# SUSTAINABLE CONDITIONS FOR THE DEVELOPMENT OF RENEWABLE ENERGY SYSTEMS: A TRIPLE BOTTOM LINE PERSPECTIVE

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## ABSTRACT

The number of studies on Renewable Energy Systems (RES) has increased over the past decade, suggesting that RES may be an effective solution to achieve sustainable development. However, the impact of municipal contextual conditions on the development of RES is still unclear. One of the literature gaps is the lack of understanding of 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 in order to understand whether municipalities ought to create contextual conditions around the TBL dimensions with the aim of supporting RES policy. Furthermore, we applied a cluster analysis to establish the patterns of RES adoption supported by the TBL. Our results document that advanced adopters of RES are more advanced regarding the economic and environmental aspects of the TBL, while regions with less RES development show a primary emphasis on social conditions. Moreover, public funding set the boundaries for RES development, being the most challenging aspects to be adopted in RES policy.

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

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## 1. INTRODUCTION

Concerns about climate change, loss of biodiversity, use of fossil fuels, and scarcity of natural resources are increasingly predominant in the 21st century. In parallel with socio-economic pressures (i.e. population growth, urbanization, and pollution), these issues are capturing the attention of many scholars who are encouraging the society to gradually move towards a more sustainable development (Zhou et al., 2016). In general, sustainable development aims at creating comprehensive solutions for processes, products and services, commercial and industrial businesses, buildings, and energy systems with focus on meeting environmental and social needs (Cabezas et al., 2005). This view on societal development can be analyzed through the "triple bottom line (TBL)" perspective which grounds sustainability on three main dimensions: economic, social, and environmental (Elkington, 1998). A sustainability focus should deal with all three dimensions of TBL to have a good balance in regional development (Aguiñaga et al., 2018).

The development of Renewable Energy Systems (RES) is a key element for the sustainable development of regions and countries (Frank et al., 2018). The number of studies on RES has increased over the past decade, suggesting that RES can be an effective solution for sustainable development (Frank et al., 2018; Kumar et al., 2017). Most of these studies focus on energy planning, development of a renewable energy industry, renewable energy strategies, and innovation policy criteria (i.e., municipal location factors, cooperation activities, and the existence of local knowledge about RES). Moreover, there is also an increasing number of municipal, sustainable energy studies in the literature due to the importance of green development in cities (Østergaard et al., 2010). A common feature in this literature is the attempt to improve the understanding of *how* RES policy might be a key aspect in RES development and adoption (Meister, Schmid, Seidl & Kaggle, 2020). However, one of the still remaining literature gaps refers to the lack of understanding of whether the balanced development of economic, social, and environmental aspects of sustainability (i.e., the TBL perspective) supports RES policy or not. The TBL perspective (Elkington, 1998) is particularly useful in this context because it is widely understood and regarded as a fundamental sustainability management framework that helps to clarify the complexity for public and private organizations (Ozanne et al., 2016). Therefore, our paper addresses RES policy in municipalities applying TBL perspective based on 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 (municipalities)?*

To answer this research question, we conducted a quantitative analysis of 727 medium- and large-sized German municipalities. Based on this large-scale sample, our research objective was to investigate whether municipalities should create contextual conditions around the TBL dimensions with the aim of supporting RES policy. This analysis helps to understand how an effective, sustainable approach to RES policy can be carried out. As the starting point for our empirical analysis, we hypothesize about the relationship between RES development and TBL. As the main step of our data analysis, we applied a cluster analysis to establish patterns of RES adoption as a specific condition of a single region using the TBL perspective. Our results document that advanced adopters of RES policy are more advanced regarding all TBL conditions, while regions with a less developed RES policy should promote TBL conditions. Overall, municipalities that are more mature in RES have focused considerably on local knowledge, engaging their RES policies with in-house R&D activities and with universities oriented to RES development. Finally, our results evidence that public funding set the boundaries for RES development in municipalities.

## 2. TRIPLE BOTTOM LINE AND ITS ASPECTS FOR RES POLICY

The development of RES is related to innovation activities for renewable energy transition (Mascarenhas et al., 2010), to the adoption of renewable energies rather than non-renewable energy sources (Mallett, 2007), to the presence of renewable energy promoters in the public and private sectors (Gerstlberger, 2004), and to the presence of renewable energy companies (Mascarenhas et al., 2010). Innovation activities are essential for RES development, because they could decrease the prices for green technologies and increase their feasibility. Innovation activities can stimulate green economy (Conti et al., 2018), and policymakers should thus create mechanisms that spur innovation activities (Frank et al., 2018).

In this study, we propose that a strong presence of the TBL dimensions at the local (municipal) level will be beneficial for RES policy (van der Schoor & Scholtens, 2015). This means that TBL dimensions are considered as ways to achieve sustainability goals and support RES transition (Neves & Leal, 2010). Each dimension can support different aspects of sustainable development. Although the literature links sustainability

with RES, it does not clarify the content of each of the TBL dimensions that are associated with RES policy development. In other words, we aim to describe and explain the relevant elements of the TBL for RES policy. Consequently, and next, we discuss each dimension and present the hypotheses that derive from these relevant elements.

### *2.1. Economic aspects that support RES policy*

The economic dimension is extremely important for the development of energy technologies because it focuses on profits (Elkington, 1998). Taking wind power as an example, previous studies have shown that both public and private funding are essential to develop wind technologies (Loiter & Norberg-Bohm, 1999). The same has been demonstrated for other renewable energy sources (Jang et al., 2018). Policymakers may thus use some mechanisms (e.g. tax policy and public funding) to improve the development of clean energies (Loiter & Norberg-Bohm, 1999). United Kingdom energy technologies, for instance, have been funded by government departments and agencies to promote renewable energy projects in the municipalities (Walker et al., 2010). This example shows how public funding has supported renewable energy transition. The presence of renewable energy promoters and companies, innovation activities, R&D infrastructure, and long-term regional economic development are also important aspects of renewable energy transition (Gerstlberger, 2004; Mallett, 2007; Mascarenhas et al., 2010). Taking energy policy development as an example, organizations should pay attention to where the energy promoters are located, and where the technology development and innovation activities are, if a part of the technology is not developed in the municipality/region (Walker & Cass, 2007). Therefore, there should be coordinated efforts to find promoters who are located close to the municipalities, due to the strategic advantages for regional RES policy development (De Marchi, 2012). Moreover, energy policy development affects R&D activities in organizations which are attempting to achieve more renewable energy matrixes to foster growth in municipalities (Kalkbrenner & Roosen, 2016). Cavicchi et al. (2014) explained that growing expenditure in the private R&D sector and increasing public R&D expenditure are important elements for energy innovation, because new low-carbon technologies could be developed based on these investments. Furthermore, developing a more sustainable long-term economic growth plan is crucial for all municipalities, the reason being that when eco-municipalities are planned and built, different generations might benefit from these changes which might

again mitigate problems of economic stagnation and poverty (Islam et al., 2003). Considering this argument, we propose the following hypothesis:

*H1: The advancement of RES policy adoption in municipalities is contextually associated with a strong emphasis on the economic dimension of a triple bottom line of sustainability.*

### *2.2. Social aspects that support RES policy*

The social dimension of the TBL refers to the main aspects of sustainable development which are related to how people will be affected, and how people can boost this development. The implementation of renewable energy sources contributes positively to employment creation (Omri et al., 2015), income generation (Selfa, 2010), and energy access (Chirambo, 2016). When we analyze the regional and local renewable energy context, there might also be some negative social impacts of 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; and for geothermal, seismic activity, odor, pollution and noise (Evans et al., 2009). Although these social impacts already play a relevant role in sustainability studies for RES policy development, social awareness is still a key element in RES transitions and fundamental for social sustainability (Assefa & Frostell, 2007).

Prior studies have shown how important the development of RES through the social perspective is (Wüstenhagen et al., 2007; Stigka et al., 2014; Mallet, 2007). However, in the early phases of policy programs for RES technology implementation, the social awareness is in many cases neglected (Wüstenhagen et al., 2007). This negligence can lead to several difficulties in renewable energy promotion and development in the society (Bronfman et al., 2012). To obtain public acceptance, governments should propose efficient clean energy policies (Del Río & Burguillo, 2008) that foster the development of green jobs. In accordance with this, Yi's (2013) study highlights how the influence of renewable energy mechanisms and local energy policies affect the development of green jobs in the United States' metropolitan areas. People are also interested in how renewable energy will affect their quality of life, jobs, and wage level and, therefore, the understanding of how energy policies will affect the municipalities' employment short-term, mid-term and long-term is included as one social awareness aspect in the TBL social dimension (Fankhaeser et al., 2008). Although job availability and new green jobs are vital aspects of the social sustainability dimension, safeguarding

existing jobs is also important, because new, more sustainability-related functions could be added to existing jobs (Abegg, 2011). Consequently, these enriched jobs might increase the wage level which is important for raising more capital for basic needs. In addition, higher investment in new green technologies for energy efficiency and related jobs is essential for RES policy development (Prognos, 2010). To illustrate this relation, employees' salary cost corresponds more than half of the added value in installed solar systems, showing how green jobs require qualified workforce (Heinbach et al., 2014). Considering how social sustainability is crucial for RES policy development, we propose the following hypothesis:

*H2: The advancement of RES policy adoption in municipalities is contextually associated with a strong emphasis on the social dimension of the triple bottom line of sustainability.*

### *2.3. Environmental aspects that support RES policy*

The environmental dimension of the TBL is related to waste management, pollution reduction, and energy management (Gimenez et al., 2012).There are different environmental aspects that support RES policy development in municipalities. One of them is the promotion of RES, but this aspect should be aligned with sustainable development. Sustainability goals are key indicators in municipalities' growth, especially in municipalities that focus on renewable energy transition (Busch & McCormick, 2014). Although there are different mechanisms to promote RES, in the German context for example, the renewable energy supply system uses intermittent sources (e.g., solar and wind). Therefore its energy matrix includes a backup energy system which uses some fossil sources (Frondel et al., 2020). Consequently, to promote a RES it is fundamental to understand how it could integrate different important aspects, such as regional/municipal sustainable space and landscape planning that focuses on spatial configuration of sustainable land use (Prados, 2010).

Sometimes, a rural area is adequate to install renewable energy plants, but may not be available because it is a natural conservation area (Zerta et al., 2008). Thus, availability of natural resources, including restrictions in environmentally protected areas, could allow or jeopardize the installation of renewable energy plants. When new renewable energy supply is being developed, an extensive analysis should be done to understand which environmental conditions will be faced, and how a renewable energy plant could affect the landscape (Akella et al., 2009). For instance, a new renewable

energy plant may not have an environmental, but a visual impact (Akella et al., 2009). Even though abundance of natural resources could become an innovation opportunity (Cavicchi et al., 2014), there are some negative aspects of implementing renewable energy sources, such as modification of the surface in negative relation to a watercourse or difficulty finding large areas to establish wind farms without impacting soil use and the natural ecosystem.

Such modifications are influenced by two main types of RES installations: centralized and decentralized ones (Tsoutsos et al., 2005; Yaqoot et al., 2016). To illustrate this influence: the future of renewable energy in some countries may be small decentralized solar photovoltaic installations that could be installed on rooftops (Faninger, 2003), while in others, centralized big solar photovoltaic parks would be created, as in Pavagada Solar Park in India (Sharma, 2011). Consequently, we need to consider different aspects of implementing a municipal renewable energy matrix. Based on this argument, our third hypothesis is:

*H3: The advancement of RES policy adoption in municipalities is contextually associated with a strong emphasis on the environmental dimension of the 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 for sustainable RES policy development because of Germany's pioneering initiative within development of RES in the country and its exemplary laws that are inspiring other countries to develop new energy policies and sustainable development scenarios (Bechberger & Reiche, 2004). According to the Association of German Cities, there are 11,300 municipalities in the country (Deutscher Städtetag, 2012). Our sampling selection was based on municipalities that can support innovation activities towards renewable energy. In other words, we selected medium- and large-sized German municipalities (with more than 1,000 inhabitants) (Rösler, 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 on some innovation concepts. After

all these procedures, we obtained 727 useful questionnaires, corresponding to a 34.6% response rate. To achieve this high response rate, we gave all respondents a guarantee that they would receive a summary of the most important results of our survey. In addition, in some German States ("Bundesländer"), municipalities have the explicit obligation to support universities' research because it is in the interest of the public. We chose to analyze the questionnaires which had a completion rate equal to or greater than 50% of all the questions and thus were considered useful. *Table 1* shows the demographic distribution of the useful sample.

**Table 1** – 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 | 20.5% |
| | North | 124 | 17.1% |
| | South | 313 | 43% |
| | West | 141 | 19.4% |
| | **Total (n)** | **727** | |

### 3.2. Questionnaire development

Before implementing the survey questionnaire, some qualitative interviews were conducted to validate categories and shed light on some innovation-related concepts with a few mayors, senior executives, and managers from municipal enterprises. Firstly, 20 public and private experts were interviewed due to their expertise in the field of renewable energies, having collaborated in a Union European project called Future Renewable Energy (FURGY) (Gerstlberger et al., 2011). These qualitative interviews lasted for an average of 40 minutes. The interviews were conducted four months before applying the survey. The questionnaire's main goal was to assess the respondents' perceptions of the RES 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 that is 100% supplied from renewable energy sources by 2050 (Nagl et al., 2011). The present study is part of this project and is based on the questions related to RES policy and sustainable development were investigated.

Moreover, all survey questions utilized a 7-point Likert scale or Yes/No questions. Using Yes/No questions, respondents were asked about two variables, i.e. *promotion of RES* (from an ENVIRONMENTAL dimension) and *public funding* (from an ECONOMIC dimension). These questions were designed to find out if a municipality promotes RES development, and if a municipality receives public funding for the development of RES. For the remaining questions, respondents were asked to respond using a 7-point Likert scale ranging from 1 – Not important to 7 – Extremely important. The questions asked respondents to rate how strongly they agreed with each statement (i.e., the highest degree shows that advanced aspects are relevant, while the lowest refers to aspects that are not relevant).

### 3.3. Variables operationalization

Our work considers three main RES policy categories (i.e., COOPERATION, KNOWLEDGE, LOCATION) and the resulting development level of RES, i.e., DEVELOPMENT in Frank et al.'s (2018) work. The DEVELOPMENT category had all variables associated with economic dimension. As a result, they were included in the economic dimension during our procedures to classify variables in TBL dimensions. All these categories and variables are presented in Table 2. As for the TBL dimensions, we built them by means of theoretical grouping. Theoretical grouping is a way of illustrating how different constructs or categories are underpinned by certain theories, and how the theories and constructs may overlap (Halverson, 2002). We aligned our three hypotheses (H1, H2 and H3) from the TBL perspective to build our categories. In other words, the variables definition and categorization of the economic, social, and environmental dimensions were done by literature review, in which we identified sixteen final variables to analyze TBL. For sustainability measurement, we derived our variables from most of our hypotheses (H1, H2 e H3), summarizing our economic, social, and environmental dimensions and their variables in *Table 2*.

**Table 2** – RES development categories (Source: Adapted from Frank et al. (2018))

| RES Policy Categories | Variables |
|---|---|
| **Policy for cooperation activities (COOPERATION)** | Public-private cooperation<br>Society cooperation<br>Community visibility<br>Society cooperation<br>Involvement of regional promoters |
| **Policy for local knowledge generation (KNOWLEDGE)** | Municipality´s knowledge of renewable energy projects<br>Previous experience in the municipality with renewable energy projects<br>Existence of internal R&D activities in local renewable energy companies<br>Existence of universities in the region of the municipality<br>Regional knowledge of development in the agriculture and forestry sector |
| **Policy to foster municipal locational factors (LOCATION)** | $CO_2$ emission reduction<br>Energy dependency reduction<br>Incentives for energy investors<br>Incentives for renewable energy entrepreneurship<br>Proximity with national energy operators |
| **Triple bottom line categories** | **Variables** |
| **Economic dimension** | Public funding<br>R&D infrastructure<br>Developing long-term regional economic planning<br>Innovation activities for renewable energy<br>Investments in renewable energies<br>Economic contribution by renewable energy promoters<br>Economic contribution by renewable energy companies |
| **Social dimension** | Social awareness<br>Wage level<br>Job availability<br>Safeguarding existing jobs<br>New green jobs |
| **Environmental dimension** | Promotion of RES<br>Sustainable landscape planning<br>Renewable energy decentralized installations<br>Availability of natural resources |

Following the literature, the economic dimension (H1) is essential for renewable energy transition. Our economic variables focus on aspects that are important for a sustainable economic development, using a funding perspective, economic contribution perspective, innovation perspective, and long-term planning perspective. As we are analyzing the advancement of municipalities regarding development of RES, *public funding* and *investments of renewable energies* become an important variable (Jacobsson & Lauber, 2006; Loiter & Norberg-Bohm, 1999). In addition, municipalities should evaluate whether energy promoters and companies are sufficiently close to energy consumers to be able to offer better energy related services (De Marchi, 2012). The

*economic contribution by renewable energy promoters as well as renewable energy companies* are key variables for RES development. Therefore, if a municipality has more public funding and various local promoters, there will be an increase capital circulation, which should boost economic local activity. Aspects such as an *R&D infrastructure* to access renewable energy technologies and *the development of innovation activities* by different stakeholders are also important. This kind of activities are only possible through a *long-term planning of the regional economic development* in which RES development is a driver of the planning process (Shimada et al., 2007).

In addition, considering H2, according to previous studies, the social dimension could be designed by assessing various perspectives. As we are focusing on a developed economy, our defined variables are proxies to measure quality of life. First, *social awareness* is a remarkable variable in the literature on RES development, so we use this as an item to measure social dimension. *Wage level job availability, safeguarding existent jobs, and new green jobs* are variables for welfare that impact society and, according to the literature (i.e., Prognos, 2010; Yi, 2013; Zafrilla et al. 2019), they are important items for the municipalities to measure in order to understand if they are maintaining or losing their jobs, if there are jobs available on the market, and if there are new green jobs. If the municipalities' citizens are employed and receiving wages, their essential needs will be easily covered and municipalities will have more resources to spend in other regional development focuses, such as RES development.

Regarding H3, and following previous studies, the environmental dimension comprises an important analysis for RES development, because it covers not only the environment itself, but also main municipality activities to protect the environment and develop a renewable energy matrix (Yu et al., 2019). Considering the literature, *promotion of RES* is our first variable on the environmental dimension, because municipalities should promote renewable energy projects to boost their local environmental concern and renewable energy adoption (Schönberger, 2013). However, it is not the only environmental variable as municipalities should also focus on assessing landscape externalities for renewable energy development (Meyerhoff et al., 2010). Consequently, *sustainable landscape planning* is our second measurement item concerning the environmental, because it is important to plan how and which types of landscape can be used to receive renewable energy industries, and how it might affect the municipal environment. Moreover, decentralized, and centralized renewable energy

industries are recurring themes in the renewable energy literature and German development policies, so we analyzed *the presence of decentralized renewable energy industries* (Faninger, 2003) (our variable is known as *central renewable energy installation*). For example, if there is scarce access to natural resources, e.g. difficult access to energy from sun or wind, or if there are no photovoltaic and wind industries, the *availability of natural resources* appears as a crucial variable, and municipalities need to evaluate if there is the necessary availability of natural resources to install renewable energy plants (Cavicchi et al., 2014).

### 3.4. Data analysis

First, we aimed to identify municipalities with different maturity levels of RES policy to find different RES development patterns. To identify the patterns of comparable RES policies, we conducted a two-step cluster analysis. Following Marodin et al. (2016) and Montoya (2009), the groups were clustered by the similarities of their RES policy (using items from the COOPERATION, KNOWLEDGE and LOCATION categories). Furthermore, we conducted this hierarchical cluster analysis to check whether the number of groups was satisfactory for our sample. We used Ward's method with Euclidean distance measure to perform our hierarchical cluster analysis.

Second, a non-hierarchical cluster analysis using K-means cluster algorithm was performed to refine our cluster solution and to define variables that discriminated our clusters. Finally, we defined our cluster composition and conducted a demographic analysis. Our aim with this last step was to understand if the groups identified in the cluster analysis by a similar RES policy were also associated to specific patterns of TBL (using items from economic, social, and environmental categories) and RES development. This approach is expressed in our hypotheses: the economic (H1), social (H2), environmental (H3) dimensions. To analyze the received 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 built a dendrogram through our hierarchical cluster procedure[1] as shown in *Figure 1*.

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

Moreover, we used this first step to determine the number of municipal groups with high similarities regarding RES policy development. As shown in the dendrogram, the sample can be divided into three clusters, allowing the analysis of RES policy patterns, while avoiding an extremely high number of fragmented subgroups.

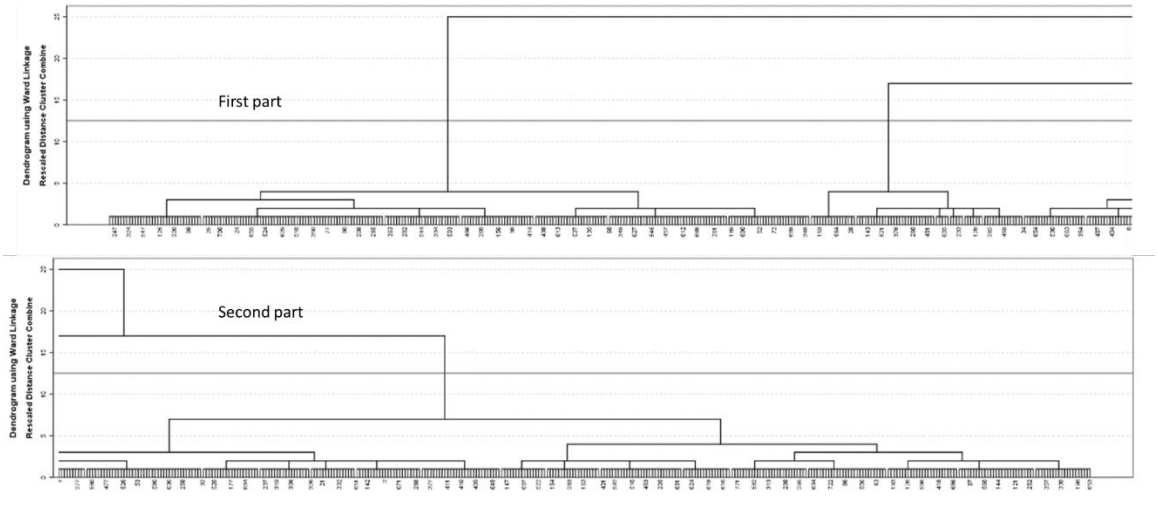


**Figure 1 -** Dendrogram for selection of the number of clusters. (Dendogram using Ward Linkage – Rescaled Distance Cluster Combine)

In the second step, we conducted a 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 3*, showing the clusters' arrangement and the contribution by each RES variable, presenting the maturity level of RES policy. When we analyzed 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 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 (>=2.94) of RES policy. Finally, the third cluster is characterized by the highest level of RES development, in which RES policy is grouped by the highest means (>=4.65). From these results we categorized three groups: low adopters (Cluster 1), moderate adopters (Cluster 2) and advanced adopters (Cluster 3) of RES policy.

**Table 3** – 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 of 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 to 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]*** |

***p<0.001

To complement our analysis, we conducted a demographic investigation of the cluster composition, in which we associated the three clusters with the TBL dimensions. We report these results in *Table 4*. Regarding the TBL analysis, our results are divided in three groups: economic, social, and environmental dimensions.

*Table 4* summarizes the results of the TBL according to the three clusters. Firstly, regarding the economic dimension, we found that six of the seven economic variables are concentrated in Cluster 3 (advanced adopters of RES policy). Moreover, we found that public funding did not show levels of high representation 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 representation in Cluster 3 (34%) when compared to the others although the lack of representation of public funding was still predominant in the advanced adopters' group (66% of the municipalities). Furthermore, we observed that the presence of renewable energy companies show high levels of representation in the three clusters, being the least accessible renewable energy development aspect for municipalities: low adopters (24%), moderate adopters (53%), and advanced adopters (66%).

Innovation activities (76%), renewable energy adoption (81%), and renewable energy promoters (79%) showed a higher level in the Cluster 3 (advanced adopters). Cluster 1 (low adopters) demonstrated a lower level of all renewable energy development: innovation activities (74%), renewable energy adoption (55%), renewable energy promoters (66%), and renewable energy companies (76%). Cluster 2 (moderate adopters) showed a low level of adoption: innovation activities (39%); adoption of renewable energy development (29%), and presence of renewable energy companies (47%). However, Cluster 2 demonstrated a high level of the presence of renewable energy promoters (70%).

R&D infrastructure (63%) and development of long-term regional economic planning (96%) demonstrate a high level of representation in Cluster 3. Cluster 1 showed a low level of adoption of R&D infrastructure (76%) and development of long-term regional economic planning (90%), while Cluster 2 demonstrated a low level of adoption of R&D infrastructure (55%) and a high level of adoption of development of long-term regional economic planning (59%).

**Table 4 –** Levels of adoption of economic, environmental and social dimensions

| TBL dimensions | | | C1 | C2 | C3 | |
|---|---|---|---|---|---|---|
| | | **Adoption** | Low adopters | Moderate adopters | Advanced adopters | |
| | | **N** | 89 | 328 | 310 | Pearson $\chi^2$ |
| **Economic (H1)** | Public funding | No | 90% | 81% | 66% | 28.85*** |
| | | Yes | 10%** | 19% | 34%*** | |
| | R&D infrastructure | Low | 76%*** | 55% | 37%*** | 49.22*** |
| | | High | 24%*** | 45% | 63%*** | |
| | Development of long-term regional economic planning | Low | 90%*** | 41%*** | 4%*** | 262.26*** |
| | | High | 10%*** | 59%** | 96%*** | |
| | Innovation activities for renewable energy | Low | 74%*** | 39% | 24%*** | 75.05*** |
| | | High | 26%*** | 61% | 76%** | |
| | Investments in renewable energies | Low | 55%*** | 29% | 19%*** | 44.91*** |
| | | High | 45% *** | 71% | 81% | |
| | Economic contribution by renewable energy promoters | Low | 66%*** | 30% | 21%*** | 67.96*** |
| | | High | 34%*** | 70% | 79%** | |
| | Economic contribution by renewable energy companies | Low | 76%*** | 47% | 34%*** | 52.57*** |
| | | High | 24%*** | 53% | 66%** | |
| **Social (H2)** | Social awareness | Low | 66%*** | 37% | 30%** | 38.39*** |
| | | High | 34% | 63%*** | 70% | |
| | Wage level | Low | 57%*** | 30% | 26% | 32.17*** |
| | | High | 43%** | 70% | 74% | |
| | Job availability | Low | 52%*** | 23% | 21% | 36.45*** |
| | | High | 48%** | 77% | 79% | |
| | Safeguarding of existing jobs | Low | 80%*** | 53%*** | 12%*** | 182.72*** |
| | | High | 20%*** | 47%*** | 88%*** | |
| | New green jobs | Low | 70%*** | 43%*** | 9%*** | 150.17*** |
| | | High | 30%*** | 57%** | 91%*** | |
| **Environmental (H3)** | Promotion of RES | No | 76%** | 65% | 46%*** | 35.88** |
| | | Yes | 24%** | 35% | 54%*** | |
| | Sustainable landscape planning | Low | 61%*** | 31% | 17%*** | 64.38*** |
| | | High | 39%*** | 69% | 83%** | |
| | Renewable energy decentralized installations | Low | 61%*** | 17% | 8%*** | 126.30*** |
| | | High | 39%*** | 83% | 92%** | |
| | Availability of natural resources | Low | 72%*** | 45% | 24%*** | 75.24** |
| | | High | 28%*** | 55% | 76%*** | |

**p=0.05;
***p=0.001

Moreover, public funding did not show levels of high representation in the three clusters, being the least accessible economic aspect for municipalities: low adopters (90%), moderate adopters (81%), and advanced adopters (66%). However, it showed a

slightly higher level of representation in Cluster 3 (34%) when compared to the others although the lack of representation of public funding was still predominant in the advanced adopters' group (66% of the municipalities). Another characteristic that stands out is that low-level adopters showed an overall less developed TBL approach, reinforcing our hypotheses. *Table 5* summarizes our results, showing hypotheses and variables supported.

| | **Variables supported** | **Hypotheses** |
|---|---|---|
| **Economic dimension (H1)** | R&D infrastructure<br>Development of long-term regional economy planning<br>Innovation activities for renewable energy<br>Investments in adoption of renewable energies<br>Economic contribution by renewable energy promoters | Partially supported |
| **Social dimension (H2)** | Social awareness<br>Wage level<br>Job availability<br>Safeguarding of existing jobs<br>New green jobs | Supported |
| **Environmental dimension (H3)** | Promotion of RES<br>Sustainable landscape planning<br>Renewable energy decentralized installations<br>Availability of natural resources | Supported |

**Table 5 –** Hypotheses results and variables supported

## 5. DISCUSSION

The main research findings are summarized in the framework of *Figure 2* to provide a general overview of TBL dimensions and RES policy adoption patterns obtained in our results for German municipalities. We subdivided this framework into two parts: the first refers to the findings related to the maturity level of the RES policy according to the results presented in *Table 3* and the second to the results concerning adoption levels of TBL dimensions according to the results presented in *Table 4*. We identified the clusters, highlighting the intensity level from the low-level adopters and low maturity level (light grey color) to high-level adopters and high maturity level (dark grey color). This framework can be compared to prior studies, such as Colak et al. (2015) and Beccali, Cellura, and Mistretta (2003). The main difference between the results of these studies and our findings is that the former present different scenarios for energy projects which support policymakers, while our results show a consolidated adoption

level of TBL perspective, RES development, and RES policy in municipalities for the benefit of policymakers.

| | | Low maturity | Medium maturity | High maturity |
|---|---|---|---|---|
| RES policy | | **LOCATION**:<br>-Energy dependency reduction<br>**COOPERATION**:<br>-Society acceptance | **LOCATION**:<br>-$CO_2$ emission reduction<br>-Incentives for energy investors<br>-Incentives for renewable energy entrepreneurship<br>-Proximity to national energy operators<br>**COOPERATION**:<br>-Public-private cooperation<br>-Community visibility<br>-Involvement of regional promoters<br>**KNWLEDGE**:<br>-Municipality´s knowledge of renewable energy projects<br>-Previous experience in the municipality with renewable energy projects<br>-Regional knowledge development in the agriculture and forestry sector | **COOPERATION**:<br>-Society cooperation<br>**KNOWLEDGE**:<br>-Existence of in-house R&D activities in local renewable energy firms<br>-Existence of universities in the region of the municipality |
| TBL pillars and aspects | Economic | | Development of long-term regional economic planning; Innovation activities for RE; Investments in RE; Economic contribution by RE promoters and companies | R&D infrastructure |
| | Social | | Social awareness; Wage level; Job availability; New green Jobs. | Safeguarding of existing jobs |
| | Environmental | | Sustainable landscape planning; Renewable energy decentralized installations; Availability of natural resources | Promotion of RES |

**Figure 2 –** Summary of the findings: municipality's RES maturity and relationship with TBL dimensions

Our framework showed that municipalities with a medium maturity level regarding RES policy have already adopted most of the discussed RES policies in their management of RES development. High maturity adopters focus not only on cooperation activities (society cooperation) but also on local knowledge generation (R&D activities in local industries and presence of universities in the municipalities) because knowledge is a key driver of renewable energy development (Conti et al., 2018). Besides, as mentioned above, our study highlighted that no municipality relies primarily on public funding which is evidenced by the lack of governmental and public agencies' monetary incentives for RES development. Knowledge plays an important role at medium and high maturity levels, but cooperation is also present at all maturity levels. The assumed reason for this finding is that cooperation activities are crucial to reduce the cost of green innovations and to move energy industries close to other main innovation actors for the development of RES (De Marchi, 2012).

Regarding the economic dimension (H1), we expected that the municipalities with advanced adopters would have shown a high degree of use of public funding and would

have made high investments in R&D infrastructure to promote RES. The moderate adopters have the municipalities begun the development of some economic elements for renewable energy (i.e., they have started to focus on the development of long-term regional economic planning and the presence of renewable energy promoters for the development of RES). Surprisingly, our study showed that for all adopters, there is a low investment level of public funding and a low economic contribution of renewable energy companies, and only among advanced adopters, there is a high implementation degree of R&D infrastructure. Such findings are different from those of prior studies that argued that public funding plays a key role in municipalities' RES development (Sen and Ganguly, 2017, Lutz et al., 2017). Mazzucato & Semieniuk (2018) discuss the fundamental role of financing in enabling the use of renewable energy worldwide. The authors found that the direction towards specific technologies is guided by the specific funder (e.g., private banks or public actors). Over the years, public financing of renewable energy projects has come to represent a considerable amount of higher risk technology projects worldwide and has significantly increased their share of total investments. However, the German scenario is quite different, because the federal government uses a decentralized energy policy system with a feed-in tariff (FIT) (Nolden, 2013). FIT was mainly created to support the exploitation of renewable energy sources. FIT is covered by long-term contracts that guarantee prices and maintenance costs. This interesting model is being copied by other countries, because FIT policies play an important role in energy policies, spurring the development of renewable energy technologies (Hille et al., 2020). For instance, by the end of 2018, 111 countries had implemented FIT (IRENA, 2019).

Furthermore, we expected the adoption of renewable energy would start with the moderate adopters because the literature shows that some small municipalities have already adopted a renewable energy matrix (Oteman et al., 2014). Also, municipalities could develop social and environmental dimensions. Finally, regarding our framework, there should be a sequence of steps, involving the presence of renewable energy promoters among moderate adopters and the promotion of RES among advanced adopters concerning the environmental dimension. Therefore, promoters of RES may be represented among moderate adopters, but they may not have the necessary integration mechanisms to coordinate their actions. However, this finding makes sense, because following the timeline, renewable energy promoters should first be present in the region

or municipality and afterwards, these promoters may also interact with other energy stakeholders to promote RES, considering the municipal context (Gerstlberger, 2004).

Regarding innovation activities and R&D, following Sinsel et al. (2020), when an energy policy is developed to protect clean technologies, unfortunately, this protection might reduce the need for complementary technology and its innovation. Then, considering this particular innovation reduction, low adopters did not focus on developing innovation activities. In contrast, when a municipality reaches a certain level of RES development, they could start focusing on innovation activities and R&D infrastructure to spur technology development, as shown in the framework.

Regarding the social (H2) and environmental (H3) dimensions, our framework shows that moderate adopters have already created a social and environmental incentive for RES development. In 2018, the renewable energy industry provided for 11 million jobs worldwide (IRENA, 2019). Consequently, job availability, social awareness, and new green jobs are essential social aspects for the renewable energy transition. As Germany implements an advanced energy policy, we expected that social awareness would be advanced among all adopters, but it started on moderate adopters. The reason for this assumption is that different studies (e.g. Mallet, 2007; Stigka et al., 2014; Wüstenhagen et al., 2007; Yun and Lee, 2015) have demonstrated the importance of social awareness for renewable energy development.

Furthermore, we observed that low-level adopters should invest in the development of a strategy to make the benefits of renewable energy sources easily understandable to their population. Following this, Rogge et al. (2020) explained that the installation of wind parks should ensure the creation of energy cooperatives or new business model to deliver benefits to society. Policymakers might also create incentives to show that these new green jobs are related to low carbon energy, having lower impacts on the environment (Battaglia et al., 2018). Finally, when a job is created in a remote area by the renewable energy industry, its promotion helps to deliver electricity, transport, or heat based on low carbon energy to this area (IRENA, 2019), leading to improvements in the quality of life and the promotion of circular economy based on renewable resources in municipalities (Tu et al., 2011).

Regarding our hypothesis about the environmental dimension (H3), only advanced adopters promote RES development at considerable levels (>50%). All

adopters should pay attention to the promotion of renewable energy sources because, according to the German Climate Action Plan 2050, the country is changing its energy matrix towards renewable energy in the coming years. These changes will influence laws and regulations, creating new environmental laws and regulations for the country during the next few years (Lutz et al., 2017). Furthermore, sustainable landscape planning and availability of natural resources would therefore be capable of affecting the installation of renewable energy plants. For example, regarding large-scale wind and solar energy plants, we believe that the characteristics of each site, including the technical feasibility and the commercial viability, will influence the strategic decision as to where such wind and solar power plants are going to be installed and operated (Roy, 2002; Turney & Fthenakis, 2011).

## 6. CONCLUSIONS

We assessed the contribution of the different sustainable development dimensions to RES development. Our study encompassed the three dimensions of sustainable development, i.e., the economic, social, and environmental dimensions as well as RES development. The study identified distinct patterns of adoption of RES policy. We conducted this investigation using a quantitative survey among medium and large municipalities in Germany. Our results support our hypotheses that the more advanced the municipalities are concerning the adoption of RES policy for the development of RES, the stronger the presence of regional social and environmental dimensions is.

Our findings also show that municipalities with an advanced level of implementation of RES policy tend to boost the economic and social dimensions, mainly about R&D infrastructure and RES promotion. In the economic dimension, our findings can help to develop new hypotheses. Considering the case of developed countries with a strong economy, the more advanced the municipalities are regarding the adoption of RES policy for the development of RES, the stronger is the presence of private funding for regional, economic factors. Regarding RES development, we also showed that advanced adopters focus on R&D infrastructure, promotion of RES, and safeguarding existing jobs.

Concerning RES policy, our study shows that (i) low maturity municipalities focus on cooperation activities and the municipal location factor; (ii) moderate maturity

municipalities focus on all RES policies studied, i.e., cooperation, knowledge, and location; and (iii) high maturity municipalities focus on cooperation and knowledge. Therefore, cooperation activities are relevant on all three levels of maturity, while local knowledge generation is relevant for moderate and high maturity municipalities, and the municipal location factor is relevant on low and moderate maturity levels.

### 6.1. Policy implications

Our findings can help policymakers working in the field of the renewable energy matrix. We have contributed to the creation of a sustainable energy system. Policymakers could use our results to focus not only on the RES policy but also on the TBL dimensions of sustainability that provide support for the renewable energy transitions. Policymakers in municipalities with low-level RES adoption should anticipate some initiatives by moderate adopters to implement RES. As aforementioned, R&D infrastructure and promotion of RES set the boundaries, considering their complexity for the adoption of RES policy. Also, the presence of renewable energy promoters is vital for RES promotion.

Moderate adopters could simultaneously focus on RES development and the TBL perspective, they should map the presence of energy promoters and the presence of RE companies. Policymakers in such municipalities should align long-term regional economic plans with municipal climate change plans because the various plans might potentially be combined to achieve a commonly agreed set of goals and objectives. While moderate adopters tend to rely on the public sector to pursue RES development, policy incentives for larger private sector engagement across the RES value chain might spur even further development.

As the advanced adopters have already concentrated on all TBL dimensions, they should now focus more on developing R&D infrastructure. Policymakers in these municipalities might create mechanisms to promote RES. Considering that the share of public funding worldwide has not only increased dramatically but also become crucial for further RES development, advanced adopters are in a better position to create policy mechanisms. With that, it is possible to attract public funding to support structured development of R&D infrastructure, promotion of RES, and even stronger innovation activities across the entire RES value chain.

### 6.2. Limitations and future research

This research study has some limitations that open the doors for future research. Firstly, our study considers cross-sectional data while a longitudinal investigation might contribute to an understanding of how evolution and co-evolution of TBL and RES work. Also, our approach is an exploratory study, which we used as a descriptive technique to evaluate contextual variables. Future research might use statistical analysis which would allow for an estimate of how much each TBL aspect contributes to RES development. Our study does not focus on *when* TBL is created and built. Future research should focus on TBL consolidation mechanisms for RES. Finally, our study considers a sample from a well-known and developed country regarding sustainable energy creation. Future research might also consider other contexts (e.g., other European or developing countries) that are not engaged in this issue to the same degree. Such additional perspective might help researchers to understand how TBL dimensions and RES policies affect developing countries' RES development. Meanwhile, this study might support policymakers from these countries in the design and further development of their policies to promote RES development.

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