.3%). Oil and its derivatives and natural gas (non-renewable sources of energy) were the main sources of the Brazilian energy supply in 2015 (37.3% and 13.7%, respectively). However, domestic electricity supply relies mainly on hydropower (58.4% in 2015) (BRASIL, 2016). Brazil is considered a low-carbon emission country due to its energy matrix and renewable electric energy sources: 3.6% and ranked 6th place globally, compared to the USA (17.9%), China (14.9%), Russia (5.8%), Indonesia (5.3%) and Japan (4%) (IPCC, 2014).

In this context, the Brazilian Electricity Regulatory Agency (ANEEL)¹ fosters research and development (R&D) investment in the national electricity sector with the aim to solve new market and technological challenges, including carbon emission mitigation (Pomper Mayer, 2009). Among such challenges, one finds support for the increase of electricity production from renewable sources other than hydropower, such as wind and solar energy.²

Considering the structure of the Brazilian electricity sector, its privatisation and economic deregulation in the 1990s (FURTADO, 2010), ANEEL implemented its Research and Development Programme in 2000 (hereon ANEEL R&D) with the aim to foster innovation activities in the sector (POMPERMAYER *et al.*, 2011). The program was implemented in accordance with Law n. 9.991/2000³ and requires firms that operate in generation (G) and transmission (T) to invest 1% of their annual net operational revenue in R&D activities (Aneel, 2012a). Electric power distribution (D) firms are required to invest 0.75% of their annual net revenue in R&D activities and 0.25% in energy efficiency (Aneel, 2012a: 9).

The main premise of ANEEL R&D Program is that R&D activities will foster interactions among key actors in the national electricity sector (ANEEL, 2012b), such as firms, research institutes (public and private), and local universities, and therefore improve systemic interactions within the sector (EDQUIST, 2004). Such interactions potentially foster: knowledge and learning exchange among actors;

1 In Portuguese Agência Nacional de Energia Elétrica (ANEEL).

2 For a discussion on the Brazilian wind energy trajectory, see Camillo (2013).

3 This law was amended by Laws n. 10.438/2002, 10.848/2004, 11.465/2007, 12.111/2009 and 12.212/2010.

technological development; and improvement of local capacities for technological, market and regulatory challenges at the national and global levels. The structure of these interactions is defined by this study as networks (Burt, 1992).

ANEEL R&D regulation is defined by the Research and Development Program Handbook (ANEEL, 2008), which provides information on the criteria for the eligibility of projects submitted by GTD firms. Projects should present goals and outcomes aligned to (mainly) applied research activities; project implementation and results are also assessed by ANEEL. Misconduct by project grantees (e.g, not performing activities defined as R&D) may imply in penalties and fines by the Agency (ANEEL, 2008). The interactions created by GTD firms to implement approved projects are characterized by competition between research consortia for financial resources.

Studies on ANEEL R&D (POMPERMAYER *et al.*, 2011) show that science and technology organisations are the most frequently accessed actors within the electricity sectoral system by applicant firms, and that only about 10% of performing organisations are firms 'mainly related to the electricity sector'. These studies suggest a potential weakness in the development of the Brazilian electric sector because the latter is supplier-dominated (JACQUIER-ROUX; BOURGEOIS, 2002, p. 416-417), and firm-firm interactions could potentially improve innovation performance at the country level. In addition, ANEEL R&D interactions are mostly concentrated in the Brazilian Southeast region, highlighting the importance of geographic proximity (BOSCHMA, 2005) for interactions between actors involved in R&D activities (discussed in section 2).⁴

This study aims to investigate networks (structure of interactions) created within the ANEEL R&D Programme for the period from 2006 to 2008.⁵ We consider the organisational (i.e., applicant firms and other performing organisations) and individual (i.e., project coordinators and applicant firms) perspectives. Studies on R&D and innovation networks in Latin America were scarce until the beginning of the 2010s (CASAS; LUNA, 2011; PAMPLONA DA COSTA, 2012). Since then, there has been renewed interest in network studies in Latin America, contributing to the understanding of innovation systems and knowledge production in the

4 According to Boschma (2005), there are other types of proximities for the interactions. This study aims to investigate only the relevance of geographic proximity.

5 It is relevant to mention that this study applied to the Brazilian Access to Information Law (application number 48700001493201791) aiming to obtain access to complementary data about firms that perform research and research coordinators for each ANEEL R&D project for all years that the programme has been undergoing. However, ANEEL provided only data that were freely accessed on their website and already used in this study. According to ANEEL, data on firms and research actors by project are not compiled and therefore could not be disclosed.

region. This study aims to contribute to the understanding of the role of R&D networks in Brazil. Hence, we investigate networks created under the ANEEL R&D Programme, their structures, the role of participating actors and their geographical distribution. We assume that R&D activities are knowledge intensive and that R&D (and innovation) networks are a subsystem of the innovation system (CANTNER; GRAF, 2010). The study proposes the following research question: *How are the actors of the innovation system of the Brazilian electric sector structured, in terms of their R&D activities and within the scope of government policies which aim at the creation of networks, such as the ANEEL R&D Programme?*

Although some studies have contributed to the understanding of interactions among ANEEL R&D actors using aggregate data (POMPERMAYER *et al.*, 2011), this study created a database of ANEEL R&D projects (see section 3) for each grantee firm in the period from 2006 to 2008. We employ social network analysis (SNA) to investigate network structure and characteristics (DE NOOY; MRVAR; BATAGELJ, 2005) and therefore delve into the results obtained from previous studies on ANEEL R&D Programme.

We draw upon the geography of innovation approach (FELDMAN, 1994; BOSCHMA; MARTIN, 2010) and geoprocessing tools to provide the geospatial analysis of the networks. The cartographic representation of the networks allows the visualisation of actors' geographical localisation, interactions driven by geographical proximity and at the regional level. The use of point mapping and network mapping indicates that partnerships among the actors outweigh geographical barriers and motivate the process of specialization and competition between regions in attracting investments.

Considering previous studies, we expected ANEEL R&D networks to show low density, potentially limiting knowledge circulation among participating actors. Our results confirm such characteristics using SNA. Hence, our main contribution to the literature on the Brazilian electric sector is empirical, we reveal the structure of the network and the role of geographical proximity. The study brings evidence on the sectoral system of innovation (SSI) of the Brazilian electric sector (MALERBA, 2002), enabling the visualization of interactions among actors which may potentially foster shared learning.

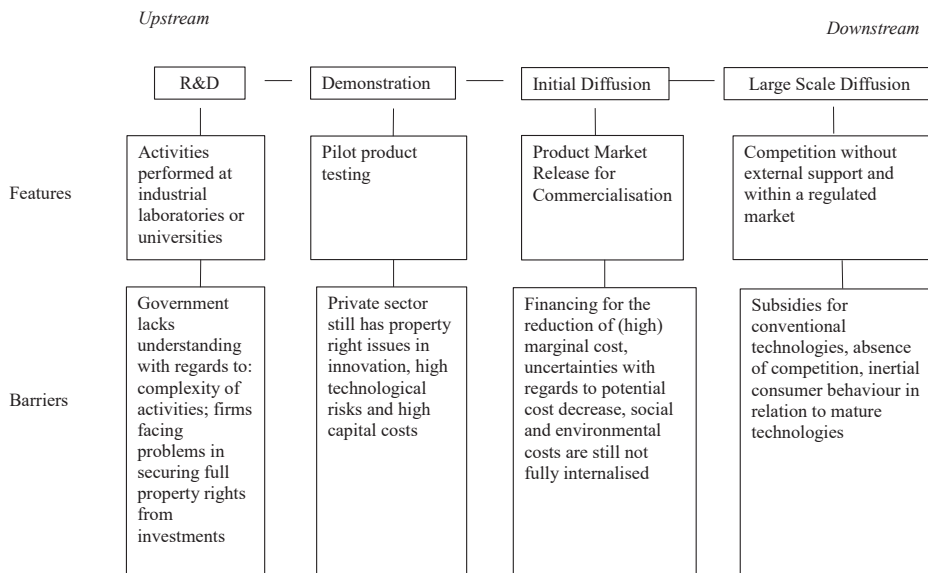
The article is organised as follows, in addition to this Introduction. Section 2 presents the electric sector and the ANEEL R&D Programme under the analytical framework of innovation systems; section 3 presents the methodology employed in the study. Section 4 presents and discusses the data and Section 5 concludes the article pointing to the main contribution, limitations and policy implications of the study.

2. The Brazilian electric sector and the ANEEL R&D Programme

2.1. The sectoral approach and geographic proximity

The electric sector employs mature technologies related to coal, oil, natural gas and nuclear fusion. Recently, emerging technologies such as wind, wave and tidal energy (Foxon *et al.*, 2005) renewed the sector.⁶ The global supply of primary energy (86.6%) and electricity generation (80.5%) in 2009 were based on non-renewable sources (IEA, 2011, p. 6, 24). Brazil shows a different path but faces technological challenges. Figure 1 presents features and barriers to the development of the electric sector in developing countries, as discussed below.

FIGURE 1
Innovation chain in the electric sector: features and barriers



Source: Own elaboration based on Foxon *et al.* (2005) and Holdren (2003, p. 34).

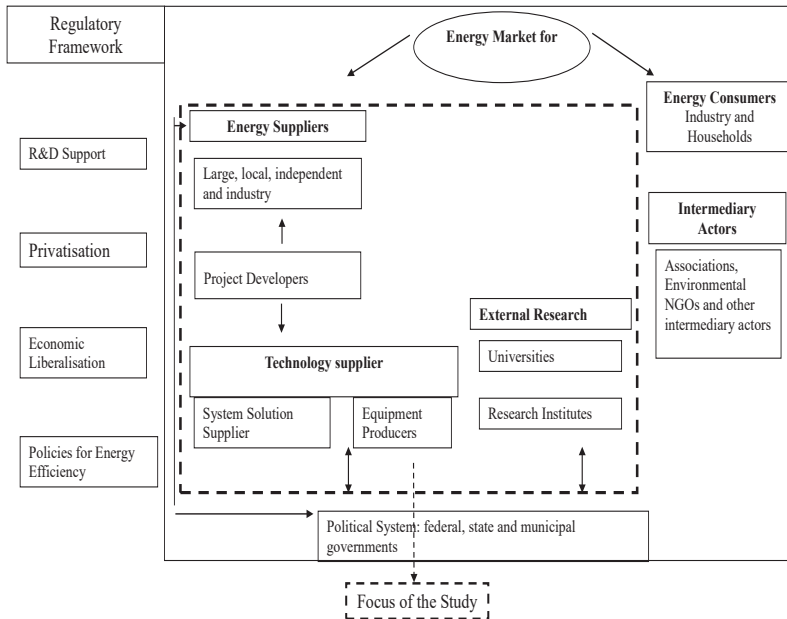
Multinational companies (MNCs) are the main actors of the SSI in electric energy generation and mainly based in developed economies (JACQUIER-ROUX; BOURGEOIS, 2002; FURTADO, 2008; ROGGE; HOFFMANN, 2010).

⁶ Hydroelectricity is a renewable source of energy generation, but hydropower technology is considered mature when related to large hydroelectric power plants.

Power generation equipment suppliers develop most of the new technologies in the sector and are responsible for interactions with organizations that create new knowledge (JACQUIER-ROUX; BOURGEOIS, 2002). This feature of the sector is a potential barrier for R&D collaboration between equipment suppliers and firms based in developing countries, the geographical distance may restrict user-supplier interactions. For instance, GTD firms based in developing countries may have lower benefits related to knowledge spillovers from suppliers' technological capacities.⁷ To overcome user-supplier limitations for local technological development in Brazil, the ANEEL R&D Programme aimed to foster interactions among local actors for R&D activities.

The main components and actors of the Brazilian electric SSI are: governmental organizations, firms, universities, vocational education organizations, public and private research organisations, non-governmental organisations and associations; and intermediary actors. Figure 2 presents the SSI of the electric sector and the focus of this study.

FIGURE 2
The electric sectoral system of innovation and the focus of the study



Source: Own elaboration based on Rogge and Hoffman (2010: Figure 1, p. 7641).

⁷ Local conditions in developing countries should be considered for local technological development, such as technological training and industrial production capacity (BELL; PAVITT, 1993).

Innovation presents a geographic dimension related to the locality of SSI actors (THOMAS, 1985). This study highlights the importance of a geographic analysis regarding interactions among actors of the Brazilian electric SSI and we consider the regional scale of analysis (i.e., regions of the country). From the innovation perspective, proximity (potentially) favours personal interaction in R&D projects and enables cognitive-based relationships and trust building among actors (STORPER; VENABLES, 2001). It can also promote learning interactions between R&D organisations, suppliers and technology users. Both the organisational and individual dimensions of interactions are developed in network arrangements.

With regards to R&D and innovation (R&D&I) activities and the role of geographic location (BOSCHMA; MARTIN, 2010), geographic proximity is assumed to have a central role in the choices of actors for the creation of partnerships (for both organisational and individual relations). According to Feldman (1994), individual proximity may enable information exchange and reduce the risks and costs of innovation activities. At the organisational level, product innovation relates to the technological infrastructure available, and the strategic location of knowledge sources strengthens knowledge inputs that can be crucial for the competitive advantages of a given location or region. Geographic proximity enables tacit knowledge exchange and the creation of trusted interactions among actors (BOSCHMA, 2005).

Networks materialize in the “geographical space” (SANTOS, 1996) and cause economic, political and social changes. Mapping the proximity of relations is central to the analysis of the geography of innovation (FELDMAN, 1994) to explain phenomena occurred in the geographic space and their relation with technological development, where innovation sources and knowledge flows materialize and create (un)expected results (SAXENIAN, 1994; STORPER, 2013). However, network actors must also show some level of cognitive proximity when accessing and creating links with regional external actors (BOSCHMA, 2004, p. 1006). In addition, they must have minimum absorptive capacity to internalize knowledge (COHEN; LEVINTHAL, 1990). A minimum level of institutional proximity is required when actors share values and expectations. This study presents empirical data regarding this in Section 4.

Regions are central to foster interactions that increase and improve local learning capacities (COOKE, 1992; DOLOREUX, 2002; DOLOREUX; PARTO, 2005). They leverage local vocations over time and become a strategic asset for local competitiveness and the formation of regional innovation systems. In turn, Regional innovation systems aim (among other things) to attract new investments related to specific sectors to a region. Brazilian regions that have undergone

industrial concentration over time have managed to attract scientific infrastructure investments, while regions with lower industrial concentration have become peripheral in the country (DE NEGRI; SQUEFF, 2016).

The geographical dimension of the Brazilian territory and its regional diversity create a geographical distance between network actors in their interactions, challenging the advantages of geographical proximity. The actors who participate in the ANEEL R&D are not geographically close in all interactions. Network creation supersedes the regional scale, and interactions are located throughout the national territory. Regional inequality and heterogeneity are likely to increase as a result of differences in access to capital, availability of trained human resources and scientific and technological infrastructure (DINIZ; GONÇALVES, 2005). The latter is unequal among Brazilian regions and this asymmetry creates inequalities in the potential for regional innovation, which is crucial for sectorial competitiveness (DE NEGRI; SQUEFF, 2016).

This study introduced the use of geotechnologies to map whether there is a connection between geography and innovation. Georeferenced information includes remote sensing, digital cartography, geostatistics and geographical information systems (GIS). These allow the analysis, management and representation of geographical location as well as of the phenomena developed in the territory (MATIAS, 2002; SOUZA FILHO; CROSTA, 2003; ROSA, 2011). This study proposes to map the networks created under the ANEEL R&D Programme; according to Garcia (2012), it is necessary to bring more empirical evidence for Brazil on the topics discussed by the evolutionary economic geography. Mapping networks through georeferencing contributes to this debate.

2.2 The ANEEL R&D Programme: a short review

The ANEEL R&D Programme was implemented in a highly regulated market.⁸ The Brazilian State has been historically present in the electric sector through state-owned companies, which have had a central role in the creation and expansion of the energy sector. The local electric sector went through a deregulation process in the 1990s which settled the institutionalization of a regulatory agency (ANEEL) and the increase of private firms' share in the sector (MASSAGUER, 2013). However, the presence of state-owned companies was still relevant in the period covered by this study.

⁸ This study considers the 2006-2008 period. ANEEL has changed some practices of its R&D Programme over time, a different period of analysis must consider the practices that regulate the programme for the relevant period.

The Programme was part of the Brazilian federal government's technology policy, which aimed at fostering local sectoral R&D activities. The policy framework deemed systemic interactions a condition to the formation of a dynamic innovation system; the objective was to create knowledge exchange between its actors (ANEEL, 2011). The Programme was implemented in conformity with the Law n. 9.991/2000 and it demands that electrical energy operators located in Brazil apply 1% of their annual net revenue in R&D activities. According to the R&D ANEEL Handbook, every project approved must comply in terms of: theme and sub-theme; stage in the innovation chain; and type of product. For each theme there is a classification of sub-themes, which indicates the wide scope of R&D activities.⁹

The projects are framed into specific phases of the innovation chain, as well as according to specific types of products.¹⁰ ANEEL evaluates submissions to classify whether or not they comply with the Programme¹¹ and follows their implementation (when approval is granted). If project outcomes are not approved, participant must pay a penalty and return the value of the grant to ANEEL (ANEEL, 2012a).

The purpose of this study is to investigate the networks resulting from the ANEEL R&D Programme to elucidate the interactions created through geographical proximity in the period from 2006 to 2008. In this way, the paper will not assess the efficiency of the Programme in relation to the outcomes of its projects. The Programme is an object of study that will enable to examine whether or not geographical proximity relates to the electric sectoral innovation systems in Brazil. In order to achieve this purpose, we applied the methodology of SNA and geoprocessing, as will be explained in the next section.

3. Research method

Data on approved projects are made available by ANEEL R&D including the following variables: project title; name of applicant firm; firm's acronyms and ANEEL code; project theme; stage in the electric production chain; type of products; cost; preliminary starting and ending date, and final report; and ANEEL's project

9 For more information, refer to <http://www.aneel.gov.br/area.cfm?idArea=641&cidPerfil=6>; accessed in March 17 2014.

10 For further details on the specificities of the Programme, see the ANEEL Handbook (2012a), this discussion is beyond the purpose of this paper.

11 The criteria include: "originality; applicability; relevance, cost reasonableness. For each criteria a pointing scheme is attributed determining the classification of the project, which will determine its partial or complete approval or even its rejection" (Manual da ANEEL, 2012a, p. 18, our translation).

assessment report.¹² However, available data on projects do not include other relevant information for this study, such as: performing organisation; and the coordinator of each project. These data were accessed only through manual search for each individual ANEEL R&D project in ANEEL's website.¹³ Completing the database with information on performing organisations and coordinators was the first step of the data collection. Final data refers to the 2006-2008 period and to 278 R&D projects (i.e., 52.2% of the submitted projects for the analysed period).¹⁴

In addition, the following data for projects are not available: geographical location of applicant firms and performing organisations; and institutional affiliation of project coordinators and their geographical location. We completed the database with information for each ANEEL R&D project on: coordinators' institutional affiliation through searches in the Lattes Platform; and the geographical location of each coordinator and applicant firms using ArcGIS (ESRI). These data are crucial for explaining ANEEL R&D networks with regards to the type of performing organisation that is involved (organisational perspective), and project coordinators (individual perspective). Interactions between actors located in the same state or Brazilian region are a proxy for geographical proximity (GARCIA *et al.*, 2015), this highlights the relevance of the regional innovation system, e.g., sharing the same scientific infrastructure (POWELL; GRODAL, 2005).

Once the database was completed, we used SNA measures and representation (DE NOOY; MRVAR; BATAGELJ, 2005) to create the following ANEEL R&D networks: applicant firms and performing organisations; and applicant firms and project coordinators. Network analysis centrality measures (Table 1) were combined with geospatial analysis.

The final step was the use of georeferencing (Geographic Information System – GIS) to map interactions between ANEEL R&D network actors. Cartography data was added to the project database for each project: geographic coordinate system (degrees, minutes, seconds) for applicant firms and performing organisations were converted into decimal degrees, allowing the use of ArcGIS 10.1 (ESRI). Each latitude (X) and longitude (Y) provides the geographical location of SSI actors based on the ANEEL R&D Programme, providing a point mapping. In geospatial analysis points are isolated and positioned geometric location, which in group create a spatial arrangement. The pattern of this arrangement emerges from the distance between

12 <http://www.aneel.gov.br/area.cfm?idArea=75&cidPerfil=6>, last accessed in 04 April 2014.

13 <https://ped.aneel.gov.br/consultaPublica/resultadoConsultarProjetos.asp>.

14 As mentioned above, data analysed in this study includes information for the 2006-2008 period shared by ANEEL.

points. The dispersion is the degree of spatial positions related to a frame in which points are present. Density is a characteristic of dispersion, which is related to the measure of an area but independent of its shape or dispersion of points (FERREIRA, 2014).

TABLE 1
Summary: SNA Centrality Measures

Centrality measures	Features	Contribution
Degree centrality	“variation in the degrees of vertices divided by the maximum degree variation which is possible in a network of the same size”	supports the interpretation about a vertex to receive information from other members of the network
Closeness centrality	“number of other vertices divided by the sum of all distances between the vertex and all others”	supports the interpretation about the number of intermediaries that exist between a vertex and other members of the network
Betweenness centrality	“proportion of all geodesics [shortest path between two vertices] between pairs of other vertices that include this vertex”	supports the interpretation about the importance of a vertex in the creation of connections in the network

Source: Own elaboration, based on de Nooy, Mrvar and Batagelj (2005, p. 318).

Networks are a spatial arrangement of links, nodes and regional nodes. Networks are integrated structures that represent the possibilities of movement and spatial interaction among SSI actors of the electric sectoral system. The ANEEL R&D network is represented by a graphic model (graph), points connected through lines.¹⁵ Graphs provide the construction of a connective matrix between nodes. In each square matrix (i, j), there is value for the interaction between the location i and the location j (nodes) of the ANEEL R&D network. This study uses the binary connectivity matrix that registers the occurrence (or absence) of connections between locations i e j . The matrix allows the calculation of number of access by the applicant firm to the performing organisation and to other actors of the network. The result was a network mapping to identify the quantity of interaction flows between applicant firms and performing organisations (FERREIRA, 2014). Geoprocessing allowed the visualisation of the cartographic representation of the ANEEL R&D network (Section 4).

¹⁵ This model does not consider the length and direction of lines, neither if lines are curved or straight.

4. ANEEL R&D mapped networks: results and discussion

This study analysed two networks created under the ANEEL R&D Programme: the organisational network of applicant firms and performing organisations, i.e., research institutions, universities and firms; and ii) the individual network of applicant firms and project coordinators.¹⁶

4.1 Applicant firms and performing organisations: the organisational network

The organisational network (Figure 1) shows low density, high fragmentation and therefore low level of interactions among actors. These features suggest that knowledge circulation among actors engaged in ANEEL R&D is lower than its potential (see Table 1 for a summary of centrality measures). Degree and closeness centralities show that a few actors are relevant as intermediaries in knowledge exchange and information diffusion within the network, among those we highlight the following performing organisations: LACTEC,¹⁷ which accumulated a variety of research capabilities in the electric sector, and the Universidade Federal Fluminense (UFF) and its Euclides da Cunha Foundation, both based in the state of Rio de Janeiro.¹⁸

In addition, a few actors are related to knowledge production through basic research activities. Applicant firms are the main intermediaries in the network, suggesting that access to and circulation of frontier knowledge offered by actors that conduct research, such as universities and public and private research institutes, may be lower than its potential.

16 This study aimed to analyse networks based on project themes and performing organisations, but there was no complete consistency on data collected from ANEEL. Hence, the analysis about the network of themes and areas of expertise was initiated but not completed. It was not possible to observe systematically whether R&D projects related to technologies are closer or more distant to the technological frontier. Such study is a future topic of research.

17 Previously known as Technological Institute for Development (in Portuguese, Instituto de Tecnologia para o Desenvolvimento) and now LACTEC Institutes (in Portuguese, Institutos LACTEC), based in Curitiba (capital of the state of Paraná). It is a Civil Society Organisation for the Public Interest (in Portuguese, Organização da Sociedade Civil de Interesse Público-OSICIP) since 2000.

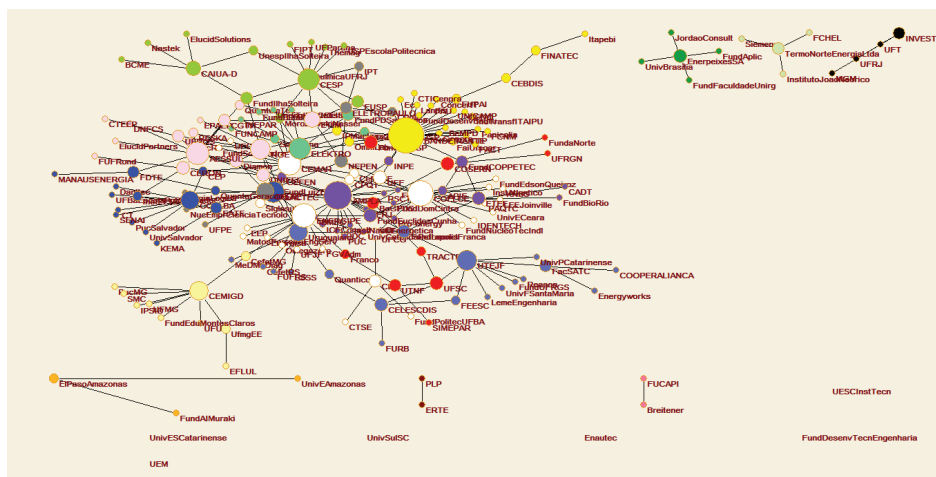
18 The identification of UFF as a relevant actor does not allow conclusions about its capabilities, once the data refer to the university level, not to a specific research centre. The same applies to its Foundation, which manages research projects and funds at the university level.

TABLE 2
SNA measures for the organisational network

Network	Applicant firms and performing organisations
Nodes	198
Links	231
Density	0.036
Degree centrality	2.33
Closeness centrality	
Average	0.16 130 nodes above average 68 nodes below average
Median	0.19 10 nodes above upper quartile (> 95%)
Betweenness centrality: main actors	EnerpeixesSA, INVESTCO, TermoNorteEnergiaLtda, EIPasoAmazonas, LACTEC, Bandeirante, Ampla, Energipe, Universidade Federal Fluminense and Fundação Leonel Franca

Source: Own elaboration based on study database.

FIGURE 3
The organisational network



Source: Own elaboration based on study database.

Figures 4 and 5 are maps which present the geographical location of applicant firms and performing organisations. The map in Figure 4 suggests that interactions created for R&D projects follow the pattern of the Brazilian land occupation (GARCIA *et al.*, 2015; FERNANDES, 2016). The majority of applicant firms

are located close to coastal areas. Geographical proximity is also an asset for project performing organisations located in the South and Southeast regions of the country, which are responsible for the majority of projects – as shown by other studies (POMPERMAYER *et al.*, 2011). Figure 5 suggests that geographical proximity is not a relevant issue for applicant firms based in the Northeast region, such as Energipe, CEMAR (both established the highest number of links in the network) and Coelce. Georeferencing showed that 35.5% of interactions occurred inside the same Brazilian state, whereas 64.5% between two Brazilian states, as shown in Table 3.

TABLE 3
Brazilian states: number of interactions, 2006-2008

Brazilian states	Number of interactions	%
São Paulo	30	36.1
Minas Gerais	9	10.8
Rio de Janeiro	9	10.8
Rio Grande do Sul	8	9.6
Bahia	5	6.0
Ceará	5	6.0
Santa Catarina	5	6.0
Pernambuco	4	4.8
Amazonas	3	3.6
Rio Grande do Norte	2	2.4
Maranhão	1	1.2
Rondônia	1	1.2
Tocantins	1	1.2

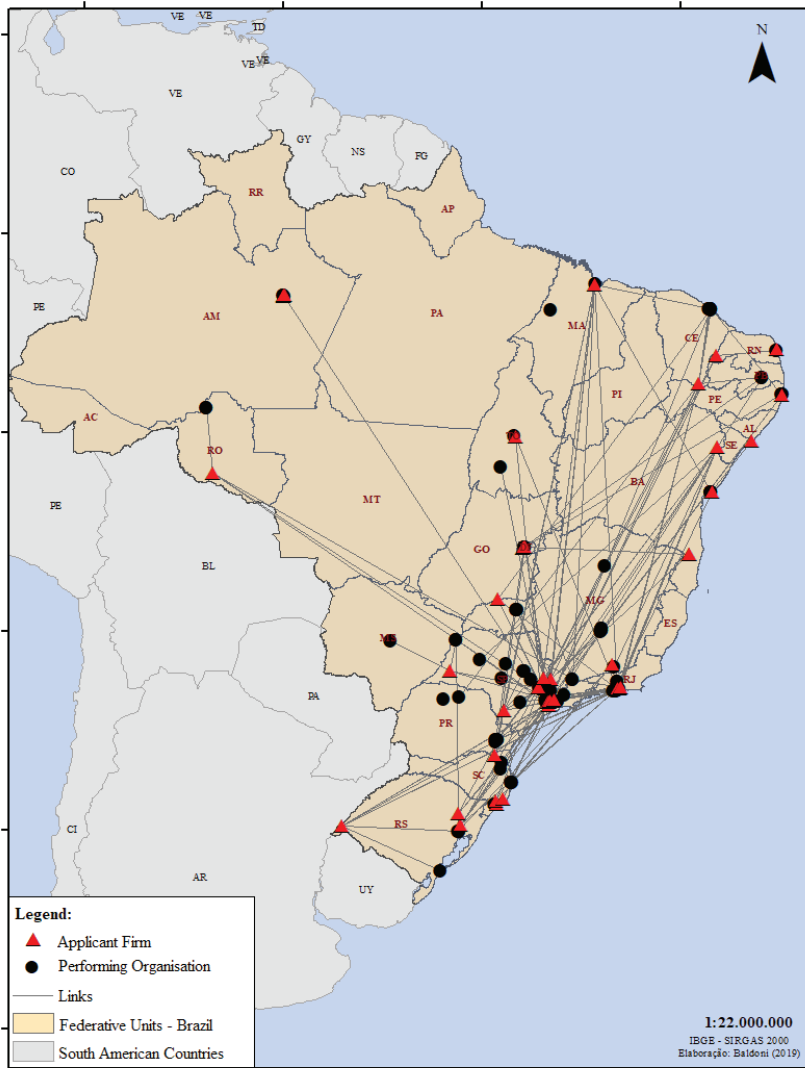
Source: Own elaboration based on study database.

It is noteworthy that cognitive proximity seems to be a determinant issue for interactions in R&D activities for Northeastern actors; knowledge and trust are essential features for the creation of this type of link (GARCIA *et al.*, 2015). In addition, project performing organisations specialised in knowledge production in the sector may not be present in locations close to applicant firms (based in the Northeast region), or there may not be the necessary knowledge capacities that foster the creation of collaborations.¹⁹ It is important to highlight that the creation

¹⁹ Note that this study does not include the motivation for the creation of interactions from the perspective of applicant firms. Explaining such motivations would demand an in-situ fieldwork data collection or a survey research. Neither of them are within the scope of this study. See more on this topic in the concluding section.

of ANEEL R&D networks are limited to ANEEL calls for project submissions that follow the scope of the programme, which specifies themes and areas within the sector.²⁰

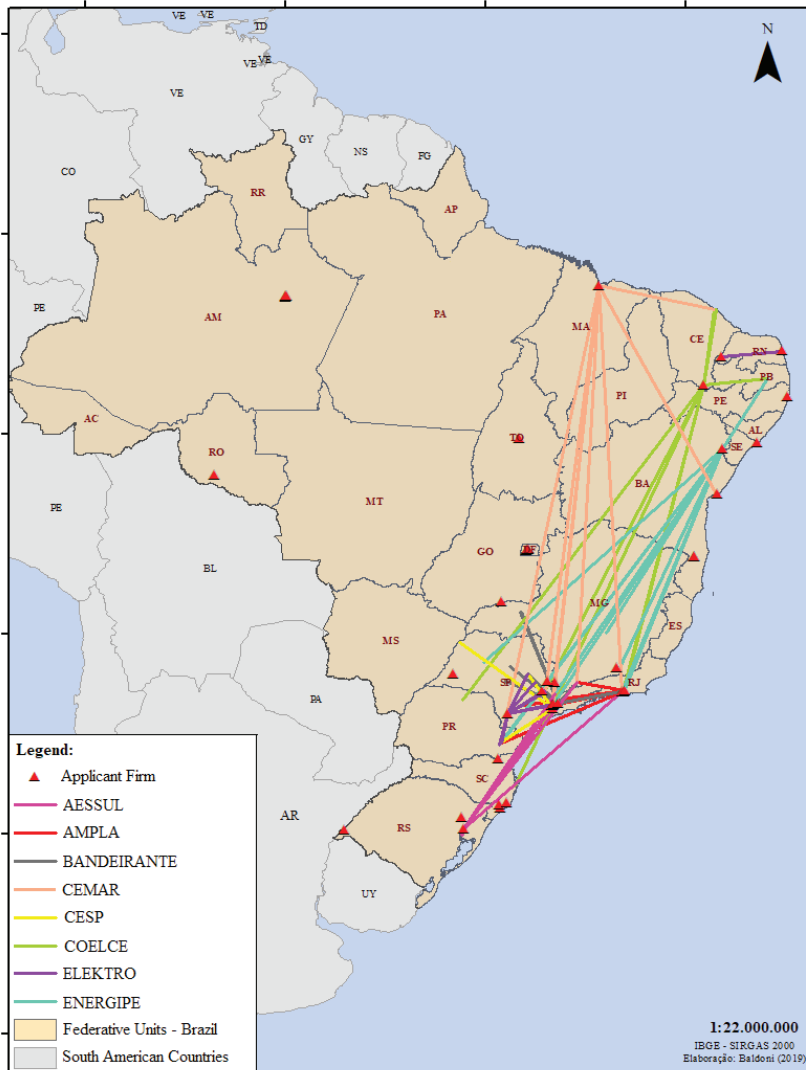
FIGURE 4
ANEEL R&D: Organisational network in the Brazilian territory – 2006-2008



Source: Own elaboration based on study database.

²⁰ We thank the comment of one of the peer reviewers, who brought our attention to this issue as a relevant fact in the creation of ANEEL R&D networks.

FIGURE 5
ANEEL R&D: the geographical location of main applicant firms
and performing organisations – 2006-2008

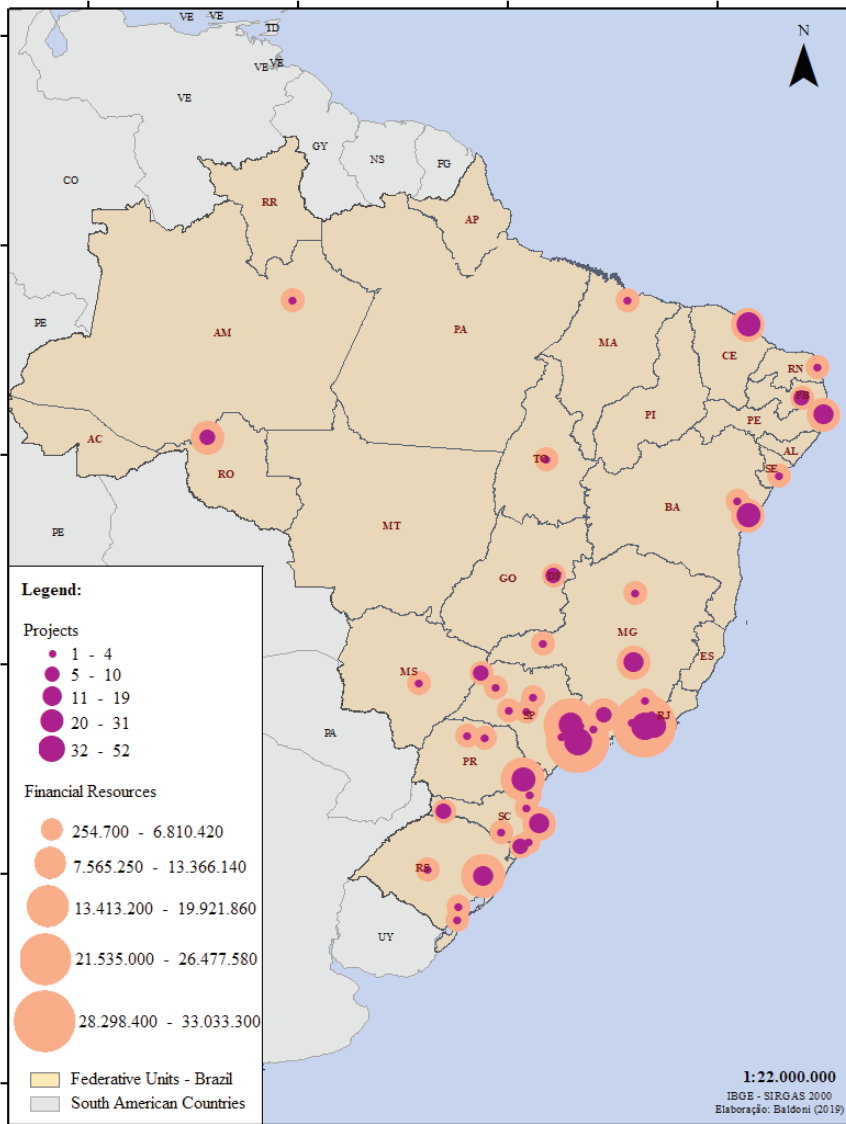


Source: Own elaboration based on study database.

The study shows that the majority of projects are performed by network actors that are located in the most developed regions of the country (both in number of projects and in financial resources, see Figure 6 below). These results are in line with the fact that Brazil presents regional inequality with concentration of capacity of

knowledge production and science and technology infrastructure in the South and Southeast regions (DE NEGRI; SQUEFF, 2016), which present vocational assets related to the themes of R&D projects.

FIGURE 6.
ANEEL R&D: number of projects and financial resources by project, 2006-2008



Source: Own elaboration based on study database.

Network betweenness centrality elucidates the relevance of a particular actor within the network for the creation of connections, the network hierarchy, and which actors are more central in interactions. Our analysis of the ANEEL R&D organizational network shows that a few actors are central for interactions (ten out of 198) and, therefore, that the network is very hierarchical. The main actors of the network are: Enerpeixes SA; INVESTCO; Termo Norte Energia Ltda; El Paso Amazonas; LACTEC; Bandeirante; Ampla; Energipe; Universidade Federal Fluminense; and Fundação Leonel Franca. Most of those actors are applicant firms, suggesting that project performing organisations have a subordinate position in knowledge generation and circulation in the Brazilian electric sector.

4.2 Applicant firms and project coordinators: the individual network

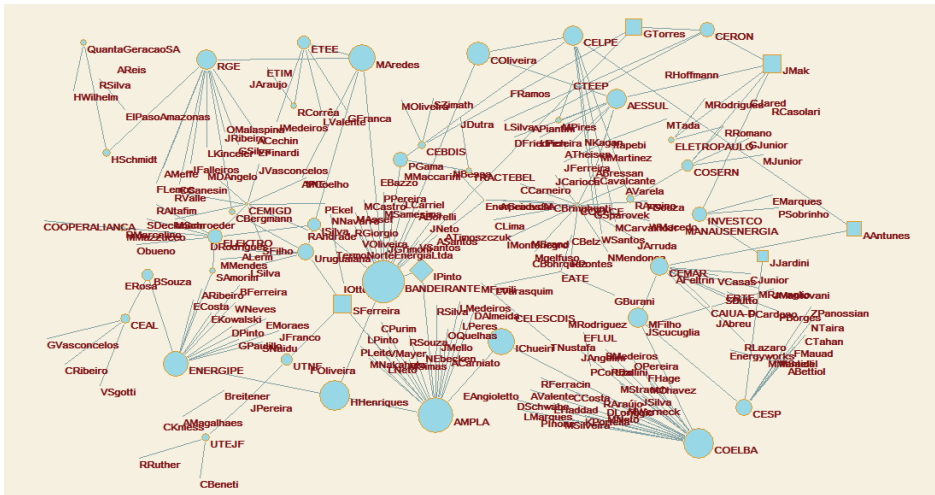
The network of applicant firms and project coordinators (the individual network) identifies which actors develop projects with grantee firms and to which organisations such actors are affiliated (Figure 7). The network shows low density; the interaction among actors are low when compared to its potential, revealing that a few coordinators can intermediate knowledge production and circulation in the electric sector. Degree and closeness centralities (Table 4) show that 28 nodes above the upper quartile (above 95%) are in majority (21 project coordinators). However, Figure 7 shows that the main actors of the network are applicant firms, such as Bandeirante and Ampla (followed by Energipe and CELPE).

TABLE 4
SNA measures for the individual network

Network	Applicant firms and project coordinators
Nodes	237
Links	211
Density	0.02
Degree centrality	1.78
Closeness centrality	
Average	0.08 156 nodes above average
Median	0.11 28 nodes in upper quartile (> 95%)
Betweenness centrality: main actors	Applicant firms: CAIUA-D, EATE, Enerpeixes SA, CELESCDIS, Itapebi, Termo Norte Energia Ltda, BANDEIRANTE, AMPLA, and COELBA. Coordinators: RRomano and HHenriques

Source: Own elaboration based on study database.

FIGURE 7
The individual network



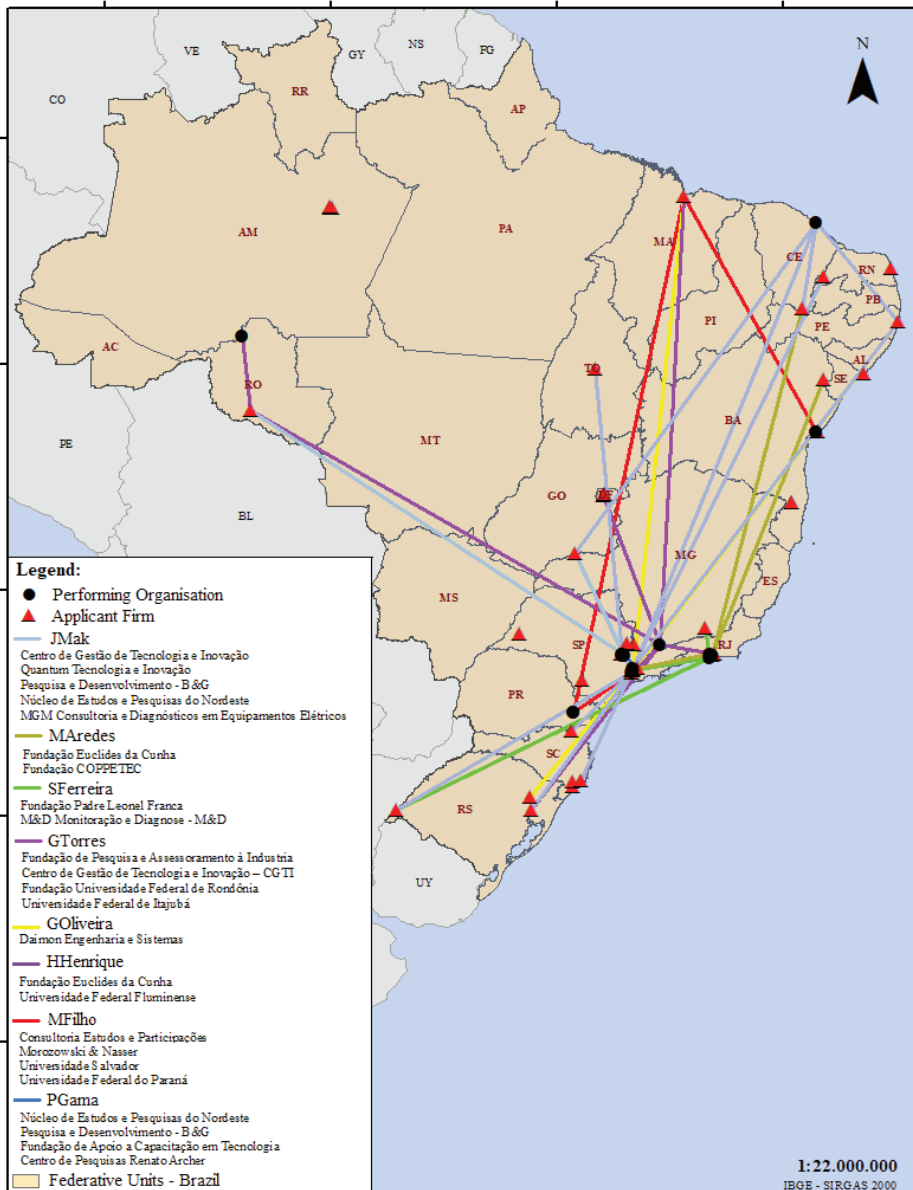
Source: Own elaboration based on study database.

The analysis of eight coordinators (higher values in the upper quartile) showed that most of them are located in the Southeast region (see Figure 8), but are accessed by actors present in other Brazilian regions, to which there is geographical distance. This result suggests that project coordinators might have specialised knowledge about the sector. It also suggests that geographically distant partners access project coordinators because they produce knowledge that is strategically relevant. Cognitive proximity may be a relevant issue in the creation of links when the necessary knowledge for the development of the sector is strategic (R&D activities show this feature). Another possible interpretation is that the knowledge accessed is geographically distant and not locally available. Even though geographical distance has not been a barrier for the creation of links, it reveals that there might be a cognitive proximity among actors.

The individual network betweenness centrality shows high hierarchy among actors in which, instead of project coordinators, applicant firms play a major role. However, two project coordinators (out of ten most important nodes) stand out: RRomano – at the time based at the Networks Laboratory and Infrastructure at the Centre for Research and Development in Telecommunications (CPqD), located in Campinas (state of São Paulo), which develops R&D activities in high technology sectors, including the electric sector (mainly related to the application

of information technology in the electric network); and HHenriques – then based at the Technological Centre of the Engineering School of the Universidade Federal Fluminense (state of Rio de Janeiro).

FIGURE 8
ANEEL R&D: main project coordinators and performing organisations – 2006-2008



Source: Own elaboration based on study database.

Other coordinators identified in Figure 8 show the highest degree centrality; most of them are located in the Brazilian Southeast region (with the exception of MFilho, located in the state of Paraná, in the South region) and are based at universities (exceptions are JMak, SFerreira and GTorres). These project coordinators were accessed by actors present in other Brazilian regions, suggesting that there is some level of cognitive proximity among them. Applicant firms such as CAIUA-D, EATE, Enerpeixes SA, CELESCDIS, Itapebi, Termo Norte Energia Ltda, Bandeirante, Ampla, and Coelba also played a central position in the network. Such feature of the network was also present in the analysis of the organisational network (Figure 3); the implications of these features for the evolution of the electric sector are present in the concluding section below.

5. Conclusion

This study analysed the Brazilian electric sector investigating two networks of the ANEEL R&D Programme in the 2006-2008 period and proposed the following research question: “*How are the actors of the innovation system of the Brazilian electric sector structured, in terms of their R&D activities and within the scope of government policies which aim at the creation of networks, such as the ANEEL R&D Programme?*”

Data analysis drawing upon SNA and georeferencing enabled inferences about the main interactions within the SSI of the electric sector in Brazil and supported the clarification of: description of the main actors in the networks in relation to their proximity (closeness centrality) and intermediation (betweenness centrality), number of projects, financial resources, geographical location (by georeferencing networks); and possible geographical specialisation of the knowledge generated within the scope of the programme.

The data showed that, in the analysed period, the majority of actors accessed by applicant firms for the creation of links were research institutes and universities, in line with previous literature about the topic (POMPERMAYER *et al.*, 2011). This study sought to contribute to the understanding of the ANEEL R&D networks investigating the structure of the organizational and individual networks. The actors of these two networks are components of the electric SSI, as shown in Figure 2 (focus of the study). The study highlighted the geographical location of network actors.

The governance of the R&D networks created under the ANEEL R&D Programme was mainly structured by applicant firms, with a secondary participation

of actors that conduct external research to intermediate knowledge created about the sector. Furthermore, we found that suppliers of technology and energy technology were scantily accessed by applicant firms (that is, at a lower level than external actors) and also had a peripheral participation in a hierarchical network dominated by applicant firms. Considering that the electric sector is supplier-dominated, and that external research actors are in a subordinate position with regard to knowledge creation through R&D activities, the absence of suppliers shows a possible lack of internal dynamics in the local creation and circulation of the knowledge needed for the electric sector. In addition, the result shows frailty of the local sector in the creation of frontier knowledge.

The analysis about the locality of interactions shows that the sector mirrors the knowledge production structure located in the main regions (South and Southeast) and near the Brazilian coast, following the national pattern of availability of research infrastructure (GARCIA *et al.*, 2015; DE NEGRI; SQUEFF, 2016). The interactions created between actors in distant localities suggest that they present minimal capacities required to access actors located in consolidated research organisations. However, the search for geographically distant actors may result from the absence of local actors with sufficient minimum capacities to produce knowledge. Given that the predominant feature of the network is the large number of interactions with actors from universities, it is possible that the creation of new higher education institutions in Brazil since 2004 could potentially promote the growth of interactions with actors based in distant areas. However, this phenomenon is expected to occur in the medium term, since it depends on the consolidation of the local capacity to produce knowledge.

This study investigated the structure of ANEEL R&D networks based on SNA and georeferencing. These methods do not allow the understanding of the type of knowledge produced (whether they are closer or further away from R&D and demonstration activities, and the technological frontier). It neither enables to explain the motivation for the creation of network links, that is, whether they were created by geographical proximity reasons, other types of proximities, organizational affinities, previous well-succeeded experiences or even for personal reasons. Another issue which was not analysed were the implications of the interactions over time, neither from the personal perspective of the actors involved in projects. The understanding of these elements for the creation of networks demands *in-situ* research (fieldwork interviews or surveys) with all the actors in the networks. We suggest this approach as an area for future research, as well as a study of the investigated networks for a

longer period of time and the observation of the financial figures involved in the projects as a proxy of the intensity of interactions. These elements are limitations of this article. Empirical evidence of this type would support the formulation of effective public policy to amend the dysfunctionalities of the SSI of the Brazilian electric sector identified by this study and the literature on the topic.

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