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Determinants of Renewable Energy Systems: triple helix and triple bottom line as key development factors

Porto Alegre
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Dissertação submetida ao Programa de Pós-Graduação em Engenharia de Produção da Universidade Federal do Rio Grande do Sul como requisito parcial à obtenção do título de Mestre em Engenharia de Produção, modalidade Acadêmica, na área de concentração em Sistemas de Qualidade.
Orientador: Professor Alejandro Germán Frank, Dr.

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Esta dissertação foi julgada adequada para a obtenção do título de Mestre em Engenharia de Produção na modalidade Acadêmica e aprovada em sua forma final pelo Orientador e pela Banca Examinadora designada pelo Programa de Pós-Graduação em Engenharia de Produção da Universidade Federal do Rio Grande do Sul.

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"Don't let anyone rob you of your imagination, your creativity, or your curiosity."

— Mae Jemison, physicist and astronaut

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CRÉDITOS

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RESUMO

A transição para energias renováveis tornou-se uma preocupação global, sendo que existem diferentes desafios para alcançar o objetivo de estabelecer sólidos sistemas de energias renováveis (RES – *Renewable Energy Systems*) que sustentem o consumo energético de um país. No nível macro, uma das preocupações é construir ambientes propícios para o desenvolvimento dos RES. Enquanto alguns países desenvolvidos têm avançado notavelmente nesse aspecto, países emergentes como o Brasil enfrentam diversos desafios estruturais. Por isso, o objetivo desta dissertação é entender como diferentes fatores institucionais e contextuais podem contribuir com o desenvolvimento dos RES, primeiramente no contexto internacional e, posteriormente, no contexto brasileiro como forma de comparação. Para tanto, o trabalho concentra-se em torno de dois grandes pilares. Primeiramente, analisa-se a contribuição de atores institucionais para o desenvolvimento dos RES, utilizando-se como lente teórica a *triple helix* da inovação (governo, setor privado e universidades). Posteriormente, consideram-se as condições contextuais que facilitam o desenvolvimento dos RES, baseando-se na perspectiva do tripé da sustentabilidade mediante a consideração de fatores sociais, econômicos e ambientais relacionados com o grau de desenvolvimento dos RES. Essas duas perspectivas são estudadas mediante uma pesquisa *survey* conduzida com 727 prefeituras na Alemanha – país de referência em RES. Os resultados encontrados demonstram que cada ator da *triple helix* age de forma diferente na construção de políticas para o desenvolvimento das RES. Os resultados também apontam que RES mais desenvolvidos apresentam um tripé da sustentabilidade mais sólido, indicando que ambos possuem uma forte associação e são necessários como forma de desenvolvimento conjunto. Por fim, a pesquisa finaliza com um estudo qualitativo no Brasil, mediante entrevistas semiestruturadas com 27 stakeholders participantes do desenvolvimento de RES neste país. Os resultados apontam cinco grandes dimensões com desafios para a consolidação dos RES no país.

Palavras-chave: Energias renováveis; sistemas de inovação; políticas energéticas; sustentabilidade.

ABSTRACT

The transition to renewable energies has become a global concern. There are several challenges to achieve the goal of establishing solid renewable energy systems (RES) that support a country's energy consumption. At the macro level, one of the concerns is to build favorable environments for the development of RES. While some developed countries have advanced remarkably in this regard, emerging countries like Brazil face several structural challenges. Therefore, the objective of this dissertation is to understand how different institutional and contextual factors can contribute to the development of RES, first in the international context and, then, in the Brazilian context as a means of comparison. The study is focused around two major pillars. First, we consider the contribution of institutional actors to the development of RES, using the theoretical lens of the innovation triple helix. Then, we consider the contextual conditions that facilitate the development of the RES. We use perspective of the sustainable triple bottom line to support the development of RES. These two perspectives are studied by means of a survey conducted with 727 municipalities in Germany – a reference country in RES. The results demonstrate that each actor of the triple helix acts differently in the definition of policies for the development of RES. The results also point out that more developed RES are associated with a solid triple bottom line, indicating that both need to coevolve in order to consolidate RES. Finally, the research ends with a qualitative study in Brazil, through semi-structured interviews with 27 stakeholders participating in the development of RES in this country. The results show five major dimensions that are challenging the consolidation of RES in Brazil.

Keywords: Renewable energies; innovation systems; energy policies; sustainability.

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SUMMARY

1 INTRODUCTION

Last decades have witnessed an increase in world energy consumption as a driving factor for economic development (Şener, Sharp, and Anctil, 2018). In order to meet this demand, the use of renewable energy sources appears as an alternative compared to traditional energy sources, since it presents benefits such as increase of energy security, sustainable economic growth and reduction of environmental impacts (Brini, Amara, and Jemmali, 2017; Can Şener et al., 2018). In this context, renewable energy systems (RES) are proposed as a solution for the sustainable development in local activities. A RES is considered as "a network of actors, rules and material artifacts that influences the speed and direction of technological change toward the specific use of renewable energy sources to produce electricity, heating/cooling and transportation" (Frank et al., 2018, p. 354). RES is a component of a technological innovation system of a larger structural layer (country, region and/or municipality) (Bergek et al., 2008). Due to recent technological advances, RES are evolving at the point to stimulate the engagement of countries in sustainable value chains, supporting the global transition to a renewable economy (Fu et al., 2017). RES development can also contribute by generating new green jobs (Lehr, Lutz, and Edler, 2012), by decreasing emissions (Zaman, and Abd-el Moemen, 2017), and by boosting a sustainable economy (Bhattacharya, Paramati, Ozturk, and Bhattacharya, 2016).

Studies on RES development are increasing at a large pace (Quaschning, 2016). Figure 1 shows an exploratory search in the Science Direct database on RES policy and development, from 1996 until 2019, and demonstrates that it is an increasing field in the academic literature. However, since renewable energy is still a new field of research, there are several gaps that need to be addressed. One of them is the relationship between innovation policy and renewable energy adoption in regional system. It is well agreed that to boost renewable energy it is vital to develop long-term energy policy to encourage adoption of these sources as substation for those conventional (Yaqoot, Diwan, and Kandpal, 2016). Nonetheless, the kind of policies and the necessary conditions for such policies to operate appropriately are still open questions in the literature (Frank et al., 2018). Frank et al. (2018) have studied the effect of innovation policy criteria on RES development and have demonstrated how important it is to establish solid policies to support RES. However, as these authors acknowledge, the contextual conditions for the operations of such policies deserve further investigation. In this sense, two aspects deserve more attention to understand their connection with the establishment of renewable energy policy and RES development. The first regards to the actors involved in the creation of RES. The literature lacks understanding on how different stakeholders contribute for the proposition of RES policy (Zhang, Shen and Chan, 2012). Such understanding may contribute for the dynamics of regional innovation systems focused on renewable energy, and to pursue a well-balanced system of interactions among different stakeholders (Panoutsou, 2008). Besides this, the literature has not yet addressed the structural conditions under which the development of RES happens in a country (Viebahn et al., 2007). The industrial organization literature has defended that when development policies are established without consider structural conditions of the region, they are likely to fail (Coniglio et al., 2018). Therefore, the literature needs to clarify what are the structural determinants that support a sustainable development of RES. Finally, besides the general need of better define determinants of RES development, our study also aims to provide a better understanding of the Brazilian contextual conditions and opportunities. Brazil is a very rich country in natural resources and has large potential for the use of renewable sources (Pao e Fu, 2013). However, establishing consolidated RES in the country may not only depend on the access to renewable sources, but also on how the system can be configurated (Pereira et al., 2011). This is also worth of studying as a reference for emerging economies in general.

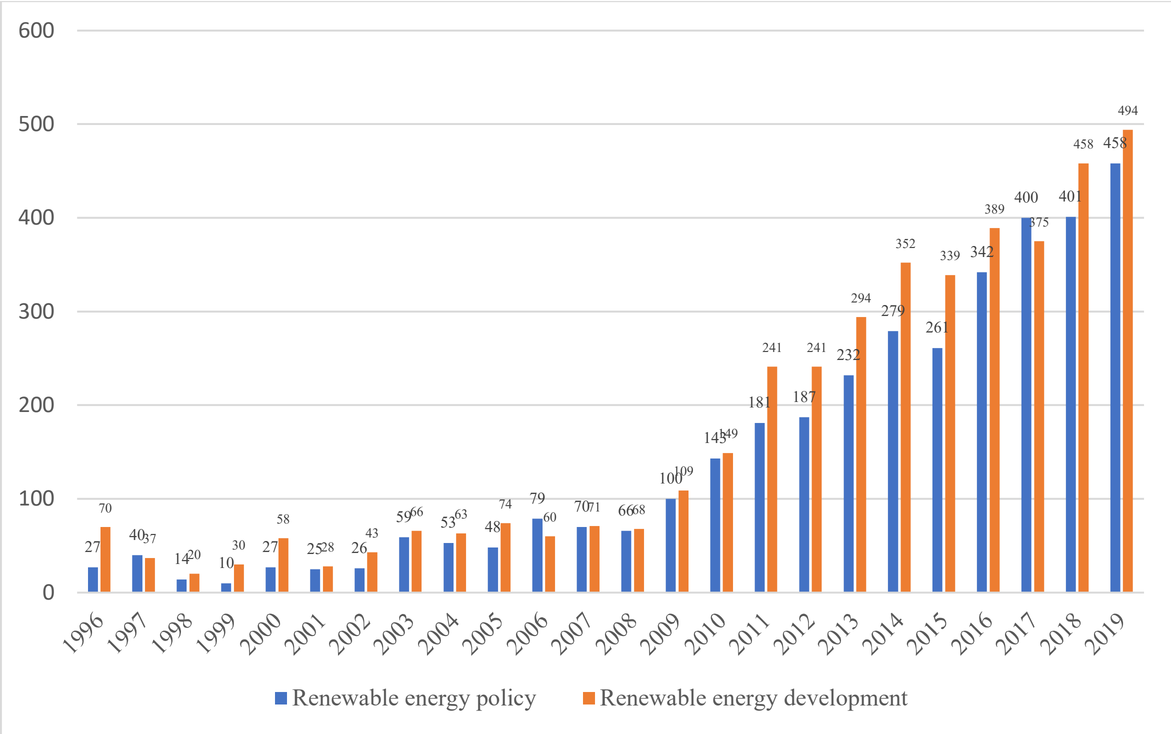

Figure 1 - Renewable energy policy and renewable energy development

1.1 OBJECTIVES

The objective of this dissertation is *to understand how different institutional and contextual factors can contribute to the development of RES, first in the international developed context and, then, in the Brazilian context as a reference for emerging countries*.

This general objective is built based through three specific objectives:

1) *To analyze the contribution of institutional actors to the development of RES*. We use the theoretical lens of the innovation triple helix to answer: What is the contribution by the different triple helix actors in the development of innovation policy criteria for municipal RES? We answer this research question by analyzing the contribution by the actors of the triple helix– i.e. government, universities, and the private sector – to three main innovation policy criteria for RES development: Creation of cooperative systems, generation and transfer of knowledge, and development of municipal locational factors (Frank et al., 2018).

2) *To define the contextual conditions that facilitate the development of the RES*. We use perspective of the sustainable triple bottom line to answer: what are the necessary contextual conditions, considering the triple bottom line perspective and renewable energy development, that are needed to support RES policy at the local level? We aim to comprehend whether municipalities should create contextual conditions around the three sustainable dimensions: social, economic and environmental pillars with the aim of supporting RES policy.

3) *To understand the Brazilian conditions for the development of solid RES*. In this objective, we address the following research question*:* What are the energy challenges for the development of renewable energy systems in emerging countries? We choose Brazil as a reference case for emerging countries, taking into account that it is one of the largest emerging countries, a member of BRICS, the largest economy in Latin America and a leader in innovation in Latin America.

These three specific objectives are developed in three independent and complementary papers that are connected around a prior study conducted by Frank et al. (2018). We use Frank's et al. (2018) study as theoretical background for the advance of this overall picture on RES development, as shown in the research model of Figure 2.

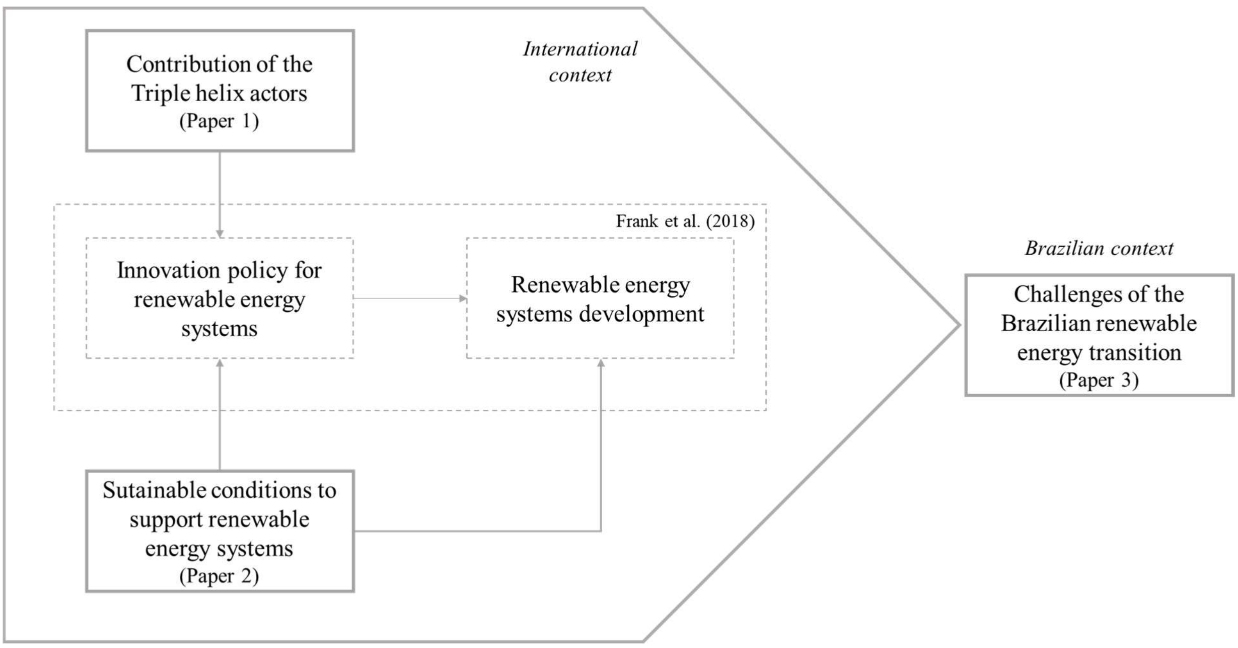

Figure 2 - Research model

1.2 RESEARCH METHODS

We adopt both quantitative and qualitative independent approaches for the different objectives addressed. We follow a dominant explanatory style because we seek to understand relationships between variables (triple helix actor, triple bottom line and RES policy), and understand adoption patterns, based on survey data. However, the final part of the study follows an exploratory strategy, in order to better understand the Brazilian context based on qualitative semi-structured interviews. Figure 3 summarizes the objectives of each article and the method.

The first article, *"The triple helix innovation model in municipal renewable energy*", comprises a large-scale survey across 727 mid-sized and large municipalities from all regions in Germany. Using a quantitative approach, we analyzed triple helix actors' role on RES policy based on the use of ordinary least squares (OLS) regression applied to the survey database.

The second article, "*Sustainable conditions for the development of renewable energy systems: a triple bottom line perspective*", considers the same large-scale survey across 727 mid-sized and large municipalities from all regions in Germany. In this study, we applied a cluster analysis in order to establish patterns of adoption of RES supported by a sustainable condition of the region using the triple bottom line perspective.

The third article, "*Challenges in the transition toward renewable energy in emerging economies: the case of Brazil",* follows a qualitative approach built on the analysis of 27 semi-structure interviews. We used a content analysis to organize and analyze the qualitative data.

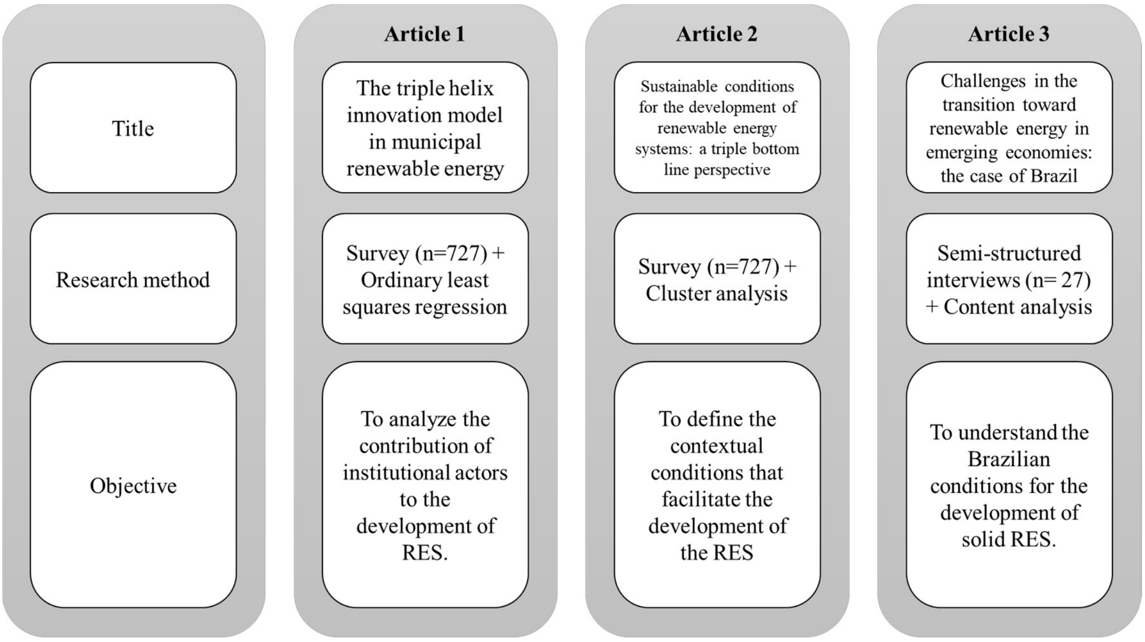

Figure 3 - Methodological structure of the study

1.3 STUDY LIMITATIONS

Renewable energy transition can be studied from different perspectives. For the purpose of this dissertation, the approach is to focus on municipal and country perspectives instead of industry and organizations approach. The first and second papers aim to conduct quantitative analysis regarding renewable energy development, triple helix actors and sustainable development in a developed country, while the third paper aims to understand challenging factors for renewable energy transition in an emerging country, following a qualitative analysis. As we conducted a transversal survey for the first and the second papers, our database showed a picture of energy policy and energy development, while, if we have conducted longitudinal analysis, we could bring a broader perspective from how energy policy and renewable energy development may grow together. Some nuances among variables could be studied, how each actor of triple helix could influence on cooperation activities and understand what main challenging factors from each one. Furthermore, other specific limitations of each article are directly explained on the same articles to facilitate readers' comprehension. With the above-mentioned limitations, we could address future researches too.

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2 ARTICLE 1 - The triple helix innovation model in municipal renewable energy systems

***This paper is under review at Energy Research and Social Science (Elsevier, IF = 5.525).**

ABSTRACT

Some countries have chosen to focus on bottom-up initiatives to enhance the development of renewable energy systems (RES), using the local level (municipalities) as a pillar in this development. Municipalities need to expand their innovation policies to support such transition toward renewable energies. The triple helix (TH) model, based on university, industry, and government, can play an important role in supporting and establishing local policies for RES. We analyze the contribution by the TH actors to the development of three innovation policy criteria for RES development: Creation of cooperative systems, generation and transfer of knowledge, and development of municipal locational factors. Our results are based on a quantitative survey of 727 mid-sized and large municipalities from all regions in Germany. We provide empirical evidence of the relevance of the TH model to support these policy criteria. We also show that rather than treating the TH model as a single effect on RES development, each of the TH actors provides different contributions to RES policies. The private sector has an important role in all three policy criteria, while we only found a contribution by universities to knowledge generation and transfer, but not to the two other criteria. The government contributes to all criteria except for locational factors. Thus, in a developed context the private sector is the driving factor of the economic activity related to RES.

Keywords: Triple helix; innovation policy; renewable energy systems; Germany; municipalities.

1. INTRODUCTION

In recent years, the interest in switching from conventional energy sources to renewable energy systems (RES) has been widespread in several developed countries. Some of these countries have focused on bottom-up initiatives to enhance RES, using the local level (municipalities) as a pillar sustainable development (Frank et al., 2018). In such cases, municipalities need to expand their innovation policies to support the transition toward renewable energies (Buschmann et al., 2014; Schoenberger, 2013). Since new policies are formulated in accordance with the overall needs of a region, actors such as different types of universities, industry, and government may play an important role in the establishment of local policies. Indeed, the evolution of RES in a regional perspective is largely dependent on the contribution by such actors. As a model of innovation, this type of multi-actor interaction is commonly known as the triple helix (TH) model (Etzkowitz and Leydesdorff, 1997). As the three actors in the TH model participate in the same region, they can contribute to the transformation of a specific RES, generating wealth through policy, innovation, and technology development (Perkmann et al., 2013). The TH model relies on regional and local innovation activity, considering geographical characteristics that influence innovation activities and actors' involvement (Strand, and Leydesdorff, 2013). In this paper, we focus our attention on the municipal microgeography level, focusing on the activity in municipalities. As Kostevšek et al. (2015) pointed out, municipalities can be considered as microcarriers for the development of RES.

The literature on renewable energy systems has not yet addressed the contribution by the different TH actors in the development of RES in a systematic and empirical manner. Recent studies have shown that RES benefited from the implementation of innovation policies at the municipal level (Frank et al., 2018). Also, previous investigations have suggested that a deeper engagement by the TH actors would be necessary for self-sustaining regional and municipal development (Etzkowitz et al., 2008). On the other hand, only a few studies have associated the TH role with RES and only in relation to very specific aspects (e.g. Klitkou, and Godoe, 2013; Deakin and Reid, 2018; Hettinga, Nikkamp, and Scholten, 2017). From the perspective of the TH model, the interaction by the three parties is generally in focus, while the specific contribution by each of the actors to the innovation system is usually neglected (I Ivanova, and Leydesdorff, 2014). In other words, although the relationship between the TH actors is essential, their contributions to the innovation policy for RES may be different. They cannot be treated as just a union of parties. Especially during the consolidation phase of RES, very different actions may be taken by each of the parties (Dzisah, and Etzkowitz, 2008). Therefore, there is a research gap in the literature as to *how* each TH actor is necessary to define and implement specific innovation policies for RES. In this sense, we address the following research question: *What is the contribution by the different triple helix actors in the development of innovation policy criteria for municipal RES?* Although the innovation literature assumes that all TH actors are essentially necessary for any innovation system (Etzkowitz, and Leydesdorff, 2000), our research question assumes that they can contribute differently (if at all) to innovation policy development for RES.

We aim to answer this research question by analyzing the contribution by the three TH actors – i.e. *government, universities*, and the *private sector* – to the three main innovation policy criteria for RES development: Creation of *cooperative systems*, *generation and transfer of knowledge,* and development of *municipal locational factors* (Frank et al., 2018). Our study is based on a large-scale survey across 727 mid-sized and large municipalities from all regions in Germany – one of the leading countries when it comes to using renewable energy sources. Using regression models, we found that: (i) All TH actors are important for the generation and transfer of RES knowledge in the region; (ii) the universities have a significant association with generation and transfer of RES knowledge, but not with the other two criteria; (iii) only the private sector seems to contribute effectively to the creation of municipal locational factors; and (iv) government and private actors are strongly associated with policies focused on cooperation for innovation in RES. Surprisingly, universities did not show any association with these policies. Thus, our results contribute to the discussion about the dynamics of the TH model in the development of innovation policies for RES, showing the potential boundaries of each of the involved RES actors. Policymakers may benefit from these results when trying to understanding how to best support the effective engagement by the different TH actors in the development of RES.

2. TRIPLE HELIX AND RENEWABLE ENERGY SYSTEMS

TH is an innovation model that focuses on the interactions between three main actors: different types of universities, private sector and government (Etzkowitz, 2003). In this model, each of these actors plays an important role in the promotion of the development of economy and society through innovation (Ranga and Etkowitz, 2003). A triple helix is crucial for the development of sustainable innovation systems, mostly because the management of natural resources involves complex problems that single actors cannot solve by themselves (Stevanov et al., 2013). Sustainable innovation projects may use the TH model to accelerate and implement innovation. Recent examples of such initiatives are the ones targeting the implementation of RES, which we consider as "*a network of actors, rules and material artifacts that influences the speed and direction of technological change toward the specific use of renewable energy sources to produce electricity, heating/cooling and transportation*" (Frank et al., 2018, p. 354). RES is a component of a technological innovation system of a larger structural layer (country, region and/or municipality) (Bergek et al., 2008). Many municipalities have focused their attention on RES while switching from conventional energy sources to renewable sources, supported by energy policies to achieve this goal (Frank et al., 2018) . Furthermore, according to Frank et al. (2018), municipalities can act as coordinators of

RES development while cooperation activities and local knowledge are enablers of RES development.

The TH model can play an important role in the development of an innovation policy focused on RES development, supporting the municipalities in this development. Frank et al. (2018) proposed three main innovation policy criteria that directly or indirectly may influence RES development: Cooperation activities, local knowledge, and municipal location factors. The *cooperation activities* criterion summarizes a policy focused on the creation of a positive and cooperative environment in the region for the implementation of RES. This policy includes reduction of resistance and cooperation by civil society to better support the RES development (Gerstlberger, 2004; Pattberg et al., 2012). Innovation policy focused on the *generation of local knowledge* comprises, among other aspects, the creation of in-house R&D activities, fixation of renewable energy knowledge in the region and the training of skilled workers for RES development (Østergaard et al., 2010). Finally, *municipal locational factors* comprise structural conditions for the development of RES, including energy consumption reduction initiatives and renewable energy promotion activities (Lund and Mathiesen, 2009; Bürer, and Wüstenhagen, 2009). Locational factors constitute a criterion where local communities have a more direct possibility to participate in and contribute to their local RES development (Frank et al., 2018). It might be expected that all the TH actors contribute equally to the creation and development of these three types of policy criteria, but we aim to investigate the specific contributions by each of these actors.

3. HYPOTHESES DEVELOPMENT – TRIPLE HELIX TO SUPPORT INNOVATION POLICY FOR RES

In this section, we present the hypotheses of our study which are based on the general theory of the triple helix as a model of regional innovation (Etkowitz and Leydesdorff, 2000; Etzkowitz and Zhou, 2017). We focus our study on the way in which each of the TH actors can contribute to these three specific innovation policy criteria, as represented in Figure 4 and discussed in the following subsections.

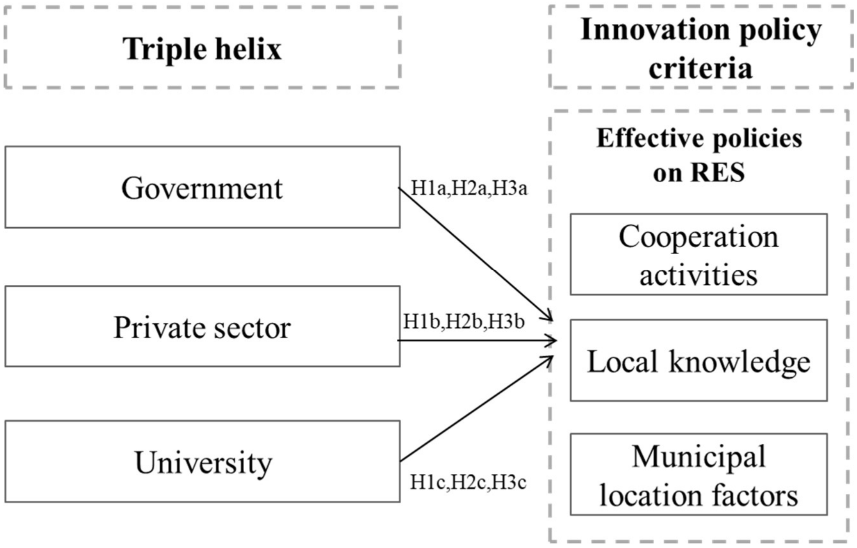

Figure 4 - Conceptual research model

3.1. Triple helix for cooperation policies focused on RES

The TH model is concerned with the interactions between the three parties in the TH system and the resulting outcomes (Etzkowitz and Zhou, 2017). One of the expected outcomes is the creation of stronger cooperation activities as reflected by the TH model (Brem and Radziwon, 2017). While the TH evolves in a RES, we expect that this process creates a synergistic effect on innovation policies towards cooperation (Mascarenhas, Marques, and Ferreira, 2019; Guerrero and Urbano, 2017): The stronger the TH, the clearer will the innovation policies focused on cooperation activities for RES development be. For example, some regions – such as Norwegian solar photovoltaic manufacturing regions – have constituted a strong TH presence that was used in a public discussion on how to enhance societal and private participation in the municipalities for the development of renewable energies (Klitkou and Godoe, 2013). As a TH actor, the government can create incentives for cooperation such as special innovation funds for university-industry interaction or for new collaborative projects among companies (Etzkowitz, 2003). The private sector can contribute by creating cooperation activities within the society, such as the creation of startup network programs focused on sustainability and green sustainable technologies (Bărbulescu, and Constantin, 2019; Brem and Radziwon, 2017) or social programs in the community (Alzyoud, and Bani-Hani, 2015). Moreover, universities can play an important cooperation role since they create an environment for public discussion and idea generation between the RES stakeholders (Mascarenhas, Ferreira and Marques, 2018; Chen, Wu, and Yang, 2016; Guerrero and Urbano, 2017). All these examples show the relevant role of the TH in enhancing cooperation activities in the municipalities regarding RES development. Although the presence of the three actors of the TH does not assure that they will cooperate among themselves (Lee and Kim, 2016), each of them can have its own stand-alone contribution to the municipality RES, providing a basis for cooperation activities that help to boost RES in the local community (Amiri and Weinberger, 2018; Rahbar, Chai, and Zhang, 2016; Taibi et al., 2016). Therefore, we propose:

H1: *A stronger presence of the TH actors in the municipality is positively associated with higher levels of cooperation policies for RES development*.

> *H1a: The government positively contributes to creating cooperation policies for RES.*
>
> *H1b: The private sector positively contributes to creating cooperation policies for RES.*
>
> *H1c: The universities positively contribute to creating cooperation policies for RES.*

3.2. Triple helix for knowledge generation policies focused on RES

The TH is a model based on knowledge generation for innovation and may contribute to knowledge generation policies (Ranga and Etzkowitz, 2003). Particularly, universities are very important for the development of knowledge and technology for RES (Osseweijer et al., 2017). By nature, universities and research centers assume a role of knowledge generation on renewable energy that can be disseminated within the municipal ecosystem (Mallett, 2007). While universities are responsible for educating and training new professionals in skills oriented towards the use of renewable energy, playing a key role in the RES progress and evolution (Assali, Khatib, and Najjar, 2019; Qu et al., 2011), the government acts proactively as an integrative agent between scientific and technological infrastructure and production structure. The government can establish strategic programs to incentivize knowledge fixation or generation in a RES (Mustapa, Peng, and Hashim, 2010). This can happen by creating government agencies focused on knowledge generation and on sustainability (Lund, 2009) or by creating funds and incentives for research programs on renewable energy in the municipality and the region (Lund, 2009). Lastly, although the private sector's main purpose is to appropriate knowledge and transform it into market value (Horbach, and Rammer, 2018), it can also support knowledge policies for RES in some ways. Large companies oriented toward RES can thus create programs for tying a labor force to the region. For example, large international solar plant companies have recently created programs to support the immigration of high skilled workers to develop RES (Luke et al., 2017). Companies can also engage with municipalities to define market needs for professionals that will influence labor incentives and laws (Lehr et al., 2008; Dincer, 2000) and provide training for RES knowledge generation (Noailly, and Shestalova, 2017). Furthermore, companies can develop their own R&D centers and labs for renewable energy which allows them to generate internal knowledge that will support a knowledge spillover to the entire RES (Leydesdorff and Deakin, 2011). Based on this argument, we propose the following hypothesis:

H2: A stronger presence of the TH actors in the municipality is positively associated with higher levels of local knowledge generation policies for RES development.

> *H2a: The government positively contributes to creating knowledge generation policies for RES.*
>
> *H2b: The private sector positively contributes to creating knowledge generation policies for RES.*
>
> *H2c: The universities positively contribute to creating knowledge generation policies for RES.*

3.3. Triple helix for municipal locational policies focused on RES

Municipal locational factors describe the contextual local conditions that create an appropriate environment for RES development (Frank et al., 2018). The local presence of the TH agents is considered as a key success element of general innovation systems with respect to local conditions (Leydesdorff, and Etkowitz, 1998), and we expect the same will apply to RES development. When government agents from different levels are involved in the development of local innovation, they can promote not only its progress, but also the welfare of the local population, creating a virtual circle of development (Smith, and Bagchi-Sen, 2012). Government agents can also be active in renewable energy regulation and local policies for the promotion of RES, including investment incentives, tax reductions, and establishment of green targets (Brem and Radziwon, 2017; Etkowitz, and Leydesdorff, 2000). In addition, universities can actively contribute to the improvement of locational factors. In recent years, many universities have been involved in the creation of job opportunities for their graduates and have leveraged the creation of university spin-offs and startups and the development of entrepreneurship mindset of the students, which is a key aspect of the local conditions for RES development (Cantner et al., 2014). Finally, in energy markets, municipal factors such as proximity to clean electricity production and orientation towards "green issues" in general are also related to technology innovation (Horbach, and Rammer, 2018), which in developed countries mostly stems from private initiatives (Simas, and Pacca, 2014). The private sector can engage in renewable energy applications and contribute to locational factors either proactively or reactively (as a response to public regulation) (Simas, and Pacca, 2014). New products based on renewable energy sources or provision of renewable energy technologies are initiatives from the private sector that can create synergy in the local community, thus creating a demand for more jobs in the market and more suppliers and even creating more market opportunities regarding renewable energies (Rösler, Langel, and Schormüller, 2013). Hence, we propose the following hypothesis:

H3: *A stronger presence of the TH actors in the municipality is positively associated with higher levels of municipal locational policies for RES development*.

> *H3a: The government positively contributes to creating municipal locational policies for RES.*
>
> *H3b: The private sector positively contributes to creating municipal locational policies for RES.*
>
> *H3c: The universities positively contribute to creating municipal locational policies for RES.*

4. Research method

4.1. Sampling

We conducted a large-scale survey through a university-based opinion research center in Germany. The target population of this survey comprised all municipalities of the 16 Federal States in Germany. We identified 11,300 German municipalities from these States listed in the Association of German Cities. We focused our study only on municipalities with more than 1,000 inhabitants, i.e., medium and large municipalities, since they have more potential for being engaged in innovation activities and, consequently, they might focus more on the transition process towards RES (Mascarenhas et al., 2016). Therefore, our final population is composed by 2,100 medium and large municipalities from the original list of the Association of German Cities. The questionnaire was sent to the respective representatives for urban/regional development. Because of the difficulty of accessing these kinds of policymakers and because of their very specific role in the renewable energy policy development, we adopted a single-respondent approach, as previously done in other large-scale innovation surveys (Buschmann et al., 2014; DeENet, 2009, Foxon et al., 2005). The questionnaire was delivered in the German language. The data was collected by means of an *online* survey, coupled with telephone interviews. We obtained a total of 727 useful responses, resulting in a response rate of 34.6%. Table 1 shows the demographics of the final sample.

Table 1 - Demographics of the final sample

Sample categories	Classification	Number of municipalities	Percentage of municipalities
Distribution by size (number of inhabitants)	≤2,500	136	19%
	2,500 to 4,999	150	21%
	5,000 to 9,999	185	25%
	10,000 to 19,999	114	16%
	20,000 to 49,999	68	9%
	≥ 50,000	74	10%
Distribution by regions	East	149	20%
	North	124	17%
	South	314	43%
	West	141	19%
	Total (n)	**727**	

4.2. Measurement definition

We conducted 20 interviews with mayors, municipality top policymakers, and company managers in order to discuss our conceptual framework and to check the viability and understandability of the research framework, testing the main ideas of the constructs of our study. We used this feedback to improve our questionnaire design. The main part of our questionnaire considered the three actors of the TH model [UNIVERSITY, PRIVATE, GOVERNMENT] and three innovation policy criteria [COOPERATION, KNOWLEDGE, LOCATION]. While UNIVERSITY was measured by a double-item scale – considering the two main types of institutions, i.e. universities and universities of applied sciences – the other constructs that represent the TH actors and the innovation policy criteria were measured by multi-item scales. Table 2 summarizes the measurements which we collected through a literature review on TH actors and renewable energy policies. The full questionnaire is shown in Table 3.

Table 2 – Constructs, measurement items and references

Construct	Measurement Items	References
[UNIVERSITY]	Universities Universities of Applied Sciences	Etzkowitz, and Leydesdorff (2000); Etzkowitz, 2003
[PRIVATE]	Large-scale energy suppliers Crafts Founders / accelerators Consulting Private banks	Etzkowitz, and Leydesdorff (2000); Etzkowitz, 2003; Stevanov et al. (2013)
[GOVERNMENT]	Ministries Regional council Regional association Local communities Economic development agencies	Etzkowitz, and Leydesdorff (2000); Etzkowitz, 2003; Stevanov et al. (2013)
[COOPERATION]	Public and private cooperation	Martins, Cunha, and Cruz (2011). Kern and Smith (2008) Østergaard et al. (2010)
	Cooperation of society	Gerstlberger (2004)
	Visibility in the community	Wüstenhagen, and Bilharz (2006)
	Social acceptance	Mallett (2007); Dooley (1998)
	Involvement of regional promoters	Gerstlberger (2004)
[KNOWLEDGE]	Municipal knowledge on renewable energy projects	Østergaard et al. (2010)
	Previous experience in municipalities with renewable energy projects	Østergaard et al. (2010)
	Existence of internal R&D activities in local renewable energy companies	Trencher, Yarime, Kharrazi (2013)
	Existence of universities in the region of the municipality	Angelis-dimakis et al. (2011)
	Development of regional knowledge in the agricultural and forestry sectors	Keijzers (2000)
[LOCATION]	Balancing and reduction of CO_2	Jacobsson and Lauber (2006); Lund and Mathiesen (2009)
	Reducing dependence on external energy suppliers	Lund and Mathiesen (2009)
	Incentive potential investors	Bürer, and Wüstenhagen (2009)
	Incentive to entrepreneurship activities	Bürer, and Wüstenhagen (2009)
	Fostering proximity and coordination with national operators	Marchi (2012)

Table 3 - Questionnaire items to assess the triple helix actors

Questionnaire items to assess the triple helix actors
1. Level of engagement of governmental actors in the municipality policies for RES development [GOVERNMENT]: Engagement Likert scale: 1 – not engaged – to 7 – extremely engaged. Construct validity: RMSEA (0.044), CFI (0.997), CR (0.987), α (0.811).
a) Ministries
b) Regional councils
c) Regional associations
d) Local communities
e) Economic development agencies
2. Level of engagement of private sector actors in the municipality policies for RES development [PRIVATE]: Engagement Likert scale: 1 – not engaged – to 7 – extremely engaged. Construct validity: RMSEA (0.027), CFI (0.999), CR (0.995), α (0.880).
a) Large-scale energy suppliers
b) Crafts
c) Founders / accelerators
d) Consulting
e) Private banks
3. Level of engagement of universities and universities of applied sciences in the municipality policies for RES development [UNIVERSITY]: Engagement Likert scale: 1 – not engaged – to 7 – extremely engaged. Construct validity: RMSEA, CFI, and CR are not available, since the construct is formed by only two items. α (0.65).
a) Universities
b) Universities of applied sciences
Questionnaire items to assess innovation policy criteria for renewable energy systems
1. Importance of the municipal locational factors [LOCATION]: Importance Likert scale for the municipality: 1 – not important – to 7 – extremely important. Construct validity: RMSEA (0.058), CFI (0.988), CR (0.984), α (0.759).
a) Balancing and reduction of CO2
b) Reducing dependence on external energy suppliers
c) Incentive potential energy investors
d) Incentive entrepreneurship activities
e) Fostering proximity and coordination with national energy operators
2. Importance of the cooperation activities [COOPERATION]: Importance Likert scale for the municipality: 1 – not important – to 7 – extremely important. Construct validity: RMSEA (0.076), CFI (0.977), CR (0.998), α (0.781).
a) Developing public-private cooperation
b) Reduction of resistances of organized interest groups
c) Increase of the visibility of the community
d) Acceptance of industrial activities by the local community and residents
e) Fostering support from possible regional promoter (e.g. environmental organizations)
3. Importance of the local knowledge about RES [KNOW]: Importance Likert scale for the municipality: 1 – not important – to 7 – extremely important. Construct validity: RMSEA (0.072), CFI (0.988), CR (0.990), α (0.82).
a) Building long-term knowledge in the municipality for renewable energy projects
b) Using previous project experience in renewable energy projects
c) Existence of in-house R&D activities on renewable energy
d) Existence of relevant universities and research institutes in the region
e) Existence of regional knowledge for the development of the agriculture and forestry sector
Questionnaire items for control variables
How strong are the following characteristics in your region?
a) Public support to renewable energy
b) Proximity to technology suppliers for renewable energy
c) Wage level of the municipality
d) Labor availability in the municipality
e) Access to research and development infrastructure for municipality
f) Did your municipality recently use public funds to invest in renewable energy projects? (Yes/No)

Questions for the [COOPERATION], [KNOWLEDGE] and [LOCATION] constructs as well as for the actors involved in the triple helix cooperation [PRIVATE], [UNIVERSITY] and [GOVERNMENT] were measured using a 7-point Likert scale. The TH actors were asked about their level of engagement in the municipality regarding RES development, while for the three innovation policy criteria we asked about the level of importance of each of the criteria for the municipality activity on RES development.

We also included six control variables in our regression model based on the contextual characteristics of the municipalities: (i) Public support for renewable energy and acceptance of renewable energy [Control_SUPPORT], which comprehends the level of acceptance of political and social support (Bürer, and Wüstenhagen, 2009); (ii) proximity to suppliers of technology for renewable energy system [Control_SUPPLIERS], in order to consider the level of proximity between the suppliers of renewable technologies and the municipality (Prognos, 2010); (iii) municipal salary level [Control_WAGE], in order to assess financial means that regular citizens have to invest in basic clean technologies and reduce energy consumption (Podsakoff, 2009); (iv) availability of labor in the municipality [Control_LABOR], which measurements the availability of the local labor force to work towards the implementation of RES (Podsakoff, 2009); (v) access to R&D infrastructure at a community level to develop renewable energy technologies [Control_R&D]; and, finally, (vi) access to public investment in sustainable projects [Control_FUNDS] (Marchi, 2012).

4.3. Common method variance

We used three main approaches to reduce common method variance bias (Podsakoff et al, 2009). Firstly, we randomized the items distribution in the questionnaire aiming to avoid that respondents correlate variables of the research design, especially between dependent and independent variables. Secondly, we addressed the questionnaire to key respondents, i.e. policymakers engaged in the municipal development of renewable energy policy. Anonymity was also guaranteed to the respondents so that they could respond to the questionnaire without any restriction. Lastly, we used the Harman's single factor to test if most of the variance in the model is represented by a single factor, which may indicate potential common method bias (Podsakoff et al, 2009). The output of this test for the four constructs (both dependent and independent) exhibited five factors, with the highest one accounting for 37.73% of variance, which is considered a low variance for potential common method bias (Podsakoff et al, 2009). However, it is not possible to ensure full independence of this bias because we could not use a multiple-respondent approach (Jöreskog, and Sörbom, 1993)

4.4. Validity and reliability of measurement

To test unidimensionality of the multiple-item measurements [GOVERNMENT, PRIVATE, COOPERATION, KNOWLEDGE and LOCATION], we used a set of confirmatory factor analyses (CFA) in Stata 13.0® (Jöreskog, and Sörbom, 1993). The outputs showed a good fit within all constructs. Therefore, their unidimensionality leads to the following values (see a summary in Table 3): COOPERATION (CFI = 0.977, RMSEA = 0.076); KNOWLEDGE (CFI = 0.988, RMSEA = 0.072); PRIVATE (CFI = 0.999, RMSEA = 0.027); GOVERNMENT (CFI = 0.997, RMSEA = 0.044); LOCATION (CFI = 0.988, RMSEA = 0.058). All items reported strong factor loadings on their constructs (factor loading p-value < 0.01). Furthermore, the measurement of the reliability of the constructs (Cronbach's Alpha) exceeded the threshold of 0.7 (Hair et al., 2009). We also evaluated the global fit of the model and the results indicate that the proposed model has good fit: $x^2_{(265)}$ = 1145.13; RMSEA = 0.068; CFI = 0.905. Moreover, we assessed discriminant validity of our model through a series of two-factor model estimations using Stata 13.0® (Bagozzi et al., 1991). In the first model, we analyzed the correlation between the two constructs, and we restricted it to unity, i.e. we placed all items of all constructs in a single construct. In the second model, we removed this restriction and calculated the quality of the fit of the original constructs. We analyzed the differences between both models' chi-square tests using an acceptance level of $p \leq 0.05$, i.e. x^2> 3.84, to consider a satisfactory discriminant validity. In Table 4, we present the correlation matrix and the chi-square values, showing that in all analyzed cases, they are valid in relation to their discriminant values. Additionally, this table presents the descriptive statistics, including means and standard deviations as well as the skewness and kurtosis for the verification of normality of the data.

Table 2 -Descriptive, correlations and construct validity

			Mean	S.D.	1	2	3	4	5	6	7	8	9	10	11	12
Δx^2 discriminant validity (upper side of the matrix)	1	GOVERNMENT	4.552	1.641	--	615.78**	698.79**	658.83**	802.44**							
	2	PRIVATE	4.127	1.764	0.677**	--	520.01**	398.34**	522.44**							
	3	LOCATION	4.669	1.246	0.341**	0.459**	--	136.41**	270.05**							
	4	COOPERATION	4.62	1.282	0.475**	0.554**	0.601**	--	95.01**							
	5	KNOWLEDGE	4.101	1.529	0.545**	0.591**	0.548**	0;661**	--							
	6	UNIVERSITY	3.241	2.107	0.579**	0.713**	0.357**	0.413**	0.560**	--						
	7	Control_SUPPORT	--	--	0.350**	0.438**	0.181**	0.301**	0.307**	0.313**						
	8	Control_SUPPLIERS	--	--	0.381**	0.454**	0.225**	0.285**	0.357**	0.380**	0.697**	--				
Pearson's correlations (bottom side of the matrix)	9	Control_WAGE	--	--	0.368**	0.396**	0.135**	0.230**	0.294**	0.304**	0.656**	0.735**	--			
	10	Control_LABOR			0.270**	0.262**	0.068	0.141**	0.213**	0.203**	0.479**	0.501**	0.652**	--		
	11	Control_R&D INF			0.308**	0.304**	0.096**	0.168**	0.312**	0.318**	0.426**	0.537**	0.558**	0,759**	--	
	12	Control_FUNDS	--	--	0.097**	0.155**	0.166**	0.115**	0.223**	0.146**	0.173**	0.123**	0.089*	0.090*	0.153**	--
Descriptives		Mean			4.552	4.127	4.669	4.62	4.101	3.241						
		SD			1.641	1.764	1.246	1.282	1.529	2.107						
		Skewness			-1.207	-0.931	-0.890	-1.303	-0.783	-0.185						
		Kurtosis			1.383	0.246	0.915	2.601	0.496	-1.117						
Validities		Cronbach's alpha			0.811	0.88	0.759	0.781	0.82	0.65						
		Composite reliability			0.987	0.995	0.984	0.998	0.99							
		CFI			0.997	0.999	0.988	0.977	0.988							
		RMSEA			0.044	0.027	0.058	0.076	0.072							

** p<0.01; * p<0.05

5. RESULTS

Our hypotheses were analyzed by means of OLS regression. As reported in Table 4, the results for the skewness and kurtosis tests indicate that the variables are distributed normally (i.e. almost all of them present values between the thresholds of -2.58 and 2.58 for both tests, except for cooperation kurtosis which was a little over 2.58 = 2.60) (Hair et al., 2009). Furthermore, we examined the plots of the partial regressions to evaluate both homoscedasticity and collinearity assumptions. Both requirements were satisfactorily met, confirming the adequate use of OLS regression to our analysis. Moreover, multicollinearity can be a potential problem for regression models with multiple independent variables (Hair et al., 2009). Therefore, we also submitted our model to a multicollinearity test, based on the variance inflator factor (VIF). The results indicate that our independent variables have a VIF < 3.5, i.e. multicollinearity should not be a problem in our OLS model.

Table 5 presents the results of the OLS regression analysis. We conducted our analyses in two hierarchical stages. In the first stage, we evaluated the impact of the control variables on the dependent variables[1]. In the second stage, we added the explanatory variables (GOVERNMENT, UNIVERSITY and PRIVATE) to the model and assessed their impact on the three innovation policy criteria (COOPERATION, KNOWLEDGE and LOCATION). We performed three independent regression models, one for each innovation policy criteria. The results showed that all three final models were statistically significant (F-value < 0.01). The final regression model for the dependent variable KNOWLEDGE (F-value = 62.69, p = 0.000) explains 43.3% of the variance, while the final regression model for LOCATION (F-value = 24.35, p = 0.000) accounts for 22.5% of the total variance, and COOPERATION (F-value = 39.70, p = 0.000) explains 32.4% of the total variance of this model.

[1] The first hierarchical stages were hidden in Table 5 to preserve the clarity of the several outputs, focusing only on the final stage.

Table 3 - Regression analysis results – The triple helix effect on sustainable innovation policies

Variables	COOPERATION	KNOWLEDGE	LOCATION
CONTROL_SUPPORT	.060*	-.008	-.028
CONTROL_SUPPLIERS	.015	.041	.077**
CONTROL_WAGE	-.032	-.010	-.0576
CONTROL_LABOR	-.013	-.045	.000
CONTROL_R&D INF	-.012	.083***	-.040
CONTROL_FUNDS	.077	.43***	.309***
GOVERNMENT	.148***	.204***	.051
PRIVATE	.293***	.211***	.270***
UNIVERSITY	.001	.147***	.026
F-value	39.70***	62.69***	24.35***
R^2	.333	.440	.234
Adj. R^2	.324	.433	.225
Change in R^2	.225***	.255***	.159***

[a] n =727. Coefficients reported are marginal effects; *p<0.1; **p < 0.05; ***p < 0.01;

For the first innovation policy criteria, COOPERATION, the final OLS regression model showed a positive and significant impact of two TH actors: GOVERNMENT (β = 0.148, p = 0.000) and PRIVATE (β = 0.293, p = 0.000). The results demonstrate that the presence and the active participation of both policymakers and companies in the private sector are crucial for the achievement of higher levels of cooperation activities for the development of RES, thus partially supporting hypothesis H1 (H1a and H1b, but not H1c). For the second innovation policy criterion, KNOWLEDGE, the results suggest that all TH actors have a positive and significant impact on this variable: GOVERNMENT (β = 0.204, p = 0.000), PRIVATE (β = 0.211, p = 0.000) and, UNIVERSITY (β= 0.147, p = 0.000), thus supporting hypothesis H2 (H2a, H2b and H2c). These results indicate that all TH actors are associated with a higher development and diffusion of specialized KNOWLEDGE for the progress and implementation of renewable energy systems. For the third innovation policy criteria, LOCATION, the final model showed a positive and significant impact for just one of the TH actors, PRIVATE (β= 0.270, p = 0.000). Our results suggest that the participation by the private sector leads to a stronger municipal characteristic for the local renewable energy. Hence, our model only partially supports hypothesis H3, since H3b was supported, but not the others.

6. DISCUSSION

Our general argument that the TH model contributes to the creation of an innovation policy for RES development is supported by our findings as all TH actors were statistically associated with at least one of the innovation policy criteria for RES development. Therefore, our results confirm the need for a TH model in RES development. Although we could not confirm that all actors are associated with each of the policy criteria studied, our findings are supported from the TH perspective. This support confirms that policymaking should be focused not on a single policy action, but on a combination (Guy et al., 2009; Nauwelaers et al., 2009). On the one hand, the three innovation policy criteria considered in our study should be combined in municipalities to support RES development (Frank et al., 2018), and the TH model supports such combination of policies. On the other hand, contrarily to what we hypothesized in our research design, we found only partial support for some of the hypotheses proposed in our conceptual research model (Figure 1). In this sense, our results call for the focusing of the TH actors' responsibility on specific innovation policy criteria as we discuss next.

Regarding the locational factors (LOCATION), our findings supported only one of the three hypotheses (H3b) associated with the private sector (PRIVATE). Frank et al. (2018) suggested that LOCATION might be an indirect innovation policy, creating conditions for RES development, but not affecting it directly. According to our results, the private sector should be able to create such conditions for locational factors. Locational factors comprise activities such as balancing and reduction of CO_2, reducing dependence on external energy suppliers, setting up incentives for potential energy investors and entrepreneurship activities, and fostering proximity to and coordination with national energy operators (Jorgensen, 2005; Reuter et al., 2012). Looking at these elements, we might expect to see a strong association of government actors with LOCATION rather than with the private sector. A possible explanation for this result is that the construct, GOVERNMENT, considers public actors at all levels and not just at the local level. Locational factors will mainly be influenced by local economic conditions where most of the public agencies only have an indirect effect. As Germany uses a decentralized policy to develop RES and the legislation guarantees autonomy at the municipal level (de Melo et al., 2016; Herbes et al., 2017), this may affect our results. In an open energy market, the private sector also plays a key role in the economic development (Sheng, Shi, and Zhang, 2013). In this sense, creating investment opportunities and entrepreneurship activities towards RES would be dependent on market attractiveness for private investments (Bürer, and Wüstenhagen, 2009). Here, GOVERNMENT should serve as support for the establishment of the private sector that will, in return, create the locational factors. Such explanation of our results reinforces the idea that the TH model has a direct effect on RES and is also indirectly reinforcing mechanisms by way of the mutual support between the TH actors (Smith, and Bagchi-Sen, 2012). Our study only focused on the direct effects of the TH actors on RES policies, while the mutual support among the TH actors has been largely studied in prior works (Sarpong et al., 2017). Yet, we did not find statistical support for the effect of UNIVERSITY on locational factors. We had hypothesized that universities can create job opportunities and attract new companies focused on renewable energy, which may boost locational factors. However, the effect may, again, be an indirect effect of the universities on the private sector rather than a direct effect on locational factors. The contribution by knowledge-oriented institutions to the enhancement of private activity has been widely demonstrated in prior research (e.g. Perkmann et al., 2013). The combination of these findings with prior research about the contribution by universities to the private sector may suggest that the TH model should focus on a dynamic system of mutual support between the TH actors that may benefit the outcomes that PRIVATE has on locational factors.

Still, regarding UNIVERSITY, we were also expecting support for COOPERATION, but it was the only TH actor that was not associated with this policy criterion in a statistically significant manner. Prior research has highlighted the supporting role that universities may have in creating innovation ecosystems and regional innovation systems, and one of these potential supporting roles is to help with the cooperation activities because of the universities' neutral role in the market (Smith, and Bagchi-Sen, 2012). However, when we addressed the specificities of RES development, our findings suggest that this is not the case. The construct, COOPERATION, considers elements ranging from a reduction of resistance in society regarding renewable energy, to increased visibility of the community's activities and to the fostering of public-private cooperation (Bergek et al., 2008; Prognos, 2017).

Our data suggest that universities in German municipalities do not play this type of political role in the RES, contrary to what happens in other countries where the universities can become a neutral actor that helps to establish cooperation (Jenning, 2009). The solid democratic institutions and low corruption levels of the public-private relationship in the country of our sample may suggest that universities do not need to assume such a role, but can focus on their main goal, i.e. knowledge generation and transfer (Liu and Huang, 2018). However, for the creation of innovation policies focused on knowledge creation and transfer (KNOWLEDGE) in the RES, our findings show that all TH actors are directly associated. Universities may play a key role in the generation and transfer of knowledge about renewable energies (Jaber et al., 2017), while the private sector may play a key role in its application and replication (Lee, Chen, and Chen, 2015; Masini, and Menichetti, 2013) and the government a key role in its fixation of the RES through institutional agents (Cai, and Aoyama, 2018), as suggested in our hypotheses. In this sense, such results are aligned with the literature that confirms that knowledge is a key factor for the achievement of sustainable development in a TH model, since all its actors are related to this policy criteria (Carayannis, Barth, and Campbell, 2012)

Finally, it is worth highlighting the central role of the private sector (PRIVATE) as the only TH actor statistically relevant for all three innovation policy criteria. We investigated a developed economy, in which the private sector is the driving factor of the economy (Khennas, 2012). In such a context, private actors are not just wealth producers, but also contribute to the creation of knowledge, to the development of the regional infrastructure, and to the creation of synergistic effects among other actors (Leydesdorff, Park and Lengyel, 2014; Strand and Leydesdorff, 2013). In other words, private actors can take a lead in the RES development when they receive sufficient support by the other two TH actors (Benner, and Sandström, 2000), as our results suggest. For instance, in Germany, one of the relevant private initiatives is related to cooperatives (called renewable energy cooperatives – RECs) as one of the key drivers for the European energy transition (Capellán-pérez, Campos-celador, and Terés-zubiaga, 2018; Hentschel, Ketter, and Collins, 2018). These cooperatives have been paid considerable attention in recent years which is a result of Germany's feed-in-tariff – a government support program for this private activity (Capellán-pérez, Campos-celador, and Terés-zubiaga, 2018; Hentschel, Ketter, and Collins, 2018). This example shows a private activity as a driver and government support as an enabler. On the other hand, universities and research centers in Germany have been important partners in the private initiatives, supporting them with R&D activities as in the case of the Fraunhofer project with the private sector (De Melo, Jannuzzi, Bajay, 2016; Herbes et al., 2017)]. Both government and universities have been demonstrated to be important supporters of the private initiatives. Therefore, our results suggest the private sector as a driving actor while universities and government may play an be important role in supporting the private sector's activities within RES development.

7. CONCLUSIONS

As a main theoretical contribution of this paper, we provide empirical evidence of the relevance of the TH model in support of the development of RES at the municipal level. We also show that rather than treating the TH model as a single effect on RES development, each of the TH actors makes different contributions to the creation of innovation policy for RES. Furthermore, we show that the private sector performs an important role in the creation of all three types of innovation policy for RES, while the universities only seem to provide a contribution to policies related to knowledge generation and transfer. In this sense, our results help to create new hypotheses: In the context of economically developed countries such as Germany, universities tend to be restricted to their knowledge role and have less influence on economic policy mechanisms such as those related to cooperative private-public systems and locational factors. In this type of an economically developed context, the private sector is the driver of RES development. Moreover, our findings show that the government has an important role in the creation of knowledge and cooperation policies, but we could not find evidence of its contribution to locational factors. Government can support the regional economy, but the private sector is the key driver of RES development in the municipalities.

7.1. Practical implications

Policymakers can use our findings as a basis for their decisions on how to promote RES in local economies. The consolidation of the TH model in local economies has been shown in this paper to be a central element in the consolidation of policy criteria focused on RES development. Firstly, policymakers should thus focus their attention on the consolidation of the TH model rather than on the creation of the innovation policy criteria, since each of the actors will be an important promoter of the consolidation of effective innovation policy criteria for RES development. Secondly, policymakers may be representative of each of the three TH actors. Depending on which one they are representing, they will have to focus on specific types of innovation policy criteria, as suggested in our findings. While we only studied the TH actors' direct contribution to the creation of innovation policies for RES, we assumed nonetheless that the TH actors support each other. This means that policymakers should maintain their twofold focus areas, one on supporting the other complementary TH actors and another one on supporting the innovation policy criteria presented in our results.

7.2. Limitations and future research

Although we applied the classic TH model, there has been some progress on extensions of it where other actors are included, such as the civil society and the environment (Carayannis, Barth, and Campbell, 2012). A deployment and extension of their specific contribution might open new avenues of research. Moreover, we did not find any statistical significance for the effect of government and universities on some of the innovation policy criteria. Although we proposed possible explanations for this, it might be beneficial to test alternative hypotheses, e.g. considering government or universities as moderating variables in the relationship between the other TH actors and the innovation policy criteria rather than just considering their direct effects on policy as we did in this study. Thus, new studies may investigate more complex relationship mechanisms.

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3 ARTICLE 2 – SUSTAINABLE CONDITIONS FOR THE DEVELOPMENT OF RENEWABLE ENERGY SYSTEMS: A TRIPLE BOTTOM LINE PERSPECTIVE

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ABSTRACT

Studies on RES have increased in the recent decade, suggesting that RES can be an effective solution for sustainable development. However, the impact of municipal contextual conditions in the development of RES are still unclear. One of the literature gaps is the lack of understanding on whether the balanced development of economic, social, and environmental aspects of sustainability – the triple bottom line (TBL) perspective – can support RES policy. We conducted a quantitative analysis of 727 medium and large-sized German municipalities to comprehend whether municipalities should create contextual conditions around the TBL pillars with the aim of supporting RES policy. We applied a cluster analysis in order to establish patterns of adoption of RES supported by the TBL. Our results showed that advanced adopters of RES are more advanced in economic and environmental conditions of the TBL, while regions with less development of RES present a primary emphasis in social conditions. Our results also evidenced that R&D infrastructure and promotion of RES are the borderlines for all adopters' levels, showing their complexity of adoption in RES policy.

Keywords: Renewable energy systems; sustainability; triple bottom line; municipalities; energy policy.

1. INTRODUCTION

Concerns about climate change, loss of biodiversity, use of fossil fuels, and scarcity of natural resources are increasingly predominant in 21st century. These issues in parallel with socio-economic pressures (i.e., population growth, urbanization and pollution) are capturing attention of many scholars, who are encouraging the society to gradually move towards more sustainable development (Zhou, Yabar, Mizunoya, and Higano, 2016; Jones, Michelfelder, and Nair, 2017). Sustainable development aims at creating comprehensive solutions for processes and products, commercial and industrial businesses, buildings, and energy systems with focus on attending environmental and social needs (Cabezas et al., 2005). Sustainable development can be analysed from the 'triple bottom line (TBL)' perspective, which grounds sustainability on three main pillars: economic, social, and environmental aspects (Li, Wang, and Roskilly, 2017; Malik, Lenzen, and Geschke, 2016). Sustainability has a fundamental role for the development of local Renewable Energy Systems (RES) (Frank et al., 2018; Lerman et al., 2020) and, therefore, a TBL structure may help municipalities to foster the development of RES (Fenton et al., 2015; Scipioni et al., 2009).

Studies on RES have increased in the recent decade, suggesting that RES can be an effective solution for sustainable development (Frank et at., 2018; Kumar et al., 2017; Ayoub and Abdullah, 2012). Most of the studies are focused on energy planning, renewable energy industry, renewable energy strategies, and innovation policy criteria. Moreover, sustainable energy studies in municipalities are also increasing in literature due to the importance of green development in cities (Neves et al., 2018; Østergaard et al., 2010). For instance, concerns about what are the main renewable energy policy for municipal RES development (Frank et al., 2018), and how energy policy could support low-carbon energy transition (Kostevšek et al., 2016) are some of the avenues portrayed in the literature. So, understanding how RES policy might be a key aspect for RES development. However, the impact of municipal contextual conditions in the development of RES are still unclear. One of the literature gaps is the lack of understanding on whether the balanced development of economic, social, and environmental aspects of sustainability (i.e., the TBL perspective) support RES policy or not. In this sense, our paper addresses RES policy in municipalities using TBL perspective. So, this leads us to the following research question: *what are the necessary contextual conditions, considering the triple bottom line perspective, that are needed to support RES development at the local level?*

In order to answer our research question, we conducted a quantitative analysis of 727 medium and large-sized German municipalities. Our aim is to comprehend whether municipalities should create contextual conditions around the TBL pillars with the aim of supporting RES policy. Therefore, this analysis can help to understand how an effective sustainable approach for RES policy can be performed. For this, we hypothesize about the relationship of RES development the TBL. We applied a cluster analysis in order to establish patterns of adoption of RES supported by a sustainable condition of the region using the TBL perspective. Our results showed that advanced adopters of policy criteria for RES are more advanced in economic and environmental conditions of the TBL, while regions with less development of RES policy present a primary emphasis in social conditions. Still, high maturity municipalities presented a considerable focus on local knowledge, engaging their RES policies in-house R&D industries and presence of universities in the municipalities. Our results showed that advanced adopters are more advanced in innovation activities and adoption of renewable energy. Finally, our results evidenced that R&D infrastructure and promotion of RES are the borderlines for all adopters' levels showing their complexity of adoption in RES policy.

2. THEORETICAL BACKGROUND

2.1. Energy sustainability and renewable energy systems

According to WCED (1987), sustainability is usually defined as the intelligent and responsible use of resources to meet the needs of the present people without compromising the needs from future generations. Because of that, many countries are pursuing more efficient and effective environmental policies that can potentially minimize conflicting demands of economic growth, social awareness, and environmental impacts (Haque and Nltim, 2018). Thus, to understand and study sustainable development and its impacts, the triple bottom line (TBL) suggested by Elkington (1998) is widely utilized because it considers social, economic, and environmental pillars in organizations and municipalities (Amer-Allam, Münster, and Petrović, 2017). In fact, each TBL pillar has different impacts on organizations and society, affecting municipalities in different levels (Salvia et al., 2015). For instance, social pillar has as goal achieves acceptable level of social homogeneity, promoting a balanced access of resources (Sachs, 2008); while environmental pillar seeks to mitigate pollution, maintain the whole ecosystem stable and righteous, and optimize natural resources use (Lozano, 2013). In the case of economic pillar, it includes macro and microeconomic elements, studying economic feasibility in an organization or in a municipality (Sachs, 2008). So, all these pillars are the fundamental structure of any organization, group or municipality which aims sustainable development through TBL perspective. These pillars aligned with the support of new green technologies (e.g., solar, wind, and hydroelectric dams) are key roles to promote RES in municipalities (Jang, Lee, and Han, 2018).

To develop these new green technologies, municipalities had to create energy policies to boost innovation for renewable energy development. Therefore, when energy policy is aligned with regional needs, municipalities can create synergy through innovation ecosystems for RES development (Busch and McCormick, 2014). So, when energy policies are aligned to foster renewable energy technologies development, it could have several positive impacts on society such as the decrease of greenhouses gases levels, and energy supply for human needs in a sustainable way, offering a renewable, clean, and sustainable development in municipalities (Hussain, Arif, and Aslam, 2017). Still, Evans, Strezov, and Evans (2009) pointed out other benefits for municipalities such as the decrease on electricity cost and on water consumption too, and the improvement of energy efficiency and land use. Furthermore, energy supply needs synergy in energy policy, so it should consider a multicriteria analysis, including sustainability scenarios to achieve economic, environmental and social goals in municipalities (Kumar et al., 2017).

One of these goals is related to the provision of sustainable electricity, being a pursued goal in developed countries, such as Germany, one of the leading countries in RES which seeks for CO_2 free sustainable provision in its systems (Kern and Smith, 2008). In this sense, countries as Germany are attempting to create synergy in their energy policies for RES development to gain competitive advantage (Lund, 2007; Lund and Mathiesen, 2009). In contrast, the difficulty to establish a competitive environment using only sustainable energy (González, Gonçalves and Vasconcelos, 2017) hinders municipalities to became independent from fossil fuels (Østergaard et al., 2010), avoiding them to transform their energy matrix to a completely renewable system. Furthermore, to change the energy matrix, there is a huge worldwide concern about how clean energies will impact the environment. For instance, how wind farms will impact their surroundings (e.g., ecology ecosystem); and what are the main socio-economic issues from wind energy adoption. To overcame these issues, the government is a key player to foster sustainable business development with sustainable policies (Bocken, 2015). These sustainable policies aligned with the presence of local resources, such as natural, financial and human capital in the municipality, could enhance RES (Roth et al., 2008). Also, energy policies implementation to foster renewable energy projects affects considerably regional industries development, contributing in municipality growth (Thollander, Danestig, and Rohdin, 2007; Nilsson, and Mårtensson, 2003). So, these energy policies should be aligned with TBL pillars considering the municipality contextual conditions to achieve good results in RES policy development (Neves and Leal, 2010). Furthermore, RES is inserted on sustainability transition, because, to achieve a sustainable model, it is vital implementing actions in different visions and configurations: supply chain efficiency, green resources, sustainable mobility and sustainable electricity (Kern and Smith, 2008).

Then, since RES is a direct driver of sustainable growth, other elements such as local support, cooperative alliances and social contribution are fundamental too (Cancino et al., 2018). Finally, understand Germany context, one of the most developed countries around the world in the use of renewable energy is fundamental to study TBL pillars for RES policy.

2.2. Development of Renewable Energy System

Renewable energy systems development is related to innovation activities for renewable energy transition (Mascarenhas et al., 2010); to the adoption of renewable energies instead of non-renewable energy (Mallet 2007, Wustenhagen et al., 2007); to the presence of renewable energy promoters (Gerstberger, 2004); and to the presence of renewable energy companies (Mascarenhas et al., 2010). Regarding innovation activities, they are essential for RES development, because they could decrease green technologies prices, and increase their feasibility. Thus, innovation activities stimulate green economy (Conti et al., 2018). However, even though innovation activities are vital for RES development, the adoption of renewable energies plays also great on role on the RES transition, because if there is a cost-benefit technology, it should be implemented. In fact, the adoption of renewable energy is an important step for sustainable transition (Faninger, 2003). This adoption might be facilitated where energy promoters and energy companies are. Energy promoters act to promote renewable energy development, they could be different actors that allow RES development based on their development strategy (Lerman et al., 2020). Thus, energy promoters could support municipal renewable energy transition. Furthermore, the energy companies also play important role on this transition, because they need to expand their scope of work, introducing or expanding renewable energy matrix (Mascarenhas et al., 2010). Therefore, we propose the following hypothesis, considering four main variables (Table 2): (i) innovation activities; (ii) renewable energy adoption; (iii) renewable energy promoters; and (iv) renewable energy companies. These variables lead us to the following hypothesis:

H1: The advance of municipalities in the adoption of RES policy is associated to the degree of RES development

2.3. Triple bottom line and its aspects for RES policy

In this study, we propose that a strong presence of the TBL pillars at the local (municipal) level will be beneficial for RES policy (Van Der Schoor, and Scholtens, 2015). This means that TBL pillars are considered ways for achieving sustainable goals and for supporting RES transition (Neves and Leal, 2010). Each pillar can support different aspects of sustainable development. Although the literature relates sustainability with RES, it does not clarify what is the content of each of the TBL pillars that are associated to RES policy development. In other words, we aim to describe and explain what the elements of the TBL relevant for RES policy are. Next, we discuss each pillar and present the hypotheses that derives from these elements.

2.3.1. Economic aspects that support RES policy

The economic pillar is strongly important for energy technologies development, because it is devoted to make profits without compromising the environment. Considering as an example the wind power, previous studies have shown that both public and private funding are essential to develop wind technologies (Loiter and Norberg-bohm, 1999), and the same has been demonstrated for other renewable sources (Sovacool, 2013). Therefore, policy makers should may use some mechanisms (e.g., tax policy and public funding) to improve the development of clean energies (Loiter and Norberg-bohm, 1999). United Kingdom energy technologies, for instance, have been founded by government departments and agencies to promote communities' renewable energy projects (Walker, Devine-wright, Hunter, High, and Evans, 2010). However, it is not only the public funding an important investment to RES policy development, being proximity to suppliers, R&D infrastructure, and long-term regional economy important aspects for renewable energy transition. Taking energy policy development as example, organizations should pay attention where are the energy suppliers and where is the technology development, since part of the technology is not developed in household (Walker and Cass, 2007). Therefore, it should be coordinated to get suppliers closer from the municipalities due to the strategical advantages for regional RES policy development (De Marchi, 2012). Moreover, energy policy development affects R&D activities in organizations which are attempting more renewable energy matrixes to foster growth in municipalities (Bergek et al., 2008; Kalkbrenner and Roosen, 2016). Cavicchi et al. (2014) explained that growing expenditure in R&D sector and increasing R&D public expenditure are important elements for energy innovation, because new low-carbon technologies could be developed. Furthermore, making long-term economic growth more sustainable is crucial for all municipalities, because, when eco-municipalities are planned and built, different generations could be benefited from these changes, which could mitigate problems of economic stagnation and poverty (Islam, Munasinghe, and Clarke, 2003). Therefore, we organize economic pillar into four main variables: (i) public funding; (ii) proximity to suppliers; (iii) R&D infrastructure; and (iv) long-term regional economy; showed in Table 7 (Section 3.2). These variables lead us to the following hypothesis:

H2: The advance of municipalities in the adoption of RES policy is contextually associated to a strong presence of the economic pillar of triple-bottom line of sustainability.

2.3.2. Social aspects that support RES policy

The social pillar of the TBL refers to the mainly aspects of sustainable development which are related about how people will be affected and how people can boost this development. Renewable energy sources implementation contributes positively on employment creation (Omri, Chtorou and Bazin, 2015), income generation (Selfa, 2010), and energy access (Chirambo, 2016). When we analyse renewable energy context, for example, there might be also negative social impacts from each renewable energy technology: for photovoltaic, toxins and visual; for wind, bird strike, high noise level, and visual impact; for hydro, displacement, agricultural and river damage; for geothermal, seismic activity, odour, pollution and noise (Evans, Strezov, and Evans, 2009). Although these social impacts play relevant role on sustainable studies for RES policy development, social awareness is a key element of RES transitions and a fundamental one for social sustainability (Assefa and Frostell, 2007). Previous studies have shown how important is the development of RES through social perspective (Wüstenhagen, Wolsink, and Bürer, 2007; Stigka, Paravantis, and Mihalakakou, 2014; Mallet, 2007). On the other hand, in the beginning of policy programs to RES technology implementation, in many cases, social awareness is neglected (Wüstenhagen, R., Wolsink, M., and Bürer, 2007), leading to several difficulties in renewable energy promotion and development in the society. Therefore, many policy makers are focused on social aspects to boost their energy policy (Bronfman, Jiménez, Arévalo, and Cifuentes, 2012). However, to obtain public mass acceptance, government should proposes effective clean energy policies (Burguillo, 2008), that fosters green jobs development. In accordance to this, Yi (2013) study highlights how the influence of renewable energy mechanisms and local energy policies impact on green jobs development in the United States' metropolitan areas. Furthermore, society are interested in how renewable energy will impact in their quality of life, jobs and wage level. So, understanding how energy policies will affect employment on short-term, mid-term and long-term in municipalities are included as social awareness aspect in the TBL social pillar (Fankhaeser, Sehlleier, and Stern, 2008). For instance, some studies have implemented employment scenarios in Germany, and from 2010 to 2030, the employment will increase around 15% (Lehr, Nitsch, Kratzat, Lutz, and Edler, 2008). Then, it will increase job availability. Although there is no doubt that job availability and new green jobs are vital aspects for social pillar, we believe that safeguard existing jobs is a strong aspect too, because new functions could be added to existing jobs (Abegg, 2011). Consequently, these new job descriptions could increase wage level, whose importance in offering more capital for basic needs, and more investments on new green technologies for energy efficiency is essential for RES policy development (Prognos, 2010). To illustrate, employees' wage level correspond more than half value added in installed solar systems, showing how green jobs require qualified workforce (Heinbach, Aretz, Hirschl, Prahl, and Salecki, 2014). Therefore, considering how social sustainability are crucial for RES policy development, we propose the following hypothesis, considering five main variables (Table 7): (i) social awareness; (ii) wage level; (iii) job availability; (iv) safeguarding existing jobs; and (v) new green jobs. These variables lead us to the following hypothesis:

H3: The advance of municipalities in the adoption of RES policy is contextually associated to a strong presence of the social pillar of triple-bottom line of sustainability.

2.3.3. Environmental aspects that support RES policy

The environmental pillar of the TBL is related to waste management, pollution reduction and energy management (Gimenez, Sierra, and Rodon, 2012). There are different environmental aspects that support RES policy development in municipalities, one of them is the promotion of RES, but it should be aligned with sustainable development. Sustainable goals are key indicators in municipalities growth, especially in municipalities that focus on renewable energy transition (Busch and McCormick, 2014). Despite there are different mechanisms to promote renewable energy systems, in Germany context, for example, the renewable energy supply system uses intermittent sources (e.g., solar and wind) and its energy matrix includes a backup energy system, which uses some fossil sources (Frondel, Ritter, Schmidt, and Vance, 2010). In fact, to promote a RES it is fundamental to understand how it could integrate some important aspects, such as regional space and landscape planning (Prados, 2010). Sometimes the region is adequate to install renewable energy plant, but it is not available, because it is a natural conservation area (Zerta, Schmidt, Stiller, and Landinger, 2008). Thus, natural conditions could allow or jeopardize an installation of renewable energy activities. When new renewable energy supply is being developed, an extent analysis where the energy is not accessed should be done (Akella, Saini, and Sharma, 2009) to understand what natural conditions will be faced and how renewable energy plant could affect the landscape. For instance, sometimes a new renewable energy plant does not cause an environmental impact, but a visual impact (Akella et al., 2009). Even though abundance of natural resources could become innovation opportunities (Cavicchi et al., 2014), there are some negative aspects of renewable energy sources implementation as: modification of the surface from watercourse or difficulty to find large areas to stablish wind farms without impacting the soil use and the natural ecosystem. These modifications are mostly influenced by two main types of RES installations: centralized and decentralized (Yaqoot, Diwa, and Kandpal, 2016; Tsoutsos, Frantzeskaki and Gekas, 2005). To illustrate, the future of renewable energy in some countries is the small decentralized solar photovoltaic installations that could be installed on rooftops (Faninger, 2003), while others create centralized big solar photovoltaic parks, as the case of Pavagada Solar Park in India (Sharma, 2011). Consequently, considering different aspects for implementing renewable energy matrix, we develop the following hypothesis, including four main environmental variables, as summarized in Table 7: (i) promotion of RES; (ii) influence of landscape; (iii) renewable energy central installation; and (iv) natural conditions. Based on this, our hypothesis is:

H4: The advance of municipalities in the adoption of RES policy is contextually associated to a strong presence of the environmental pillar of triple-bottom line of sustainability.

3. RESEARCH METHOD

3.1. Sampling

We conducted a large-scale online survey in German municipalities. We chose Germany's municipalities as a model of sustainable RES policy development, since the path to the development of renewable energy in Germany has proved to be burdensome, and Germany pioneers and exemplary law push other countries to develop new energy policies and sustainable development scenarios (Bechberger and Reiche, 2004). According to the Association of German Cities, there are 11,300 municipalities whose local public administrates (Deutscher Städtetag, 2012). Our sampling selection was based on municipalities that are able to support innovation activities towards renewable energy. In other words, we selected medium and large-sized German municipalities (more than 1,000 inhabitants) (Rösler, Langel, and Schormüller, 2013), totalizing 2,100 municipalities to which our questionnaire was sent. The questionnaire was addressed to the German municipalities' representatives for urban and/or regional development. To complement the online survey, we have collected some data through phone calls to shed light of some innovation concepts. After all these procedures, we obtained 727 useful questionnaires, which correspond to a 34.6% answer rate from our questionnaires. We used as useful questionnaires, the ones which had a fill equal to or greater than 50% of the total amount of questions. Table 6 shows the demographic distribution of the useful sample.

Table 4 - Demographic distribution of useful answers from German municipalities

Sample categories	Classification	Number of municipalities	Percentage of municipalities
Distribution by size (number of inhabitants)	≤2,500	136	19%
	2,500 to 4,999	150	21%
	5,000 to 9,999	185	25%
	10,000 to 19,999	114	16%
	20,000 to 49,999	68	9%
	≥ 50,000	74	10%
Distribution by regions	East	149	20%
	North	124	17%
	South	314	43%
	West	141	19%
	Total (n)	**727**	

3.2. Variables definition

Before implementing the questionnaire, we conducted some qualitative interviews in order to validate our constructs and to shed light about some concepts related to innovation with some mayors, senior executives, and managers from municipal enterprises. The questionnaire main goal was to assess perceptions on renewable energy systems development in municipalities based on the German Climate Action Plan 2050. The German Climate Action Plan 2050 is a German initiative with the aim to provide electricity 100% supplied from renewable energies by 2050 (Nagl et al., 2011). So, questions related to RES policy and sustainable development were performed. For sustainability measurement, we based our variables on our hypotheses (sections 2.2.1, 2.2.2, 2.2.3), summarizing our economic, social and environmental pillars and its variables on Table 7. Following Frank et al. (2018) work, RES policy can be grouped into three main categories: cooperation activities, local knowledge, and municipal location factors, and renewable systems development could be grouped in four variables, as shown on Table 7. Cooperation activities considers energy policy whose focus is implementation of cooperative and integrative environment to support the renewable energy transition. This category includes some variables: public and private cooperation (Foxon et al., 2005; Martins, Cunha, and Cruz, 2011); cooperation of society (Gerstlberger, 2014); visibility in the community (Kern and Alber, 2008); social acceptance (Mallett, 2007; Wüstenhagen and Bilharz, 2006), and involvement of regional promoters (Gerstlberger, 2014). The generation of local knowledge compiles knowledge and previous experience with renewable energy projects (Østergaard et al., 2010), presence of internal R&D activities and universities on municipalities (Dooley, 1998; Trencher, Yarime, and Kharrazi, 2013), and development of environmental knowledge (Angelis-dimakis et al., 2011), because knowledge is a key factor for RES development. The municipal locations construct plays a great role as RES policy, because it is composed by some municipalities goals: balance and reduction of dioxide of carbon (Keijzers, 2000; Lund and Mathiesen, 2009), decrease the dependence of external suppliers (Lund and Mathiesen, 2009), incentive of potential investors and entrepreneurship activities (Bürer and Wüstenhagen, 2009), and fostering proximity with national operators (Jacobsson and Lauber, 2006). Following Frank et al. (2018), RES development was composed by four items: innovation activities for renewable energy transition; adoption of renewable energies instead of non-renewable energy; presence of renewable energy promoters; and presence of renewable energy companies. Additionally, to measure almost all variables, we used a seven-point Likert scale varying from 1 – Not important to 7- Extremely important. Thereby, the highest degree shows an advanced importance while the lowest refers to aspects not relevant. In addition, we used some Yes/No questions only for promotion of RES and public funding. We aimed to classify RES patterns in medium and large German municipalities to help us to achieve a better understanding about different profiles among municipalities.

Table 5 - Categories and variables (source: Adapted from Frank et al., 2018)

Triple Bottom Line categories	Variables	RES development categories	Variables
Economic Pillar	Public funding	**Policy for cooperation activities (COOPERATION)**	Public and private cooperation
	Proximity to suppliers		Cooperation of society
	R&D infrastructure		Visibility in the community
	Long-term regional economy		Social acceptance
			Involvement of regional promoters
Social Pillar	Social awareness	**Policy for local knowledge generation (KNOWLEDGE)**	Municipal knowledge on renewable energy projects
	Wage level		Previous experience in municipalities with renewable energy projects
	Job availability		Existence of internal R&D activities in local renewable energy companies
	Safeguarding of existing jobs		Existence of university in the region of the municipality
	New green jobs		Development of regional knowledge in the agricultural and forestry sectors
Environmental Pillar	Promotion of RES	**Policy to foster municipal locational factors (LOCATION)**	Balancing and reduction of CO_2
	Influence of Landscape		Reducing dependence on external energy suppliers
	Renewable energy central Installations		Incentive potential investors
	Natural conditions		Incentive entrepreneurship activities
			Fostering proximity and coordination with national operators
		Development of Renewable energy systems (DEVELOPMENT)	Innovation activities for renewable energy
			Adoption of renewable energies
			Presence of renewable energy promoters
			Presence of renewable energy companies

3.3. Data analysis

Firstly, we aimed to identify municipalities with different maturity levels in RES policy to find different RES development patterns. To identify these patterns with similar RES policy, we conducted a two-step cluster analysis. Following Marodin, Frank, Tortorella, and Saurin (2014) and Montoya, Massey, Hung, and Crisp (2009) previous works, the groups were clustered by their similarities of RES policy. First, we conducted a hierarchical cluster analysis to check the satisfactory number of groups for our sample. We used Ward's methodology with Euclidean distance measure to perform our hierarchical cluster analysis. Secondly, a non-hierarchical cluster analysis using K-means cluster algorithm was performed to refine our cluster solution and to define variables that discriminated our cluster. After, we defined our cluster composition, we conducted a demographic analysis. Our aim was to understand if the groups identified in the cluster analysis by similarities of RES policy were also associated to specific patterns of TBL, as previously expressed in our hypotheses: economic (H2), social (H3), environmental (H4) pillars, and RES development (H1). To analyze these groups, we used a Pearson's Chi-squared standardized measure of association to reject our null hypothesis that there is no association between variables.

4. RESULTS

We performed a hierarchical cluster analysis using the RES variables, and we built a dendrogram through our hierarchical cluster procedure[2] as shown in Figure 5. We used this first step procedure to determine the number of groups with high similarities between municipalities regarding RES policy development. As shown in the dendrogram, the sample can be divided in three clusters, which is a number that allows to analyse RES policy patterns and avoid a very high number of fragmented subgroups.

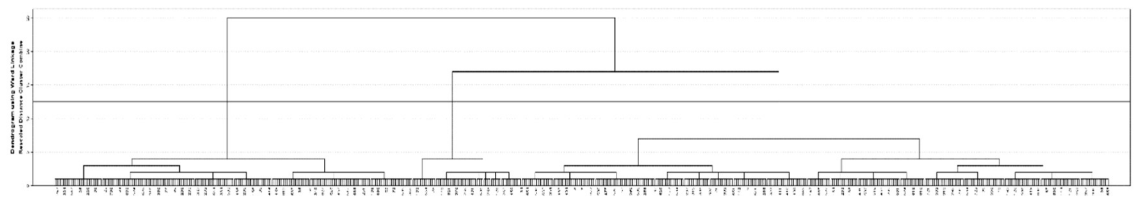

Figure 5 - Dendrogram for the selection of the number of clusters.

In the second step, we conducted the K-means analysis to refine the cluster memberships, using a pre-set number of $k = 3$ clusters obtained from the hierarchical analysis. We summarize these results in Table 8, showing the clusters' arrangement and the contribution from each RES variables presenting the maturity level of RES policy. When we analysed the K-means outputs, we observed that the cluster configuration is based on different levels of RES policy. The first cluster is characterized by the lowest

[2] We performed the cluster analysis using IBM SPSS® version 22 software platform.

means (between 1.033 and 3.55) of adoption of RES policy. The second cluster is characterized by the moderate level between the highest level (<=4.96) and the lowest level (>=2.85) in RES policy. Finally, the third cluster is characterized by the highest level of implementation of RES, in which RES policy are grouped by the highest means (>=4.65). From these results, we categorized into three groups: low adopters (Cluster 1), moderate adopters (Cluster 2) and advanced adopters (Cluster 3) of RES policy.

Table 6 - Cluster analysis and maturity level of RES policy

	RES policy	Cluster Mean + S.D.						F-value	Significant Pairwise
		Low maturity (N=89)		Medium maturity (N=328)		High maturity (N=310)			
Local knowledge	Municipality´s knowledge for renewable energy projects	2.06	±2.16	4.72	±1.21	5.91	±0.89	333.65	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
	Previous experience in the municipality with renewable energy projects	1.38	±1.67	4.02	±1.45	5.21	±1.12	284.08	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
	Existence of in-house R&D activities in local renewable energy firms	1.03	±1.43	3.02	±1.47	4.94	±1.26	330.36	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
	Existence of universities in the region of the municipality	1.26	±1.73	2.94	±1.70	5.22	±1.48	275.68	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
	Regional knowledge development in the agriculture and forestry sector	1.96	2.20	4.06	1.86	5.51	1.46	155.83	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
Cooperation activities	Public-private cooperation	2.11	±1.96	4.53	±1.44	5.56	±1.28	198.56	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
	Society cooperation	1.60	±1.77	3.76	±1.50	4.65	±1.45	142.06	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
	Community visibility	2.65	±2.27	4.96	±1.31	5.98	±0.91	223.06	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
	Society acceptance	3.12	±2.50	4.92	±1.59	5.71	±1.22	93.30	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
	Involvement of regional promoters	1.87	±1.87	4.18	±1.25	5.36	±1.24	245.41	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
Municipal location	CO_2 emission reduction	2.73	±2.05	4.43	±1.61	5.50	±1.35	115.44	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
	Energy dependency reduction	3.55	±2.23	4.80	±1.62	5.75	±1.27	74.95	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
	Incentives for energy investors	2.96	±2.13	4.54	±1.51	5.78	±1.15	144.21	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
	Incentives for renewable energy entrepreneurship	2.43	±2.02	4.08	±1.44	5.65	±1.06	221.92	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***
	Proximity with national energy operators	2.22	±1.90	4.07	±1.53	4.89	±1.36	109.31	[1,2]***[1,3]***[2,1]*** [2,3]***[3,1]***[3,2]***

To complement our analysis, we conducted a demographic analysis of the cluster composition, in which we associated the three clusters to the TBL pillars. We reported these results in Table 10. Our results are divided in three groups characterized as: economic, social, and environmental pillars of the TBL.

We conducted a demographic analysis of the cluster composition, in which we associated the three clusters to the level of RES development. Our results are reported in

Table 9. Considering RES development, we found that three of the four renewable energy development variables are adopted in Cluster 3 (advanced adopters of RES policy). Furthermore, it is observed that the presence of renewable energy companies did not show high levels of adoption in the three clusters, being the least accessible renewable energy development aspect for municipalities: low adopters (96%), moderate adopters (76%), and advanced adopters (55%). In contrast, the presence of renewable energy companies showed a slightly higher level of adoption in Cluster 3 (45%) when compared to the others, the lack of presence of renewable energy companies is still predominant in advanced adopters' group (55% of the municipalities. Innovation activities (56%), renewable energy adoption (61%), and renewable energy promoters (64%) showed a high level of adoption in the Cluster 3 (advanced adopters). Cluster 1 (low adopters) showed a low level of all renewable energy development: innovation activities (87%), renewable energy adoption (76%), renewable energy promoters (80%), and renewable energy companies (96%); while Cluster 2 (moderate adopters) showed a low level of adoption: innovation activities (65%); adoption of renewable energy development (52%); and presence of renewable energy companies (76%). Cluster 2 showed a high level of the presence of renewable energy promoters (52%).

Table 7 - Levels of adoption of Renewable energy systems development

			C1	C2	C3	
		Adoption	Low adopters	Moderate adopters	Advanced adopters	
		N	89	328	310	Pearson χ^2
Development of renewable energy systems (H1)	Innovation activities for renewable energy	Low	87%***	65%	44%	61.743***
		High	13%	35%	56%***	
	Adoption of renewable energies	Low	76%***	52%	39%	39.437***
		High	24%	48%	61%**	
	Presence of renewable energy promoters	Low	80%***	48%	36%	54.270***
		High	20%	52%	64%**	
	Presence of renewable energy companies	Low	96%***	76%**	55%***	66.772***
		High	4%	24%	45%	

Table 10 shows the results of the TBL according to the three clusters. Firstly, regarding economic pillar, we found three of the four economic variables are adopted in Cluster 3 (advanced adopters of RES policy). Moreover, it is possible to see that public funding did not show levels of adoption in the three clusters, being the least accessible economic aspect for municipalities: low adopters (90%), moderate adopters (81%), and advanced adopters (66%). However, public funding showed a slightly higher level of adoption in Cluster 3 (34%) when compared to the others, its lack of adoption of public funding is still predominant in advanced adopters' group (66% of the municipalities). Proximity to suppliers (71%), R&D infrastructure (63%) and long-term regional economy (96%) showed a high level of adoption in the Cluster 3. Cluster 1 showed a low level of adoption of Proximity to suppliers (72%), R&D infrastructure (76%) and long-term regional economy (52%); while Cluster 2 showed a low level of adoption of R&D infrastructure (76%), and a high level of adoption of Proximity to suppliers (58%), and long-term regional economy (68%).

Table 8 - Levels of adoption of Economic, Environmental and Social pillars

TBL pillars		Adoption	C1 Low adopters	C2 Moderate adopters	C3 Advanced adopters	Pearson χ^2
		N	89	328	310	
Economic (H2)	Public funding	No	90%	81%	66%	28.848***
		Yes	10%**	19%	34%***	
	Proximity to suppliers	Low	72%***	42%	29%	54.915***
		High	28%	58%	71%**	
	R&D Infrastructure	Low	76%***	55%	37%	49.222***
		High	24%	45%	63%***	
	Long-term regional economy planning	Low	52%***	32%	4%	58.660***
		High	48%	68%**	96%***	
Social (H3)	Social awareness	Low	66%***	37%	30%	38.388***
		High	34%	63%	70%	
	Wage level	Low	57%***	30%	26%	32.172***
		High	43%	70%	74%	
	Job availability	Low	52%***	23%	21%	36.450***
		High	48%	77%	79%	
	Safeguarding of existing jobs	Low	31%**	28%***	9%***	44.158***
		High	69%	72%	91%	
	New green jobs	Low	25%	28%***	8%	41.570***
		High	75%	72%	92%**	
Environmental (H4)	Promotion of RES	No	76%**	65%	46%	35.879**
		Yes	24%	35%	54%***	
	Influence of landscape	Low	52%***	21%	14%**	58.660***
		High	48%	79%	86%	
	Renewable energy central installations	Low	53%***	21%	18%	49.808***
		High	47%	79%**	82%***	
	Natural conditions	Low	38%**	28%	18%**	18.933***
		High	62%	72%	82%	

Secondly, considering social pillar for RES policy, our findings support H3, since the five social variables are most adopted in Cluster 3 (advanced adopters of RES policy). Indeed, social awareness (SA), wage level (WL), and labour availability (LA) moderate and advanced adopters showed a high level of adoption (SE: 63% and 70%; WL: 70% and 74%; LA: 77% and 79%, respectively). SA (66%), WL (57%), and LA (52%) showed a low level of adoption in Cluster 1 (low adopters of RES policy). Surprisingly, safeguarding existing jobs, and creating green new jobs showed a high adoption in all three clusters: low adopters (69% and 75%), moderate adopters (both are 72%), and advanced adopters (91% and 92%) respectively.

Regarding environmental pillar our findings support H4, since the four environmental variables are more adopted in Cluster 3 (advanced adopters of RES policy). All adoptions level showed high use of natural conditions for RES policy: low adopters (62%), moderate adopters (72%), and advanced adopters (82%). In fact, only advanced adopters showed a considerable amount of adoption level in promotion of RES (54%) while low and moderate adopters showed a low promotion of RES (76% and 65% respectively). Regarding influence of landscape (IL) and renewable energy central installations (RECL), moderate and advanced adopters showed a high adoption of both – IL (79% and 86%, respectively) and RECL (79% and 82%, respectively) - while low adopters showed a low adoption of both (52% and 53% respectively).

Our results show that advanced adopters showed high adoption on all TBL aspects (except for public funding, and promotion of RES). From this perspective, advanced adopters differentiated from low and moderate adopters, because low and moderate adopters subside their action on public-sector activities while advanced RES are focus on private sector, as shown by Lerman et al. (2020), because private sector is engaged on RES policy for energy development.

Another finding characteristic that stand out is that low adopters show TBL approach less developed in overall, reinforcing our hypotheses. On the other hand, social and environmental pillars are more developed than economic pillar. Furthermore, safeguarding existing jobs are high strategy priority for low adopters, which show that employments are priority on low adopters' municipalities. In this sense, low adopters concern focuses on safeguarding existing jobs more than moderate and high adopters, while high adopters focus on new green jobs. Finally, a third main general observed characteristics are homogenous elements between different adopters. No municipality relies primarily on public funding (low adopters 10%; moderate adopters 19%; and advanced adopters 34%), and all levels of adoption show high level of access of natural conditions. Therefore, our findings show that natural conditions might be not determinants for observed differences between municipalities.

5. DISCUSSION

We summarized our findings in the framework of Figure 6 to illustrate a general overview of TBL pillars, RES development and RES policy adoption patterns obtained in our results for German municipalities. We subdivided this framework in three parts: the first refers to the findings related to the maturity level of RES policy according to the results of Table 8; the second to the results from adoption levels of TBL pillars according to the results presented in Table 10; and the third to the results from adoption levels of RES developments presented on Table 9. We identified the clusters results highlighting the intensity level from the low adopters and low maturity level (light grey color) until high adopters and high maturity level (dark grey color). This framework can be compared to other prior studies from the literature, such as (Colak et al., 2015; Beccali, Cellura and Mistretta, 2003). The main difference between these studies and our findings is that they present different scenarios for energy projects, which support decision makers, while our results present a consolidate adoption level of TBL perspective, RES development and RES policy in municipalities for policymakers.

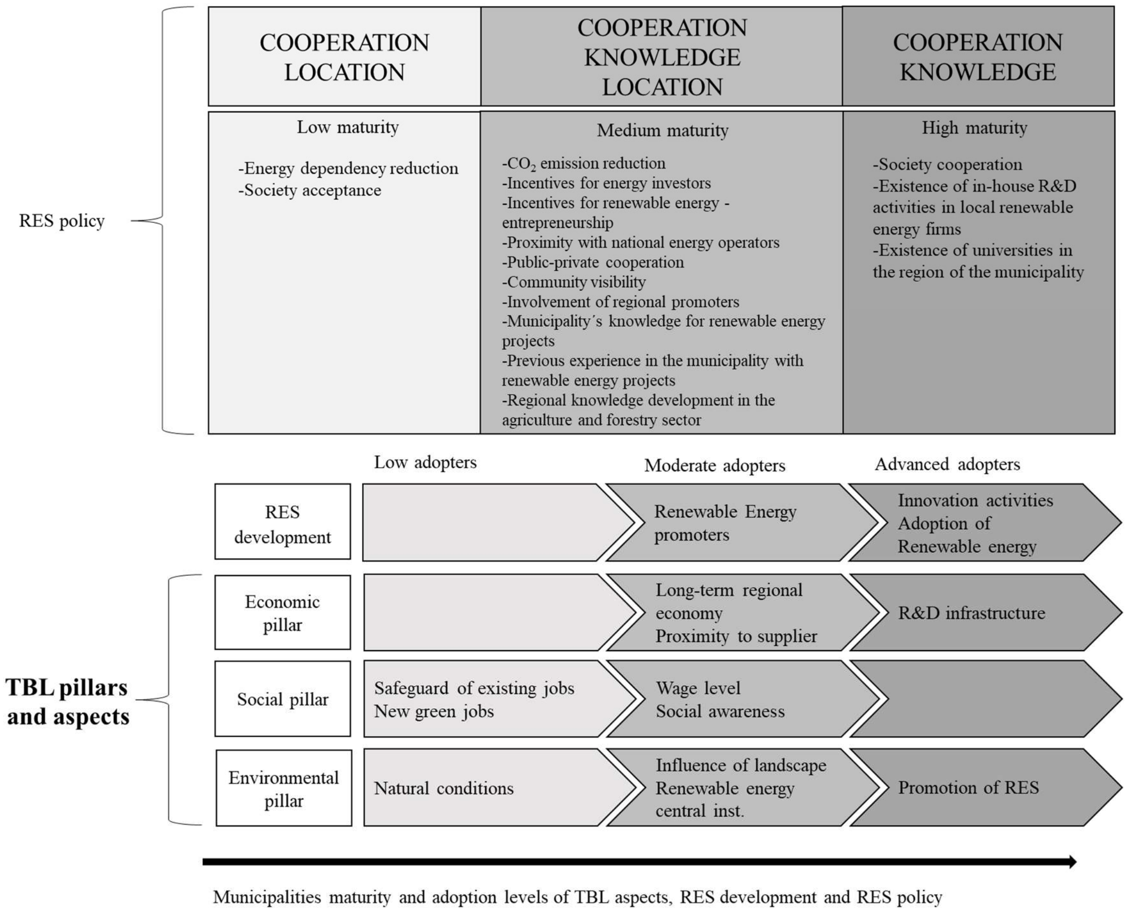

Figure 6 - Summary of the findings: municipality’s RES maturity and relationship with TBL pillars

Regarding RES policy maturity, municipalities with low maturity level tend to focus on two main points: reducing energy dependence and social acceptance. Therefore, they start focus on two main RES policy: creating a cooperative system (COOPERATION) and developing municipalities location factors (LOCATION). Then, on medium maturity level, they began to focus also on generation and transfer of knowledge, including municipality´s knowledge for renewable energy projects, and municipalities finish to focus on municipal location factors. In medium level, we could observe three RES policy: COOPERATION, KNOWLEDGE, and LOCATION; alongside with most of RES policy variables adopted. These results show that municipalities with medium maturity level in RES policy already have adopted most of RES policies in their management for RES development. In relation to high maturity adopters, they focus not only on cooperation activities (society cooperation) but also on local knowledge generation (to illustrate, in-house R&D industries and presence of universities in the municipalities). Knowledge is a key driver of renewable energy development (Conti et al., 2018); therefore, there might be some firms which invest on in-depth R&D on high maturity municipalities, developing new renewable energy technologies or process. However, different studies show the impact of public funding for R&D on firm-level low-carbon innovation (Bai et al., 2019; Sung, 2019), and our study, as aforementioned, showed that there is no public funding for all adopters. Also, regarding knowledge criterion, universities are not presented on all municipalities, so the presence of university could boost local knowledge for renewable energy transition. Although knowledge plays a great role on medium and high maturity levels, cooperation is presented on all maturity levels, because cooperation activities are crucial to reduce costs for green innovations (Unteutsch, and Lindenberger, 2016), and to get closer energy industries from other stakeholders (Amiri, and Weinberger, 2018).

Considering RES development (H1), we expected that advanced adopters' show high use of all variables analyzed (Frank et al., 2018). Surprisingly, our study presented that, to all adopters, there is a low presence of renewable energy companies. Therefore, the presence of energy companies on the municipalities may not be a key driver for renewable energy transition, energy companies might be close, but not on the municipalities. Only advanced adopters show a high implementation of innovation activities and adoption of renewable energies. We expected that adoption of renewable energy happens before, because cities and small municipalities have already adopted renewable energy matrix, as decentralized German Energy policy show (Oteman, Wiering, and Helderman, 2014). Furthermore, it is interested to analyze the relationship between presence of renewable energy promoters on moderate adopters and promotion of RES on advanced adopters on Environmental pillar. Therefore, promoters of RES are presented on moderate adopters, but they may not have integration mechanisms to join their actions. However, it makes sense, because, following the timeline, first, renewable energy promoters should be in the region, then they may also interact with energy stakeholders to promote RES, considering municipal context.

Regarding economic pillar (H2), we expected that advanced adopters' municipalities show high use of public funding and apply high investment in R&D infrastructure to promote RES, and low adopters began some economic initiatives for RES but only at moderate adopters level the municipalities began the development of some economic elements for renewable energy. Surprisingly, our study presented that, to all adopters, there is a low investment from public funding, and, only to advanced adopters, there is a high implementation of R&D infrastructure. Our results do not corroborate some previous studies, following Sen and Ganguly (2017, p.1175), "most of RE [renewable energy] technologies are available in the open public domain", and public funding plays a key role on municipalities renewable development (Lutz et al., 2017). When a municipality is more developed than others, it is expected that there is a public funding to increase their budget, and, consequently, increasement in investments on renewable energy sources (Martín-Barrera, Zamora-Ramírez, and González-González, 2016). However, German scenario is quite different, because they use a decentralized energy policy system with feed in tariff (FIT) (Nolden, 2013), so, they pay more for the generation from renewable energy sources. Therefore, this interesting model is being copied by other countries, because FIT policies play an important role to energy policies, for instance, by the end of 2018, 111 countries implemented FIT (IRENA, 2019). Instead of using public funding, there are several support mechanisms that could be used to promote renewable energy sources: fiscal incentives, FIT, and premium FIT (Prussi, Padella, Conton, Postma, and Lonza, 2019) because these instruments can boost development of clean technologies for energy industry, and subsidize corporate growth (Sen and Ganguly, 2017). Regarding social-economic pillar, we could understand that when there is a policy incentive, it boosts industrial development, and creates cascade reaction: jobs creation, labor availability, and increase of wage level.

Regarding social pillar (H3), our findings show that low adopters have already created a social incentive for RES development, they focused on safeguarding existing jobs and creating new green jobs. In 2018, renewable energy industry summed 11 million jobs worldwide (IRENA, 2019). So, job availability, safeguard existing jobs and new green jobs are essential social aspects for renewable energy transition. On the other hand, as Germany show an advanced energy policy, we expected that social awareness would be advanced to all adopters, because different studies (e.g., Batel, Devine-Wright, and Tangeland, 2013; Mallett, 2007; Stigka et al., 2014) have shown its high importance on renewable energy development. In addition, we can observe that low adopters should invest on developing a strategy to engage their population for understanding benefits from renewable energy sources. They could start with the perspective that renewable energy sources are creating new green jobs and safeguarding existing jobs for all adopters' levels, so people could keep their jobs, or have new ones related to green labor. Furthermore, policymakers could create incentives to show these new green jobs are related to low-carbon energy, having lower impacts on environment. Additionally, when a job is created in a remote area by renewable energy industry, its promotion also helps to deliver electricity, transport, or heat based on low-carbon energy to this area (IRENA, 2019). This leads in life quality improvement, and promotion of circular economy based on renewable resources in municipalities (Tu, Zhang, Zhou, Liu, and Fu, 2011).

Moreover, following environmental pillar (H4), even though all municipalities showed natural conditions to use renewable energy sources, only advanced adopters promote RES development in considerable levels (>50%). In contrast, all adopters should pay attention to the promotion of renewable energy sources, because according to German Climate Action Plan 2050, the country is changing its energy matrix to a renewable one in the following years (Wasserman, Reeg, and Nienhaus, 2015; Pegels and Lütkenhors, 2014). Additionally, these changes will impact in their laws and regulations, creating new environmental laws and regulations for the country in the next years (Lutz et al., 2017). Even though German Energy policy is a strong policy, seen as a model for countries seeking a transition to energy matrices based on RES, it could be also improved by including projects to promote renewable energy sources all over the country. In fact, as Germany uses a decentralized energy policy system (Beermann and Tews, 2017), and renewable energy cooperatives are scattered all over Europe (including in Germany) (Viardot, 2013), we expected that central installation will be low adopted for all level of adopters, but only low adopters showed a low adoption degree in this matter. In fact, central installation and influence of landscape show almost the same level of maturity for all adopters, so, maybe influence of landscape and natural conditions could impacts on how will be installed renewable energy industry. As stated by Sánchez-Lozano, García-Cascales, and Lamata, (2015), investors will evaluate urban land and protected and undeveloped lands, areas of high landscape value, watercourses, archeological sites, roads and railroad networks, areas of special protection, sea shores, and mountains to implant new power plants. For instance, regarding wind and solar large-scale energy industry, we believe that characteristics of each site will interfere on strategic decision, technical feasibility and commercial viability to where is going to be installed and operated wind and solar power plants (Roy, 2002; Turnery and Fthenakis, 2011). On the other hand, when we are analyzing biomass energy, it could be developed all over country, and, when solar energy is from micro-scale generation, it should be analyzed each case, because it depends on how much each family or company can invest, how much they spend on electricity or heating, how long it will take to return investment and if there is enough solar radiation to this payback. Therefore, these aspects will decide if it is feasible or not to install solar boards in houses or only in industrial sector.

6. CONCLUSIONS

We assessed the contribution of sustainable development of RES. Our study encompassed the three pillars of sustainable development: economic, social, and environmental and RES development, and identified distinct patterns of adoption of RES policy. We have done this using a quantitative survey from medium and large municipalities from Germany. Our results support our hypotheses that the more advanced the municipalities are in the adoption of RES policy for the development of RES, the stronger the presence of regional social and environmental pillars will be. Our findings show that municipalities with an advanced level of implementation of RES policy tend to boost economic and social pillars, mainly in relation to R&D infrastructure and RES promotion. In contrast, municipalities with a low level of adoption tend to focus on social and environmental pillars: safeguarding existing jobs, creating new green jobs, and analyzing municipal natural conditions. Furthermore, we showed that the environmental pillar performs an outstanding participation in all levels of adoption of RES policy while economic pillar only has begun on moderate adoption level. For that matter, our findings help to develop new hypotheses: considering the case of developed countries with strong economy, the more advanced the municipalities are in the adoption of RES policy for the development of RES, the stronger the presence of private funding for regional economic factors will be. Considering RES development, we showed that advanced adopters focus on innovation activities and adoption of renewable energies, while moderate adopters focus on presence of renewable energy promoters. Regarding RES policy, our study shows that (i) low maturity municipalities focus on cooperation activities and municipal location factor; (ii) moderate maturity municipalities focus on all RES policy studied: cooperation, knowledge, and location; (iii) high maturity municipalities focus on cooperation and knowledge. Therefore, cooperation activities are presented on three levels of maturity, while local knowledge generation is presented on moderate and high maturity, and municipal location factor is presented on low and moderate maturity levels.

6.1. Practical implications

Our findings can help policymakers that look for low-carbon energy matrix. We contributed towards the creation of a sustainable energy system. Policymakers could use our results to focus not only on the RES policy, but also on the sustainable development pillars that provide support for the renewable energy transitions. Our results show levels of implementation of several sustainability factors, and policymakers who are starting RES transition should develop social and environmental pillars before designing the new renewable energy policy. In contrast, municipalities should not focus only on the low adopters' levels, because economic pillar should begin with the other pillars. Therefore, they could anticipate some initiatives from moderate adopters to achieve renewable energy systems. As aforementioned, R&D infrastructure and promotion of RES are the borderlines considering their complexity of adoption of RES policy. In addition, the presence of renewable energy promoters is vital for RES promotion.

6.2. Limitations and future research

This research has some limitations that open opportunities for future research. Firstly, our study considers a transversal sample while a longitudinal one could contribute on understanding how evolution and co-evolution of TBL and RES work. Additionally, our approach is an exploratory study which we used a descriptive technique to evaluate contextual variables. Future researches could advance on statistical analysis which allow to estimate how much each TBL aspect contributes for RES development. Moreover, our study focuses on existence or on degree of existence from TBL on RES development, and associate both. However, our study does not focus when TBL is created and build. Future researches should focus on TBL consolidation mechanisms for RES. Finally, our study considers a sample from a well-known and developed country in sustainable energy creation. So, considering other contexts (e.g., other European or developing countries) not so engaged in this issue could help researchers to comprehend how TBL pillars and RES policies affects countries' RES development. Meanwhile, this study could support policymakers from these countries to engage their policies to promote RES development.

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4 ARTICLE 3 – CHALLENGES IN THE TRANSITION TOWARD RENEWABLE ENERGY IN EMERGING ECONOMIES: THE CASE OF BRAZIL

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ABSTRACT

Renewable energy transition has been considered as the new generation of solutions for reducing the high dependence on fossil fuels. However, there is a lack of understanding on the energy challenges that allows or not renewable energy development. Therefore, we aim to identify what are the main challenges energy policy must overcome to achieve a renewable energy system (RES) in emerging countries. Thus, based on five literature challenging factors, we identify the main challenges and propose actions to mitigate them toward the development of a RES. We conducted 27 semi-structured interviews with different triple helix stakeholder in Brazil. Our results show that Brazilian context is composed of twelve sub-challenges, for instance: lack of consolidated national industry, policy and program consolidation, innovation actor, environmental, and awareness activities. Also, the findings show a lot of opportunities regarding electric mobility, and industry 4.0.

Keywords: renewable energy; energy policy; emerging countries

1. INTRODUCTION

The development and diffusion of renewable energy technologies reduce the high dependence on fossil fuels (Vasseur, Kamp, and Negro, 2013). Everyone could benefit from the renewable energy transition, but the benefits are distributed differently according to socioeconomic aspects (IRENA, 2018). Indeed, renewable energy penetration has proven to be a success in different countries and is becoming a vital component in the energy matrix (Abdmouleh, Alammari and Gastli, 2015). Therefore, several countries, especially developed ones have increased their policies related to renewable energy (Negro et al, 2012; Mendonça et al., 2018). The German government, for example, developed a plan called "Energiewende" (energy transition) that aims to transition to a renewable energy-dominated energy portfolio (BMUB, 2016). For emerging economies, which rely on local energy sources, renewable energies are an attractive solution as they can reduce environmental concerns and keep fossil fuel import costs in line (Surie, 2017). For the unsustainable conditions of emerging countries in relation to global warming and rising fuel prices, the development of the renewable energy systems (RES) is being a solution to all expanding energy problems (Asif and Muneer, 2007). Moreover, many of these countries, especially the BRICS countries, have abundant natural resources, which would make possible a greater exploitation of these renewable energy sources.

Developed countries have been leaders in technological innovation in the renewable energy sector, however, in recent years, emerging countries have been accelerating their transition to renewable energies through the development of some innovation policies (Salim and Rafiq, 2012; Samant et al., 2019). Despite the focus on renewable energy innovation, emerging countries still face political and economic instability, which represent a challenge for innovation in general (Frank et al., 2016), including innovation in renewable energy (Mendonça et al., 2018; Samat et al., 2019). Emerging economies often lack stable institutions with clear goals and metrics that encourage these innovation efforts (Negro et al., 2012). According to Samant et al. (2019), the difficulties in properly positioning their innovations in the market leads to knowledge sharing failures, which discourages companies from investing in technology development. Thus, it is crucial to understand the dynamics of innovation in emerging countries, as companies face significant barriers and challenges to the development and implementation of innovation strategies, mainly related to innovation systems (Frank et al., 2016). Furthermore, RES need additional attention from policymakers and other actors of the innovation ecosystems, such as universities and the private sector, that have focused on driving and implementing successful energy systems (Mobjörk and Linnér, 2006; Ruppert -winkel, 2018). Policymakers must focus the political process on integrating combined policies and creating synergy and coherence (Rogge and Reichardt, 2016), concentrating not only on technology projects, but also on all systemic concerns and issues.

Considering the context presented, our research question is*: What are the energy challenges for the development of renewable energy systems in emerging countries?* Therefore, our objective is to identify what are the main challenges of energy policy that must be overcome in order to achieve a RES in emerging countries. We choose Brazil as the unit of analysis, taking into account that it is one of the largest emerging countries, a member of BRICS, the largest economy in Latin America and a leader in innovation in Latin America (Olavarrieta and Villena, 2014; Zeng et al., 2017). In addition, Brazil presents important energy structure and economic challenges (Santos, Weiss and Zimmermann, 2019). To achieve this objective, we conducted 27 semi-structured interviews comprising the different stakeholders involved in the development of innovation policies. We categorize our results into five main challenging factors for the development of RES and some proposals to mitigate some challenges. Our results can support policymakers' decisions regarding energy transition challenges, how they can overcome their problems and how they can increase their renewable energy matrix.

The remainder of this article is organized as follows. Section 2 presents the theoretical foundations of our study. Section 3 presents the research method employed. Section 4 contains the results and section 6 the discussions of our findings. Finally, the study conclusions, limitations and future research questions are presented.

2. THEORETICAL BACKGROUND

2.1. Renewable energy policy

The transition to RES is increasingly probable since solar and wind energy system costs have been decreasing while oil and gas prices have been floating (Akella, Saini, and Sharma, 2009). In fact, fossil fuels and renewable energy prices are going in opposite directions, and, as a consequence, economic and policy mechanisms are quickly evolving to support renewable energy systems dissemination (Akella et al., 2009). Therefore, some authors defend that policymakers should create an environment that strengthens scientific research and technological capabilities for RES development (Seyfang, and Smith, 2007). On the other hand, researches and policymakers are facing challenges restructuring sustainable RES (Kern and Smith, 2008), because of the global transition for renewable energy resources. Developing a policy mix goes beyond the combination of interacting instruments, but also includes a policy strategy, processes, and policy characteristics (Rogge and Reichardt, 2016), and policymakers should consider combining instruments with policy to achieve their renewable energy goal. Furthermore, to achieve green energy policy, policymakers should identify the adequate instruments according to demographic, geographic, political and economic characteristics (Mendonça et al., 2018).

2.2. Challenges to renewable energy transition

Although there is no doubt that energy policy could create the appropriate environment for renewable energy development, this is a challenging task. Thus, some authors apply tools to assess what are the main factors that could boost or not renewable energy transition. The tools usually used to evaluate are the SWOT matrix (strengthsweakness-opportunities-threats), and SCORE model (strength-challenges-opportunities-responses-effectiveness) (Njoh et al., 2019). Despite the use of these methodologies, it is hard to evaluate energy system impact, so studies usually address only one energy type. For instance, Irena reports show barriers from a different perspective to each energy. To wind energy sector, challenges are classified into four main categories: technological; economic and market; regulatory, policy and social; and environmental (IRENA, 2018). In addition, solar photovoltaic deployment challenges are grouped into technological; market and economy; policy; and regulatory, political and social (IRENA, 2019) .

Furthermore, there are distinct types of challenges for renewable energy development. (Ghimire and Kim, 2018)describe six types of barriers: social, policy and political, technical, economic, administrative, and geographic. For example, companies in the renewable energy segment face challenges related to governmental financing to the renewable energy transition. Bamati and Raoofi (2019) propose five challenges perspectives: Financial and economic factors; Regulatory and institutional factors; Technical, infrastructure and innovation factors; Social factors; Environmental factors. Although there are distinct typologies, studies bring specific technical challenges on energy transition and what technologies are available to overcome the challenges (Sinsel, Riemke, and Hoffmann, 2019). According to Sinsel, Riemke and Hoffmann (2019), regarding the technical perspective, challenges could be divided into four main categories: quality, flow, stability, and balance. In fact, the authors focus their study on the power sector.

Based on the categorizations presented, we based our categories on Bamati and Raoofi (2019), Ghimire and Kim (2018) and Painuly (2001) studies. Since we are working with a RES development, we focus on five categories:

- Financial and economic factors;
- Environmental and energy factors;
- Social and cultural factors;
- Technical, infrastructure and innovation factors;
- Regulatory, administrative, policy and political factors.

2.2.1. Financial and economic factors

Financial and economic factors are drivers to a sustainable energy matrix because they are enablers for its development. In fact, energy industry, which includes renewable energy, is a capital-intensive sector, and this high-level financial projects could influence on the economic viability of new energy industry, and rule out potential new competitors (Adhikari, Mithulananthan, Dutta, and Mathias, 2008). However, even though the need for high investment and high payback period could be barriers to entry on this market, there are other variables that influence renewable energy development: credit access, market size, subsidies/funds (Rezaee, Yousefi, and Hayati, 2019). To illustrate, if credit access to consumers are not available, market size would be reduced (Painuly, 2001). Therefore, government should create an environment in which private and public sectors and customers have access to low-cost capital. Additionally, subsidies and funds from the government could help renewable energy technologies gain competitiveness and efficiency (Painuly, 2001) because if private sector has more budget to invest, they will be able to develop more technologies. The low-carbon industry does not only need money, but also strong policies to achieve its whole potential (Przychodzen and Przychodzen, 2020). Njoh et al. (2019) point out the risk of monopolies in the generation and distribution of electricity, which decreases competition in the energy sector; therefore, there is no incentive to find alternative sources. Related to the previous point, policymakers face the challenge of substantial opposition from state-owned enterprises, which are still of relatively strong economic importance in many countries and generally have interests in fossil fuels (Przychodzen and Przychodzen, 2020).

2.2.2. Environmental and energy factors

Environmental aspects need to be assessed when implementing a new energy matrix because each matrix has its own carbon footprint. In addition, the energy matrix could impact differently on the environment: carbon dioxide pollution, noise and visual impact, and air quality issues. There is no doubt about global warming, and the fact that countries should follow the Kyoto Protocol to develop their renewable energy matrix aligned with sustainable energy development. Indeed, the crucial idea is to mitigate environmental impacts in order to develop a green energy scope. Furthermore, it is inevitable to measure carbon emissions, carbon emissions per capita, renewable energy production, and renewable consumption to understand how new energy sources are affecting socio-economic and environmental requirements (Hainoun, Omar, Almoustafa, Seif-Eldin, and Meslmani, 2014). Przychodzen and Przychodzen (2020) considered the reduction of national dependence on labour-intensive and high-emission industries and increase the role of high-tech and service sectors as a key factor for a successful energy transition. Also, it is crucial to assess cost analysis of greenhouse gases (GHG) mitigation, because it can optimize energy solutions (Hainoun, Omar, Almoustafa, Seif-Eldin, Meslmani, 2014). However, there is a lack of metrics and ways to measure these metrics, and a lack of targets to achieve.

2.2.3. Social and cultural factors

Although there is no doubt that social acceptance determines the success of renewable energy transition, understanding how it drives to low carbon energy system is crucial for policymakers and other stakeholders (Darmani, Arvidsson, Hidalgo, and Albors, 2014). FAlso, the importance of public awareness to boost low-carbon technologies has already been recognized (Surendra, Khanal, Shrestha, and Lamsal, 2011). In fact, people involvement in local committees and non-governmental organization (NOGs) are ways to increase social acceptance and to show how unfamiliar and new technologies can be used (Bamati and Raoofi, 2019). In developing countries now facing rising unemployment, adequate promotion of renewable energy can play a vital role as a potential job creation mechanism (Przychodzen and Przychodzen, 2020).

2.2.4. Technical, infrastructure and innovation factors

In terms of infrastructure, renewable energy sources differ from conventional sources of energy generation, which leads to challenges related to the absence of infrastructure or in some cases denied access to the use of current infrastructure (Sinsel et al., 2019). Renewable energy technologies find it difficult to innovate in the energy market dominated by fossil fuel technologies that benefit from economies of scale, long periods of technological learning and socio-institutional incorporation (Negro et al., 2012). Furthermore, the incompatibility of RETs with the large-scale centralized generation paradigm is an important technological challenge (Negro et al., 2012). Thus, the authors point to the necessity of development of standards, codes, and certifications that could guarantee a high quality of products and their acceptability. In fact, if there is no stamp on the product, quality, origin, and technical standards should not be so reliable, and it could increase the risk of the product not being accepted on the market. This is because technology specifications should be met (Darmani et al., 2014). Moreover, to achieve high technical specialization, skilled and training people are required, because, without them, ideas and solutions to innovate and to improve products and services might not be aligned with sustainable strategies. In addition, new green technologies could reduce prices and increase renewable energy penetration. Indeed, there is a modernization of the electricity system which includes information technologies, digitization and digital infrastructure. Since innovation presents an intrinsic risk and uncertainty, a mechanism could be developed to facilitate research and development.

2.2.5. Regulatory, policy and political factors

Several authors considered that clear policy targets for renewable energy generation at the national level are vital (Negro et al., 2012; Przychodzen and Przychodzen, 2020). Even though energy policy creates regulated mechanisms to support strategic decision-making process, it is not clear how the decision process is done, because sometimes there is divergence on political mindsets. Therefore, they are not able to align decisions, and renewable energy development could be not prioritized by instability between political leaders. Furthermore, public incentives are a way to boost low carbon technologies, but they should be supported by a coherent renewable energy policy. Therefore, technologies aligned with country strategies should be created. However, although public incentives play key roles in energy policy, the commitment of government and citizens should be encouraged by stakeholders. Negro et al. (2012) highlight that it is necessary to continually reflect on the effects of policies on innovation systems for renewable energy, due to the changing needs of the actors that make up this ecosystem. Therefore, it is imperative that policymakers listen and involve all actors in the formulation and implementation process, including small innovative companies.

3. METHOD

Since innovation policy development requires a variety of actors, based on the triple helix approach, we conducted interviews with actors from universities, private sector and government. Therefore, we could cover different perspectives from different stakeholders. In addition, we sought to cover interviews with triple helix actors from renewable energy types. Therefore, we conducted an empirical study to understand *what are the main energy policy challenges that should be overcame to achieve a RES in emerging countries*. Considering this objective, we adopt a qualitative approach as a research strategy, based on the collection and analysis of data from case studies (Yin, 2009). This research approach is useful for theoretical construction based on field analysis when researchers should understand how a certain phenomenon happens (Eisenhardt and Graebner, 2007; Yin, 2009).

3.1. Sampling and Research Design

We chose Brazil as a representative case of emerging country because the country is the leading economy in Latin America, standing out in sustainable development activities and renewable energy development (de Oliveira et al., 2016). Also, the Brazilian energy matrix and its energy policy are a single context, and it could generate new insights for renewable energy development. Studies on renewable energy policies in Brazil have as their main focus the historical development of policies, or the analysis of the implementation of specific projects and policies for some types of renewable energy (Mendonça et al., 2018; Pischke et al., 2019). These studies have mainly a theoretical and qualitative character. This may be because although there are different renewable energy development programs, quantitative data on the impact of these projects is difficult to access and often no records are found. In addition, none of these studies analyzes the role of different actors in the development of these policies

Our interview guideline was developed based on the literature on sustainable development, renewable energy, and triple helix, see appendix A. Our interview guideline asked about the five main challenging: financial and economic; environmental and energy; social and cultural; technical, infrastructure and innovation; and regulatory, policy and political factors, based on previous literature about challenging factors (Bamati and Raoofi (2019), Ghimire and Kim (2018) and Painuly (2001). To illustrate, regarding financial, we asked if the interviewees received public or private funds and investments. Regarding environmental and social, we asked if there is a relationship between policies and sustainable development (economic, environmental and social growth). Regarding technical, we asked if the interviewees perceived innovation process upgrades. Regarding regulatory, we asked about energy policy and renewable energy policy. Additionally, to improve our research, we conducted a pilot study with some respondents and refined our first interview guideline. Thus, the first few interviews of the research were extremely important for the interview guideline.

3.2. Data Collection

We selected interviews through theoretical sampling. According to Eisenhardt and Graebner (2007), theoretical sampling means the cases are selected because they are suitable to comprehend relationships between constructs. We selected interviewees from a public university, private university, public sector, private sector, holdings and government, which are involved in energy, innovation, and sustainable projects.

To collect qualitative data, we used in-depth and semi-structured interviews (Legard et al., 2003; Johnson, 2002). During the interview, the audio was recorded, and the participants took notes to register some impressions. Interviews were conducted in Portuguese. Later, the results were translated into English. Interviews lasted 35 minutes, in avergae. Some interviews were conducted in person, others by videoconference (Skype and Whereby), and others by phone calls. Data collection occurred from July 2019 to October 2019.

In order to validate the information, we consulted other multiple sources of evidence as secondary data, such as YouTube, reports, websites (Voss et al., 2010). The Brazilian Electricity Regulatory Agency (ANEEL) provide some documental sources, we used these sources for understanding of the interviewees context and market relationship. Therefore, we could contrast different data sources. We add links on our analysis: some interviews recommended some support materials, readings and videos. Thus, we could understand what the context of the competition was, the actors who participated, its objectives, and results achieved. When it was possible, we visited research labs, government institutions, and companies. We visited research labs from public and private universities, and we made a technical visit on public companies. Additionally, we collected data from ANEEL observatory, FINEP, and city council.

Regarding evidence review and validation, evidences were validated by a fellow researcher that was not part of interviews, as a means to avoid bias and misinterpretations.

Table 11 depicts interviewees' characteristics, as aforementioned, we interviewed different actors from academia-industry-government. Therefore, we could scatter our perspective. We looked for renowned public and private research centers, and universities. Government actors who implemented green technologies participated in legislative debates for sustainable development and pursued enough knowledge about innovation. We interviewed holdings, which worked with a wide range of renewable energy issues, and startups that highlighted on international notices.

Table 9 - Overview of the interviewees

Group	Stakeholder	Role
Private sector	Biomass energy consulting	Co-founder
	Holding - power distribution, generation, transmission and renewable energy	Innovation manager
	Holding - power generation, transmission and renewable energy	Technological development and innovation manager
	Private sector	Editor
	Renewable energy power generation project	Chief Executive officer
	Renewable energy startup	Chief Executive officer
	Solar engineering and education enterprise	Chief Executive officer
	Solar enterprise	Engineer
	Solar installation enterprise	Sales
	Venture building	Chief Marketing Officer
	Developers of large centralized renewable energy projects	Chief Executive officer
Public sector and government	Hydroelectric power plant	Engineering intern
	Legislative	City councilor - resilience and climate change
	Ministry of Foreign Affairs	Diplomat
	Power distributor	Head of Department of Technological Studies and Development
	Public company	Planning analyst
	Public university	Engineer
	Agro-energy public enterprise	Head of technology transfer
University	Private university	Professor, researcher and research group leader - solar and wind energy
	Private university	Professor, researcher and research group leader -renewable energy and energy efficiency
	Private university	Professor, researcher and research group leader
	Public university	Professor, researcher and research group leader
	Public university	Professor and researcher
	Public university	Energy policy researcher
	Public university	Professor, researcher and research group leader -smart grid and electric power systems
	Public university	Professor, researcher and research group leader - technology for wind turbines
	Public university	Professor, researcher and research group leader - bioenergy and energy planning

3.3. Data Analysis

Our analysis was conducted by two authors independently. We followed the methodology process proposed by Mayring (2000) for deductive research application. The first step of this model was defined following our research question. The second phase is the category' theoretical base formulation, where we define the coding rules for each category and organize the data according to these definitions. After, we reviewed the categories and coding agenda to ensure data reliability. Finally, we passed to do the interpretation of our results. Following these phases, firstly, we transcribed our interviews. Later, we created a document where we pointed out: innovation and energy policies; and key interview points. Then, we categorized our data into three main aspects: listing challenges and highlighting actions to mitigate. Then, we clustered the most cited challenges on five challenging factors. So, we added new categories on challenging factors (for example, regarding technical, we grouped on industry 4.0; electric mobility, and innovation actors) and variables which could form constructs of categories. Then, our categorization was reviewed by a third author.

We conducted internal validity when we decided to use challenging factors literature to compare and categorize our findings. We classified the challenges identified in the interviews into the five categories covered in the previous theoretical background session: Financial and economic factors, Environmental and energy factors; Social and cultural factors; Technical, infrastructure and innovation factor and Regulatory, administrative, policy and political factors. Therefore, we used these five challenging factors to support our findings on (i) challenges for renewable energy policy implementation and (ii) propositions to mitigate these challenges. Furthermore, we separated (iii) renewable energy policies, programs, and plans in Brazil. Therefore, we organized the data collection by (i) challenges for renewable energy policy implementation, (ii) propositions to mitigate challenges, and (iii) renewable energy policies, programs, and plans in Brazil.

4. Results

4.1 Challenging factors

- Financial and economic factors;

Regarding the Financial and economic dimension, we identified the main challenges related to the *consolidated national industry, market economic situation and Investments, funding, and credit lines.* Interviewees pointed out that the Brazilian industry is not so competitive compared with international industries, because Brazil is a technology buyer, not a technology provider. This finding indicates a lack of a **consolidated national industry,** regarding the development of RE technologies. One of the private sector representatives pointed out "*the fact of Brazil not having a semiconductor industry, does not have a strong solar industry, it is also a big loss for the economy, these aspects could be better explored."* For instance, international companies do not invest in R&D in Brazil, they invest in their foreign headquarters. Consequently, renewable energy technologies are imported as black-box technologies, because there are greater international players in the market. Therefore, it is important to measure the percentual of imported and national technologies. Furthermore, some foreign technologies are more cost-efficient than Brazilian technologies. To illustrate, an interviewee highlighted that a university lab is trying to improve wind turbine blades with national supplies, when they use international supplies, requirements are achieved, but when they use national supplies, they do not achieve the technical requirements. In fact, national supplies do not achieve quality requirements. Consequently, it shows the high dependence of imported technology. An interviewee pointed out possible reasons to the lack of technological development: lack of investments in R&D; lack of R&D in Brazil; lack of a high value adding industry. Interviewees also gave examples about the solar panels industry: what adds value is solar panel manufacturing, which includes the following steps: silicon beneficiation; cell and module manufacturing; ingots assembly. In contrast, the Brazilian industry focuses on silicon extraction and panel mounting which has little value added. As one interviewee from the academia representatives highlighted that energy policies could help creating an environment for the development of a higher value-added renewable energy industry. Thus, it is important to analyze the percentual of R&D invested in Brazil.

Brazilian industry should develop internal green technologies and reduce external technology dependence to **consolidate national industry**. As one interviewee from the academia representatives highlighted *"enough to buy black box technology, we need to develop our own solutions, and we are capable."* Another idea is approximate research institutes to the private sector. One public sector representative affirmed, "*a* *clear policy that encourages, favours the development of innovative research in this segment [Bioenergy] and an ever-closer approach largest public science and technology institution with agents in the productive segment".* Additionally, interviewees pointed out that they are always seeking to get closer to the private sector. As other private sector interviewee mentioned: "*we try to get closer to these companies that have more advanced technology to constantly have a more innovative product".*

Interviewees pointed out private sector are always trying to invest in products and services that meet market needs. However, to sell products, the industry needs a favourable environment, thus, market dynamism should be presented. In contrast, interviewees mentioned Brazilian crisis, then they are not investing in new industry. Therefore, there might be related to ***crisis and market.*** In fact, interviewees also mentioned Brazilian economic recovery, uncertain future, and search of new economic solutions. Therefore, companies tend to structure their corporate governance and trace their strategy. However, even though interviewees show a consensus that Brazil should develop a renewable energy industry, some industries are not competitive yet. An interviewee mentioned an example of a businessman that gave up on implanting a solar module factory in Brazil because it was not feasible to compete with the Chinese market. Furthermore, another interviewee mentioned that photovoltaic energy producers cannot sell their solar energy surplus. Therefore, some projects are undersized, and they should focus on energy waste management.

A lot of academic projects' goals are reducing costs. As illustrated by an academia representative: *"this project served and still is serving us today to try to lower the costs of wind power generators."* Therefore, a partnership with universities could reduce costs, as universities are developing new technologies with a reliable knowledge base. Indeed, public-private partnership projects are composed of four main components: technical competence, private sector problem, public resource and private resource. When the four components meet, public-private partnerships could be developed, and there is a high possibility to be successful, because cooperation activities could boost innovation. Additionally, it is vital to develop fare co-development contracts where public-private partnerships are benefited, because it could guide technology development. Indeed, contractual parties should clarify technology supply, knowledge, cooperation and intellectual property by contracts.

Regarding developing Brazilian green industry, interviewees highlighted that they are looking for a way to enable the green industry. Moreover, it is crucial to bring science and technology institutes closer to productive segments and to bring private sector closer to all stakeholders. In fact, it is essential to invest in research centres and to know how national technologies are positioned in the market. Brazil should invest more in R&D activities, research, patents intellectual property, and brands development.

Power and energy industries are sectors that demand high investment, however, according to interviewees there is a ***lack of financial resources*** to invest on new projects and to innovate, mainly for startups and small enterprises, as large companies are usually awarded with financial projects. For instance, if there is no public investment available, interviewers look for private and international investments. Interviewees also emphasized about the lack of financial resources, lack of credit lines, and tax incentives. They highlighted some specific points about startups because startups could access only limited public notice. Moreover, sometimes, there are no open call s for startups. So, they should find another way to have funding. Although there are incentives to free energy market for wind and photovoltaic parks, there is a lack of investment in bioenergy. Therefore, investments, funding and credit lines should be created not only for renewable energy technologies but for also innovation projects. Additionally, some interviewees highlighted that there are few tax incentives for RES development, as, according to them, some states stimulate better than others renewable energy transition. Thus, other states should use states with tax incentives as a benchmark to boost low-carbon technologies development, generating a return for society. Considering the elements of economic and financial factor, we introduce the three following propositions that result from our findings:

P1: Policymakers and other players should focus on developing green energy industry;

P2: Stakeholders should invest in public-private partnership projects for RES development. To that end the main criteria should be to attended: private sector problem, presence of technical competence, public and private budgets available;

P3: Investments, funding, and credit lines should be created for renewable energy and innovation projects.

- Environmental energy factors

In the Environmental and Energy dimension, challenges have been identified in relation to *environmental commitment* at different levels of governmental organization, as well as in *controlling the costs of energy wastes*. We bring another perspective based in an emerging country that presents more than half of power generation from the big hydroelectric matrix. Most RE programs in the country were developed at the federal level, in the case of the municipal levels, interviewees highlighted that **municipal climate change and municipal energy efficiency committees had** closed. One of the private sector representatives pointed out "*I was part of the municipal committee on climate change and energy efficiency [...], however the committee closed".* As a result, municipalities do not have a clear strategy for sustainable initiatives, and they do not develop **strategies for the climate agreement.** When this fact meets with **lack of green thinking and lack of knowledge for garbage separation**, countries and its policies should create mechanisms to promote environmental awareness in all spheres: the government on all levels and the citizen in all stages of life. Therefore, they should develop municipal climate change plans in order to focus on municipal sustainable growth.

Regarding industries, interviewees commented that there is a ***lack of control of energy waste***, so it leads to energy efficiency projects for reducing energy consumption. One of the academia representatives remarked: *"we experience a level of 40% to 50% of wasted energy".* Few people know about energy efficiency and management, but energy efficiency knowledge is vital because it could mitigate greenhouse gases, related to the Paris Agreement. When companies invest in energy efficiency, they focus on energy saving, but there is an environmental gain too. Energy efficiency projects are relatively complex, so they should be developed in partnerships with universities, private companies, and public companies.

Municipal climate change plans are crucial since they cover distinct aspects, in which renewable energy is included. In addition, although it is crucial to develop environmental conscious at the municipal level, bring climate and sustainable international conferences to Brazil is vital for Brazilian industry development. Thus, with such actions Brazilian industry would get closer from greater technology and identify future trends. One of the academia representatives stated, "*we organized annually an international conference on materials and processes for renewable energy.*" Therefore, it would help rethink how cities could be smart, green and sustainable. Salvador has already headquartered international sustainable conferences, and it is developing initiatives to become a sustainable city. Furthermore, to verify if a technology is sustainably attested, there are sustainability stamps under development. Therefore, consumers could be certificated of product quality, and citizens could choose better from where they are going to buy their products, and it is vital to understand the gap between stamps requested and granted because this metric could help identify how products could improve. Thus, based on the environmental and energy factor, we introduce the three following propositions:

P4: Municipalities should create municipal climate change plans that include renewable energy transition and sustainable development concerns.

P5: The use of sustainable stamps should be promoted to guarantee quality of low-carbon technologies;

P6: Increasing the number of meetings and conferences regarding sustainable development and renewable energy hosted in Brazil.

- The social and cultural factor;

About the Social and cultural dimension, our study shows that there is a lack of information and ways to measure this information, so actions and policies to inform and educate the population do not seem to be an important aim in stimulating the renewable deployment in Brazil yet, because people do not know **basic information** about power lines and energy systems. Although there are several technical reports, people are not warned about **metrics and targets** used by the sector. Therefore, it impacts on social acceptance for renewable energy development. In fact, the **lack of information and its dissemination** do not support energy initiatives. For instance, years ago electric energy distributor put the maximum time period for inactivity in bills. They took off this information from bills. One of the academia representatives pointed out: *"in the electricity bill, energy bill, in the lower-left corner, it was mandatory to inform the target of these indicators, the limits, how many times you could be without power."* Furthermore, many respondents commented on the **lack of indicators and monitoring**, highlighting that they send technical reports to the regulatory agency, but do not know how this is disclosed to society. However, there might be some metrics that could be used by companies: service availability that is available on companies' websites, but this information is not disseminated among citizens. Therefore, companies should reinforce their metrics and targets achieved and improve their ability to add value to their portfolio.

On the other hand, they should inform consumers to let them know what their rights and duties are. As mentioned by interviewees, Brazil is a new country, and the ***culture of education*** has not been developed yet. Therefore, Brazil should try ***collective initiatives*** to increase knowledge transfer and cooperation activities in order to develop renewable energy solutions, because there are several specific solutions that could be replicated and amplified to other places and improve collective thoughts. To illustrate, it is crucial to see which key metrics should be disseminated and measure its number of individual and collective actions per inhabitant per year. In fact, even though there is no doubt that organizations must evaluate their potential, it is also crucial to see that local initiatives are playing a great role and their actions are being replicated, as it improves collective thoughts and actions. As a result, such actions could help people understand what right and duties citizens have. So, based on a social and cultural factor, we introduce the three following propositions:

P7: Improve the dissemination of the energy metrics and targets, showing how energy is crucial for society;

P8: Develop social awareness about citizens' rights and duties, as it could support improving service quality and availability;

P9: Replicate great social initiatives to other locations and boost some collective low-carbon thoughts towards society.

- Technical, infrastructure and innovation factors;

In the Technical perspective, infrastructure and innovation dimension, we identify three principal categories of challenges related to: *electric mobility, Industry 4.0 technologies and innovation actors.* Our results showed that regarding to technological challenges there is interest and efforts to develop new technologies related to **electric mobility.** Interviewees also mentioned the use of new digital technologies applied to power generation and network monitoring, such as artificial intelligence tools, new technologies for human protection and advance software. Interviewees highlighted the importance of mobility substitution from fossil fuel to electric ones, which should come with new mobility models, including carsharing and mobility management apps. One of the private sector representatives remarked: "*This can be possible because some studies point out that the price of batteries are decreasing, while their capacity and life cycle are increasing*". For example, one interviewee of private sector analyzed electric car viability for a ride-sharing company, and although an electric car is more expensive than fossil fuel vehicle, this format is feasible for cars that run more than 11 hours a day. Additionally, there is a reduction in labour lawsuits for companies, because engine noise decreases. Interviewees stated that electric bus drivers suffer less from engine noise because they are quieter. Interviewees explained different ways to boost electric mobility. Initiatives for cooperation with national and international automobile manufacturers should be boosted. This cooperation could be seen in specific context: interviewees gave examples regarding developing electric cars only for the internal use, so they are not available for commercialization yet. Also, different stakeholders could cooperate for electric mobility development. For instance, projects with partnerships between the university and private sector are ways to boost for technologies development for electric mobility. To illustrate, interviewees mentioned three main actions to improve electric mobility partnerships with automobile manufactures, participation in public notices of cars with renewable energy (biodigester), and the participation on international events for electric cars.

The interviewees pointed out different aspects about ***Industry 4.0***. For example, distributors had difficult monitoring some stations, because they needed action in a/the locus. Nowadays, distributors are implementing a monitoring system, in which they have remote access to the station, and they are using Industry 4.0 technologies for remote network status monitoring. And, if the problem could not be solved remotely, distributors designated a team to solve. Consequently, they are developing solutions to assist human activities. Based on monitoring systems, they could collect data and use intelligence algorithms to understand unpredictable patterns, aligned to Industry 4.0 trend. In fact, some metrics could be developed to support this industry transition. For instance, private sector could measure the percentage of digitalized transmission lines; pattern recognition/artificial algorithms; work accidents. Furthermore, power transmission technology is quite old and analogue, so maintaining all power services working and modernizing transmission lines are crucial actions. Thus, interviewees highlighted that there has been a move toward digital transmission, however this is not complete yet. Consequently, energy distributors could scan transmission lines and, if there are fails, find them quickly and correct it. Furthermore, there is some initiative for using artificial intelligence and analytics at the energy and power sectors. One of holding representatives interviewed remarked: "*today they are going through a digitization process. This is an important milestone that companies in the electricity sector are going through, a transformation of transmission due to digitization, the concept of artificial intelligence, analytics".* Moreover, new technologies are being developed for human protection. For instance, machinery to cut tree branches to maintain power lines, decreasing human accidents with falls and electrocution. However, although the energy industry is a technology-intensive sector, the energy sector in Brazil is not a technology developer, but a technology integrator. Therefore, there is a high dependence on specialized software from large industries. Interviewees pointed out possible reasons to the lack of technological development: lack of investment in R&D; lack of research centres; lack of R&D in Brazil and lack of high added value industry.

The interviewees pointed out different aspects about **innovation actors**, there are three main highlights: lack of partnerships with startups, universities, private sector, and government; startups solve problems auctioned by companies, and startups and universities provide knowledge and solutions. Interviewees commented about the great importance of incubators and technology parks in universities in order to boost partnership, innovation and entrepreneurship because universities are known by their qualified knowledge and skilled professionals. However, interviewees do not see cooperation between universities and other players in areas other than incubators and technological parks. Therefore, it is crucial to understand how incubators and technological parks could influence on a certain region. However, first, it is vital to understand how much incubators and technology parks there are in universities. Second, it is necessary to verify if there are renewable energy startups on these places, and they auction problems to startups solve it. One of the academia representatives highlighted: *"companies are auctioning their problems so that startups offer solutions."* Additionally, interviewees remarked innovation hubs as a way to boost innovations, so it is important to know if energy hubs are being promoted because this environment could create a new partnership, in which these actors could develop new products and services. One of the private sector representatives pointed out: *"innovation hubs are also starting, mainly, when it comes to renewable energy generation, biomass".* Therefore, based on the innovation factor, we introduce the two following propositions:

P10: Innovation environment (innovation hubs and university incubators) should be created to get science and technology institutes closer to the productive segment;

P11: Develop renewable energy with industry 4.0 technologies projects: creating technologies and using monitoring systems that facilitate human activities, and using new algorithms that could help understand patterns;

- Regulatory, administrative, policy and political factors

Related with the Regulatory and policy dimension, the interviews highlighted the challenges concerning the consolidation of programs and policies, and clear and well-defined policies according to the technical knowledge of the RES and the real needs of the Brazilian market. In some cases, the existing **regulations** are rigid and even make technological development impossible. Often these projects require environmental licensing, which in the Brazil is a very bureaucratic and time-consuming process. In fact, there is a delay in municipal environmental licensing, in some cases of, at least, six months. Therefore, this legislation affects environmental licenses. If there is a large gap between granted and requested licenses, this may show that environmental licensing does not show clear requirements. Therefore, this metric is important for understanding what the key issues are. About legislation modification, some policies are reedited in 2019, bringing an international bias. ANEEL is changing its resolution for distributed generation, named Resolution 482. Periodically, there are changes in regulatory goals. One of the private sector representatives highlighted: "*We are going through a process of reformulation in ANEEL resolution 482".* The prior 482 goals were promoting decentralized solar energy in Brazil, now they are changing for centralized solar energy, and it is the first step for modernizing the electric sector. Therefore, respondents pointed out the need for greater clarity of RE regulations, but they commented that ANEEL public calls are vital to expand the view to the relevant aspects of renewable energy policy. Probably this lack of regulation clarity is related to a few technical knowledge and little approximation to the real needs of the RE Brazilian market by the policymakers. Some interviewees commented about bidding laws lead to plaster some renewable energy projects. To illustrate, a private sector representative mentioned: *"We have already tried some small partnerships with city hall, in general, we fall under a bidding regime".* Interviewees commented that they could not achieve the requirements, because they are a small company. Furthermore, there is a lack of well-defined legislation for startups, but it is a growing theme on federal and sector legislation. One of the private sector representatives affirmed: *"the startup theme itself is a theme that has been placed both in specific sector regulation and in federal public regulation."* Therefore, all laws should be clarified for renewable energy development, because stakeholders would understand better what main rules must be followed.

The interviewees highlighted some aspects of **policy and program consolidation:** lack of technical understanding in policy and in public notices development, lack of proximity between stakeholders and policymakers, lack of in-depth policy monitoring, and limited public notices. They explained that some policies and notices are designed without technical support, as illustrated by one of the academia representatives: "*we notice that the person who made the public notice does not have a very large experience of reality. Mainly in these installation projects, of equipment in the community, the tenders end up being very restrictive"*. Renewable energy development needs a strong collaboration between the different stakeholders in order to develop innovative policies aimed at the energy sector, they affirmed that cooperation needs to be boosted, as commented by one of the private sector representatives: *"I think that cooperation, interactions, only happen when stimulated, or happen much more if stimulated, I think that it is not something 100% natural for us to seek cooperation for innovation*". Interviewees also commented that they send reports showing their results, but they do not receive a report showing what main projects were and their results. Most of the interviewees stated that they do not know if there are reports, few others commented that there are only technical reports about microgeneration and carbon footprint, for instance. Therefore, they highlighted that in-depth policy monitoring is needed. Additionally, they commented the use of vertical orders, how it can be restrictive because participants need to develop a specific product with a defined budget. However, it is a way to optimize resources allocations for priority actions. Thus, policymakers should maintain an energy policy strategy to guide initiatives for RES developments. Consequently, based on regulatory and policy factor, we introduce the two following propositions:

P12: Regulations, policies and programs should be clarified, policymakers should make initiatives for clarifying society understanding about innovation and environmental concerns;

P13: When an energy policy is chosen, its strategy should be maintained.

4.2 Major policies, programs, and plans for renewable energy development

Interviewees pointed out the major policies, programs, and plans related to renewable energy development. The interviewees highlighted R&D ANEEL, in which power companies invest 1% of their revenues in research and development projects. All are coordinated and centralized by ANEEL, which later verifies if all energy innovation requisites are met, if not, enterprises do not receive the benefits. In fact, energy efficiency projects are nearly the same as in research and development projects. Even though R&D ANEEL is crucial to Brazilian energy development, Brazilian Enterprise for Industrial Research and Innovation (EMBRAPII) could also help this development. EMBRAPII creates mechanisms to approximate research centres and the private sector, since all projects must involve the industrial segment. Therefore, EMBRAPII could support industry development. However, there are some financial challenges, as one interviewee form the public sector representatives affirmed in the interview: *"these are financing lines that you put in, and often end up"*. Therefore, it is difficult to maintain long-term innovation projects.

The interviewees pointed out the need of financial support from different institutions, the most highlighted were Financier of Studies and Projects (FINEP), CAPES (which is an agency in the education ministry), Brazilian National Research Council (CNPq whose focus is scientific and technological development). Also, they brought other institutions, such as foundations and Secretary of Science and Education. However, they commented that there are fewer fiscal incentives to renewable energy innovation and there is a lack of funding to invest in renewable energy projects, mainly for startups. Thus, startups look for international investments and international partnerships. In the interviews, sector funds were also highlighted, since they are vital to integrate stakeholders and to fund the energy sector. Furthermore, there is other legislation related to sustainable development. For instance, Biodiversity Access Law, called by the interviewees as Benefit Sharing Law*,* in which any company that makes generic access to Brazilian biodiversity must share benefits, as pointed out by one of the private sector representatives. The same interviewee stated that "*Benefit Sharing Law is probably the best government policy to date". According to the interviewee* sometimes energy projects are part of major projects, such as climate change projects. Therefore, protects related to the environment and biodiversity should be prioritized on all projects.

Interviewees commented that some initiatives, such as the pro-alcohol and ReLuz Program, are vital for energy efficiency and renewable energy development. Pro-alcohol goal was to change the energy matrix from fossil fuel to renewable fuel, which comes from sugar cane. Later, the automobile industry invested in flex fuel cars, whose engine could work with gasoline and alcohol. Therefore, Pro-alcohol change car and energy industries. In addition, ReLuz implantation-national program was developed nationally to remove mercury vapour lamps from public lighting, because they presented high energy consumption, and could damage the environment as are made with a heavy metal. Therefore, ReLuz goal was energy efficiency on public lighting and decrease environmental impacts. A government representative added that *"It has saved the city 36% of its energy consumption in terms of street lighting."* Nowadays, there are initiatives to use LED lamps on public illumination systems. For instance, some municipalities changed their lamps on municipal buildings, traffic lights, and public lamps itself. As one of the government representatives highlighted "*in 2017, we approved the project that establishes that in the municipality of Porto Alegre in public buildings and roads the municipality priority is to use LED lamps."* LED lamps initiative is decreasing energy consumption, and they are developing public-private partnerships for boost this transition. Even though there is no doubt that energy efficiency must be prioritized, there are some places in Brazil with no access to power, thus, the "*Light for All Program*" (*Programa Luz para Todos)* was created, and universities developed mechanisms to deliver low-carbon energy to these localities. One of the academia representatives highlighted important aspects from Light for All Program *"we chose communities in the Amazon to put the project on, as long as the community did not have electrification"*

Regarding bioenergy, there are some policies, programs, and plans that were highlighted: National Biofuels Policy *(*RenovaBio*)* and national policies to encourage energy use of biogas and biomethane. RenovaBio is a new policy that remunerates some links of biofuel chain because they consider biofuel production positive externalities, and Renovabio is aligned with the new environmental era: bioproducts, bio-supplies, and bioeconomy. One of the public sector representatives highlighted that Renovabio *"creates a market that seeks to remunerate the biofuel chain in some links*." Then, it is crucial to encourage innovation and research to add value to national biodiversity and develop renewable products. Furthermore, to assess some requirements, similar to an eco-label, such as Brazilian Monetary carbon credits (CBIO), are created because they are a way to verify life cycle assessment and to promote biofuels market. As a result, biofuel energy efficiency is evaluated, and they can also measure dioxide carbon emissions. In fact, they highlighted the new wave of the circular economy demanding high biofuel participation, so investments in R&D are required. In contrast, although biogas national policy has been created, there is a lack of incentive of biogas in Brazil.

Financial and economic

Consolidation of national industry

- Lack of investment in R&D
- Black box technology importation
- Difficulty of competition between Brazilian and foreign industry
- Most cost-effective international products
- Great international players
- Difference in country maturity and resource allocation
- Lack of R&D areas in companies
- Lack of high added value industry
- Technology integrator
- High reliance on international products

Crisis and Market

- Meet market needs
- Favorable environment to sell
- Search for new economic solutions
- Withdrawal of implanting solar module factory
- Economic recession
- Withdrawal of implanting solar module factory
- Does not sell solar surplus
- Economic Recovery
- Energy project undersizing
- Lack of corporate governance
- Lack of market dynamism
- Uncertain future

Investments, funding, and credit lines

- Lack of financial resources
- High investment sector
- Private investment
- Lack of public investment
- Free energy market for wind and solar parks
- Lack of credit lines
- Lack of tax incentive

Regulatory and policy

Regulation

- Delay in enviromental licesing
- Changes in regulatory goal
- Biddin law - plaster
- Lack of clarity in legislation

Policy and program consolidation

- Lack of technical understanding in policy development and in the notices development
- Lack of proximity between stakeholders and policy makers
- Lack of in-depth policy monitoring
- Limited notices

Technical, infrastructure and innovation

Eletric Mobility

- Mobility substitution
- New apps to car sharing and mobility management
- New business model
- High demand on eletric energy
- Engine noise reduction
- Battery life and price

Industry 4.0

- Power monitoring system
- Energy demand system with linked batteries
- Transmission line scanning
- Operation improvements based on artificial intelligence
- Technology development for human protection
- Specialized software from large industries

Innovation actors

- Lack of partnerships with startups, universities, private sector and government
- Startup solves problem auctioned by companies
- Startups and universities provide knowledge and solutions
- Lack of research centres

Environmental and Energy

Environmental

- Lack of municipal climate change committees
- Lack of strategies for Climate agreement
- Lack of green thinking
- Lack of knowledge for garbage separation

Energy

- Lack of control of energy waste
- Lack of municipal energy efficiency committees

Social and cultural

Information and measurese dissemination

- Lack of metrics and targets
- Lack of information creation and dissemination
- Lack of energy indicators monitoring

Awareness activities

- Lack of culture of education
- Lack of collective initiatives

Figure 7 - Challenging factors for renewable development energy

5. DISCUSSION

Our results shed light on the main challenges for energy policy to develop RES in an emerging country like Brazil. The use of renewable energy in Brazil is responsible for almost half of total energy consumption (Pischke et al., 2019). Brazil is a rich country in natural resources, so its energy supply could come from different sources: solar, wind, and hydropower are important examples of renewable energy sources. The main Brazilian low-carbon energy is hydropower. Large hydroelectric plants cover 60.26% of power generation; and all hydroelectric plants cover 63.86% of potential installed, according to ANEEL. Thermoelectric energy, a non-renewable energy, covers 24.42% of energy generation in Brazil. Wind energy, according to information from ANEEL (2019), represents 9.11% of power generation, and photovoltaic power plants encompasses 1.42% of the installed potential in Brazil. Brazil has 8774 power generation plants and 167.686.622 installed potential. Therefore, historically, Brazil maintains a renewable energy matrix, and the country is taking initiatives for wind and solar energy besides hydropower. Thus, even though solar energy encompasses less than 2% of the installed potential, Brazil has many regions situated in the sun-drenched belt. Surprisingly, Brazilian less solar irradiation levels receive higher levels of the incidence of sunlight than many European countries (Martins et al., 2008). Therefore, there is economic growth and social development opportunities while there is solar energy development. Other emerging countries are trying to change their energy matrix from traditional to renewable energies too. For instance, such as Brazil, Indian geographic and weather conditions provide a great environment that leads to renewable energy development, and they are facing challenges towards renewable energy transition too (Luthra et al., 2015).

Nevertheless, our results show that the Brazilian energy system today is not prepared for all technologies and innovations placed on the market, which is why a modernization program for the energy sector was created, in which different changes and improvements are being made to prepare the Brazilian matrix for the renewable energy transition. Although private investments in R&D in Brazilian companies are not high, there are many opportunities in technical and innovation factors such as industry 4.0. In fact, the energy system is quite complex, and energy management can help to improve energy efficiency (Palensky, and Dietrich, 2011). Currently, with the development of Industry 4.0 technologies such as big data and data analytics, there are greater possibilities for creating smart energy systems (Zhou, Fu and Yang, 2016). In developed countries, Industry 4.0 could boost transparency of renewable energy system, then more data mining and predictive analysis could be running to understand how energy consumption and generation are interleafed (Scharl and Praktiknjo, 2019), authors added that industry 4.0 technologies could support flexible systems for renewable energy transition, and they highlighted that energy efficiency could be increased because service-oriented organizations will improve energy efficiency (Scharl and Praktiknjo, 2019).

Developing a strong new industry is vital for renewable energy transitions, but, to that end, long-term investments are necessary. Therefore, the creation of investments, financing and credit lines for renewable energy and innovation projects is essential to develop the energy sector. Our results show that Brazilian challenges are related to the lack of public investments in the renewable energy area. However, some studies show that there is high importance of different types of investments for renewable energy development. Canada, for instance, has developed energy technology innovation system, showing the high importance of government and private initiates for developing a low carbon energy system, trying to minimize knowledge asymmetry between stakeholders, through open and transparent data access. So, Canada could attract private investments (Jordaan et al., 2017). Even though private investors play a great role in the renewable energy transition, Canadian strategy encompasses different types of investments and renewable energy policy development (Jordaan et al., 2017). Our results show that there are initiatives to encourage international and private funding instead of public funding, however industries' R&D department do not invest in renewable energy matrix in emerging countries, focusing their R&D investments on their foreign headquarters. As some renewable energy research are trying to do in Brazil without success, Australia is also trying to nationalize some renewable energy technologies. Therefore, they created a strong regulation to boost its industrial development. Australian energy policy focuses developing new assets, less expensive than existent ones. Moreover, Australia had great success on developing solar energy assets, but they should rethink to increase the country's investment scope for different renewable energy technologies (Byrnes et al., 2013), in order to seek for diversification of their renewable energy matrix. Therefore, the country could develop a low-carbon economic growth.

Furthermore, contrary to developed countries, Brazil is still characterized by being an integrator of imported technologies and not a developer of technologies for RES.

The Brazilian renewable energy market, in general, is controlled by multinationals, as aforementioned. Although the government has endeavoured in recent years to promote the renewable energy market, mainly focusing on solar and wind energy, there are still difficulties related to financial resources. The government and private R&D incentives in the renewable energy sector are still modest and decreased in recent years with the economic crisis in the country. In this sense, Brazil should invest more in R&D, research, patent of intellectual property and brand development activities. Our results also show the relevance of partnership projects with universities and research centres to reduce costs. Additionally, it is crucial to understand how incubators and technology parks can influence certain regions. However, first, it is vital to understand the number of incubators and technology parks in universities. Second, it is necessary to check whether there are renewable energy startups in these locations. In addition, innovation hubs have been identified as a way to drive innovation; therefore, it is important to know if energy hubs are being promoted, as this environment can create new partnerships, in which new products and services could be developed.

The innovation system approach is a major step forward to developing renewable energy technologies because it requires a strong collaboration between different stakeholders in order to create renewable energy policies. The policy manifests itself in multi-stakeholder networks, creating sometimes formal hierarchies and, therefore, must be based on a comprehensive empirical understanding of local collaboration processes that enable investments in renewable energy projects (Moallemi et al., 2014; Newell et al., 2017). These networks can involve project developers, contractors, public authorities, teaching and research institutes, startups, non-governmental organizations, and, in the case of specific renewable energy projects, many of the relevant interactions occur at the local level (Newell et al. al., 2017). In addition, the innovation systems approach is particularly stimulating by University-Industry-Government bonds, and their knowledge transfer and cooperation activities, giving rise to the triple helix model (Etzkowitz and Leydesdorff, 2000; Etkowitz, 2017). Regarding the dissemination of renewable energy systems, studies have shown that the creation of a triple helix cooperation structure with a focus on collaborative innovation activities is an essential factor (Sato, 2017; Frank et al., 2018).

Furthermore, creating an innovation environment is not an easy task, according Negro et al. (2012) the differences in political needs are determined by the phase in which the innovation system is found, by specific problems related to technology, acquisition of financial resources, distance to the market, strength of the network, field of action. Therefore, innovation policymakers for RES need to develop adequate resources to analyze the specific circumstances of the renewable energy innovation system in Brazil. In addition, renewable energy innovation actors need be supported by energy policies and other incentives to boost their partnerships, as, according to Liu et al. (2019), fiscal instruments do not appear to be enough to promote the development of renewable energy. Political uncertainty is an important factor in relation to taxation; therefore, investors may have little or no confidence in policies that depend on public finances, as they are likely to be abruptly withdrawn due to management or financial crisis, when resources are limited (Liu et al., 2019). This is a factor that directly affects renewable energy policies in Brazil, as the policy changes at the federal level when presidential term changes. National plans are often discontinued that replace the previous management plan and replace employees of government agencies; in this case, many policies included in the final plan are terminated and new policies are implemented (Pischke et al., 2019). This sometimes makes it difficult or disables the continuation of renewable energy projects and limits private investment because of the high financial risks. In addition, countries could spend resources on producing numerous renewable energy policies, but without coordination between different levels of government or a joint effort to ensure that policy instruments are effective, these resources can be wasted (Pischke et al., 2019).

In this sense, our results also approach the municipality level, there is also no clear strategy for sustainable initiatives. Different case studies demonstrated that municipal plans at different government levels are crucial because it covers distinct aspects, in which renewable energy is included. Even though municipalities have some environmental legislative freedom, Brazilian municipalities struggle to create municipal renewable energy plans. In contrast, developed countries are creating municipal strategy energy planning for the renewable energy transition. Denmark is on the way to reach a 100% renewable energy system. Thus, Denmark developed strategic energy planning and integrated some key responsibilities to different levels, central level, and municipal level (Sperling, Hvelplund, and Mathiesen, 2011). Therefore, Denmark is developing strategic municipal plans, which includes different subjects: municipal heat plan; plan for the reduction of energy demand, and municipal electric vehicle charging infrastructure plan (Sperling, Hvelplund, and Mathiesen, 2011). Canada implemented a different plan, known as Community energy planning (Denis and Parker, 2009). On their community energy plan, they are prioritizing social awareness, and energy conservation and energy efficiency instead of renewable energy development (Denis and Parker, 2009). Altavilla Silentina, the Italian city, is developing strategies to depend only on renewable energy sources by 2030, they focused their actions on boosting energy efficiency; installing new technologies for electricity and heat production; and changing to more efficient public transportation (De Luca et al., 2018).

Regarding cities, there are few specific initiatives in Brazil, regarding smart and sustainable cities. On the other hand, several countries such as the United States, the European Union, Japan, South Korea, Singapore and China moving toward smart and sustainable city planning that supports sustainable and renewable projects: GI-REC (Global Initiative for Resource Efficient Cities) by the United Nations, European Innovation Partnership on Smart Cities and Communities (EIP-SCC) by the European Union and the Smart Cities Initiative by the United States (O'Dwyer et al., 2019). According to Liang et al. (2019), smart energy became a key area of smart cities. The number of verified smart city projects all over the world increased from 170 projects in 2013 to 235 in 2015, mainly covering key areas of smart energy, smart transportation, smart buildings, and smart government. Among the 235 existing smart city projects, 45% of the projects involve the energy sector (Liang et al., 2019).

To develop a sustainable city, social acceptance is crucial, and transparency information plays a key role in public awareness. For instance, there are some metrics that energy stakeholders could measure: energy service availability, and percentual of savings in the use of renewable energy. Both are available on stakeholders' websites, but this information is not disseminated among citizens. Therefore, companies should reinforce their metrics and targets achieved and improve their ability to add value to their portfolio. Furthermore, Fobissie (2019) considered other actions based on the study of the impact of environmental values and political ideology on public support for renewable energy policy in Ottawa, Canada, namely: more early education in schools to make citizens more familiar with renewable energy and its benefits in fighting climate change. Creating a higher level of awareness among individuals toward less polluting sources of energy may take time to produce good results but is necessary. The municipal government should do more on informing people about the different incentives that the policy has because some people do not know how they can benefit from these incentives and so tend to be resistant without a full understanding.

In summary, Brazil needs to take advantage of the natural resources that the country has, and the energy infrastructure created. For example, a large number of universities, the growth of startups, among other initiatives to work in the construction of innovation ecosystems, with the objective of developing consolidated industry for renewable energy technologies development. To do this, the country should support not only public funds but also creating a stable economic environment to attract private investments. In addition, data collection and periodic dissemination of results from renewable energy innovation projects should be formally established, so the population would have easy access to this information, and it could increase social acceptance of renewable energy sources. Moreover, more initiatives should be allocated to encourage other renewable energy sources, such as biomass, and solar energy.

6. CONCLUSIONS

Our study presented renewable energy challenges in an emerging country. Our results showed Brazilian energy system is facing a lot of challenges, but there is a lot of opportunities related to electric vehicles, industry 4.0, and new forms of funding. Brazil energy policy created different programs and plans in order to boost renewable energy sources, as aforementioned. However, our results show that there is a difficulty in consolidating these policies, which may be overcome with the political and economic stability of the country. In addition, in municipalities, little efforts are being made regarding renewable energy development, our results show also little effort to disseminate information, metrics, and goals related to renewable energy. Our results show that there are some initiatives spread among regions, but they are not connected. Therefore, there are no uniform results for renewable energy development at the municipal level. Furthermore, the Brazilian energy market is dominated by multinational companies, and this environment makes competition difficult. Other companies want to enter the market, but they cannot, because dominant technology is imported, and there is little internal development in research and innovation. Therefore, it is essential to increase cooperation actions, with different stakeholders: university-startups-industry-government, in order to develop technologies for renewable energy development. Our study shows empirically what are the key challenges for the development of a renewable energy matrix in an emerging country. Therefore, this knowledge should base energy policy development for renewable energy and implementation.

6.1. Limitations and Future Research

For future research, we suggest the development of a quantitative model to understand how each actor (startups, universities, government and industry) influence on the mitigation of renewable energy challenges. However, such type of data is difficult to be accessed. Thus, starting measuring what renewable energy advances are and who the key actors would be vital to assess such phenomena.

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APPENDIX A

1. Name of respondent:
1.2. Institution Name
1.3. Respondent's role within the institution
1.4. Years of experience
2. What innovation policies in Brazil do you know? Especially in which sector? Are there in policies in the energy sector?
3. Were you a beneficiary or participated in a project financed by the policies. If so, by which? **No!***
4. Which innovation policy? What was the appeal received? For what purpose?
5. How was the appeal made? Did you have any limitations in the Notice?
6. Did you notice any improvement in the innovation process from aid? (for example, in technological development)
7. Do you use any indicators to measure the impact of policies? Which?
8. How do you perceive the role of the government (public institutions) in the implementation of the projects?
9. How do you perceive the role of universities in the implementation of projects?
10. How do you perceive the role of the private sector (product and service companies) in the implementation of the projects?
11. How is the interaction between government-universities-companies perceived in the development of policies?
12. How is the interaction between government-universities-companies perceived in the application of policies?
13. How do you see the relationship of these innovation policies in relation to sustainable development (economic, environmental and social development)?
14. How do you deliver the impact of policies on society? Do you use any indicator? Do you make reports?

No!*

4. How do you perceive the impact of innovation policies in Brazil?
5. Do you know any indicators to measure the impact of policies? Which? Government indicator, university indicator, company indicator?
6. How do you perceive the role of the government (public institutions) in the implementation of the projects?
7. How do you perceive the role of universities in the implementation of projects?
8. How do you perceive the role of the private sector (product and service companies) in the implementation of the projects?
9. How is the interaction between government-universities-companies perceived in the development of policies?
10. How is the interaction between government-universities-companies perceived in the application of policies?
11. How do you see the relationship of these innovation policies in relation to sustainable development (economic, environmental and social development)?

5 FINAL CONSIDERATIONS

5.1 CONCLUSIONS

This dissertation brings contributions for renewable energy transition. The first paper analyzed the contribution of institutional actors to the development of RES, considering German mid-sized and large municipalities. As a main theoretical contribution of the first paper provided empirical evidence of the relevance of the TH model in support of the development of RES at the municipal level. We also showed that rather than treating the TH model as a single effect on RES development, each of the TH actors makes different contributions to the creation of innovation policy for RES. While private sector performs an important role in the creation of all three types of innovation policy for RES, the universities only seem to provide a contribution to policies related to knowledge generation and transfer. In this type of an economically developed context, the private sector is the driver of RES development. Moreover, our findings show that the government has an important role in the creation of knowledge and cooperation policies, but we could not find evidence of its contribution to locational factors. Government can support the regional economy, but the private sector is the key driver of RES development in the municipalities.

The second article showed that the highest maturity municipalities may adopt cooperation and knowledge activities for their energy development. The article also showed that low adopters invest on three main sustainable development pillars. As low adopters may not pursue a strong economy, they could focus on social pillar (job availability, safeguarding existing jobs, for example), while advanced adopters might focus on economic and environmental pillars, they can involve stakeholders on R&D activities, and promotion of RES. Additionally, this paper proposes a framework for RES policy that includes different variables that encompass renewable energy transition and sustainable development.

The last paper sought to identify the challenging factors of renewable energy transition in an emerging country, based on the findings of the others two articles. Based semi-structured interviews of triple helix actors, we showed that Brazilian energy transition faces a lot of challenges but also has a lot of opportunities. We categorized the challenges into five main factors, and interviewees highlighted some financial and economic aspects that could boost renewable energy transition.

Based on these three papers, we could identify differences between a reference country like Germany and a reference emerging country like Brazilian. The first and second articles analyzed German municipalities and they showed that cooperation activities are influenced by the three triple helix actors, and all adoptions levels focus on cooperation activities. In contrast, when we analyzed this cooperation in Brazil, we observed that triple helix actors lack of cooperation between them. Regarding cooperation activities, Brazil is also dependent of startups for renewable energy development, bringing a new actor for the triple helix model. Brazilian municipalities should develop cooperation activities between different actors to find ways to overcome the challenges identified in the third paper of this work. Also, Brazil is recognized as a country with much natural resources and environmental protection. In this sense, we showed in the second paper that municipalities with low development of RES focus on natural condition to support their renewable energy transition, so the framework from that paper could support municipalities strategies to achieve sustainable energy. Brazilian interviewees also pointed out that renewable energy initiatives are part of climate change strategies and committees, but some of them were discontinued. In fact, this is aligned with the findings of the second paper, because only advanced adopters focus on promotion of RES. Therefore, Figure 8 summarizes our results, showing how triple helix actors may influence on low-carbon energy transition, how sustainable development could support RES policy, and the main challenging factors that emerging countries should overcome to change their energy matrix from non-renewable energy source to renewable one.

Based on our findings, this dissertation aims to expand the knowledge on the interfaces between renewable energy transition, sustainable development, triple helix actors, and energy policy. In this sense, we provided an analysis of how renewable energy transition could be developed, showing the greatest innovation actors that could support this transition, how level of adoption of RES policy are aligned to sustainable development and what the main triple bottom line that supports the RES policy adoption. So, we developed a framework based on our findings. And, then, what challenging factors could be faced by emerging countries for the promotion and the use of renewable energy.

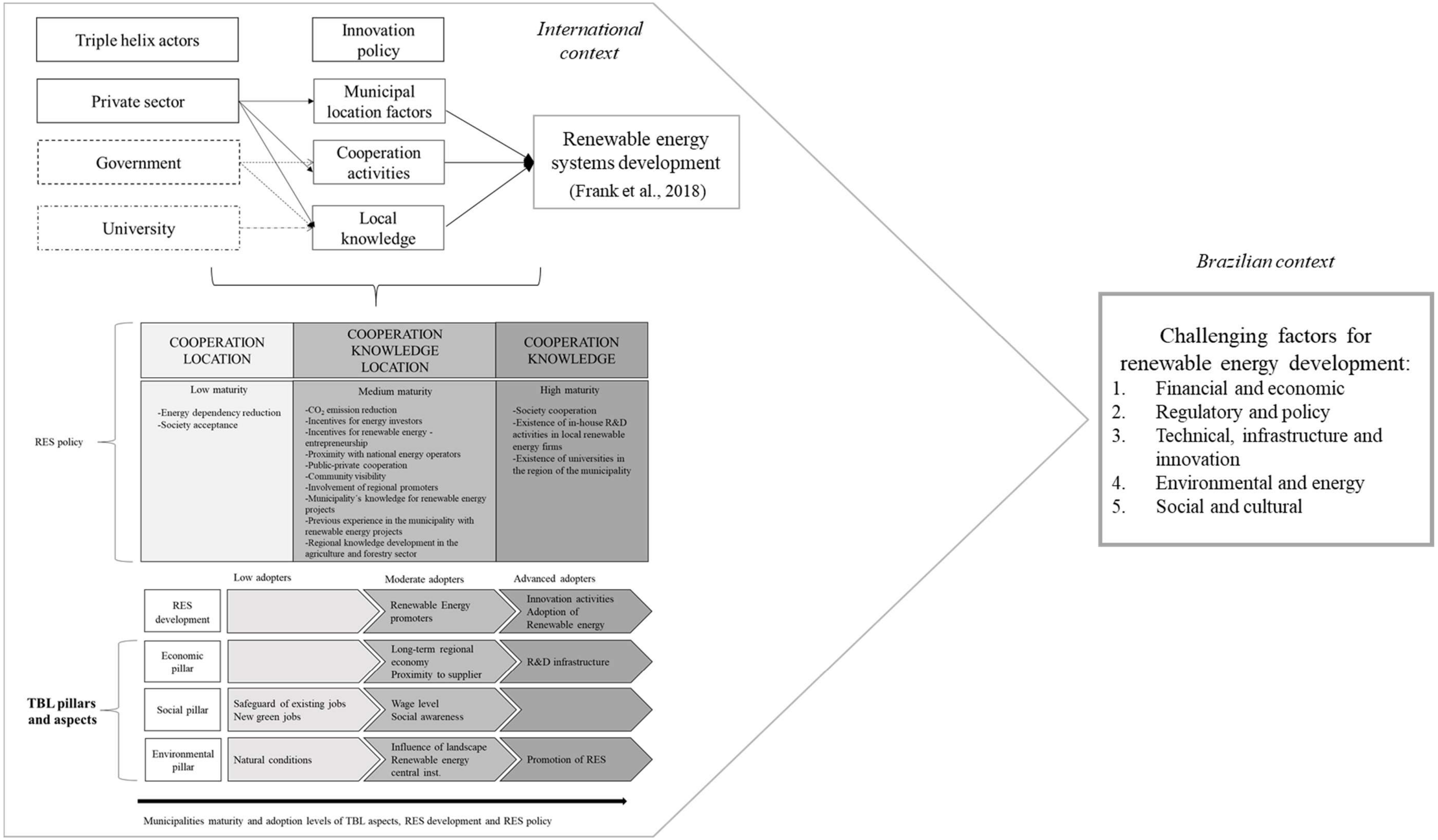

Figure 8 - Dissertation final model

5.1 Future research

Our findings can provide support for future work. In this sense, we identified that there might be a lack of longitudinal studies for RES development on the literature, because some policies outputs may focus on long-term regional development. Therefore, further studies could address how renewable energy matrix could increase, while new sustainable energy policies and green technologies are developed. In addition, our results pointed to the lack of studies focused on startups. A study analyzing the segments of renewable energy startups and how they interact with another stakeholders is vital to understand how green technologies could be improved, and to comprehend how startups could affect the development of national industry, because startups and their partners could create patents, and other brands. This would contribute to the better understanding on how renewable energy market works, and how to develop better strategies for low-carbon energy development. Moreover, we suggested that government or universities could be moderate actors in the relationship between the other TH actors and the innovation policy criteria rather than just considering their direct effects on policy as we did in this dissertation. Regarding sustainable development, future researches could advance on statistical analysis which allow to estimate how much each TBL aspect contributes for RES development.

Additionally, further studies could also verify how energy sector modernization could impact on all energy market, and on renewable energy central installations, since central installations should provide energy supply for various areas, but socially, economically, and environmentally only impact one region. In contrast, renewable energy decentralized installation should generate fewer energy, but, as it is scattered among numerous regions, it could benefit economic, social, and environmental different areas.