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A Composite Index to Identify Appropriate Locations for Rural Community Renewable Energy Projects

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Abstract

This study develops a composite index to identify and prioritize the most suitable geographical locations for rural Community Renewable Energy (CRE) projects. CRE is central to the sustainable energy transition, but its strategic deployment in rural areas is challenging due to uneven development, the necessity of coordinating diverse resources, and the need for governments to guarantee the prudent use of scarce funds. Framed under the Resource Mobilization Theory, the proposed index helps mitigate these uncertainties by providing a structure for site evaluation. Although the empirical application is performed in a specific Portuguese region, the methodological approach is explicitly designed to be transferable to other national and regional contexts. The index provides significant practical implications for CRE promoters, investors, and spatial planners, offering a transparent, clear-cut tool to define targets and optimize resource allocation. Furthermore, this study contributes to rural development literature by merging entrepreneurship and renewable energy fields, demonstrating how local CRE can effectively leverage available resources to deliver both private and community benefits.

Keywords: Community Renewable Energy; composite index; rural; Resource Mobilization Theory; Principal Components Analysis



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1. Introduction

The sustainable energy transition (SET) is an essential and necessary process [1] to achieve sustainable development (SD) and mitigate climate change. The local sphere, where global SD strategies touch ground [2], is essential [3], but local authorities have rarely been explicitly considered in the design of these SD agendas [4] and energy plans [5]. Greater attention must be paid to municipal energy and climate plans as contributors to most of the 2030 Agenda goals [6,7], especially in rural municipalities [8–10].

Rural areas are uniquely positioned for contributing to Sustainable Development (SD) [11–13] and hosting Community Renewable Energy (CRE) [14]. This derives from resource advantages, namely their invariable great renewable energy (RE) potential and extensive land availability [5,15,16], and from a socioeconomic need, characterized by

their disconnection from gas mains and a higher risk of fuel poverty [17]. CRE has a great potential to drive the SET [18–21] and to positively contribute to Sustainable Rural Development (SRD) [10,11,22,23].

Rural CRE initiatives show an uneven development and demand more research [9,16,24] and policy and financial support [9,12,25,26]. The high investments needed [27] and long payback periods [21,28–30] can be serious constraints. Potential promoters of CRE projects and public authorities need to carefully analyze their feasibility and success at specific rural settings, but location-specific evaluation tools are lacking.

Identifying optimal locations for specific forms of rural CRE projects would help to reduce the perceived risk for potential promoters [31,32] and to support a prudent use of scarce public funds, searching for the highest efficiency, efficacy, and effectiveness of the governmental interventions [33]. This study develops a methodological approach to identify optimal locations for rural CRE through a composite index labelled as CRERAL (Community Renewable Energy Rural Appropriate Locations), based on the inclusion of indicators related to different forms of capital (economic, human, social, natural, and physical). Two weighting options are considered, namely equal weighting and weights based on Principal Component Analysis (PCA). The index configuration is exemplified and tested on the rural areas of a specific territory in Northern Portugal.

The rest of the paper is organized as follows: Section 2 provides a literature review dealing with how previous research has approached the interrelations between CRE projects and rural development, and what preconditions, related to different forms of capital, can influence the deployment of rural CRE projects oriented to the energy self-sufficiency of an entire village. Section 3 presents the study area and explains the specific variables and methodology applied in the construction of the proposed CRERAL index. Section 4 shows and discusses the results, and finally the conclusion section presents the implications, limitations, and future research venues derived from the proposal to construct a CRERAL composite index combining multiple capital dimensions to support rural CRE planning.

2. Literature Review

2.1. CRE Conceptualization

CRE projects involve the active participation of communities in the planning and development of RE projects to produce, market, and/or self-consume electricity and/or heat [23,25,34,35]. Members can volunteer in the planning and development of projects and/or commit economic resources to them [36,37]. There is a great heterogeneity and diversity of CRE projects [18,35,38,39], and of CRE members [40]. This is acknowledged as a strength [41,42] that contributes to its adaptability to alternative contexts [12,25,43].

An operative classification of CRE projects is that distinguishing between interest-based communities (without geographical nexus, common in most RE cooperatives) and place-based communities (gathering people with a geographical nexus) [44]. This last one is acknowledged as the most successful [45], particularly in rural contexts where it can drive the possibility of achieving the energy autonomy of a whole municipality or village [46–48]. These forms of CRE have received scarce attention in the academic field and are the focus of this study.

2.2. Contribution of CRE to SRD

Previous literature has only limitedly analyzed CRE potential to foster the development of rural areas, and this remains a controversial issue [11,23,49]. Despite this, many authors have advocated a potential positive contribution of CRE to SRD [10,12,13] and to the resilience of rural communities [12,50,51]. CRE projects in rural settings are not only expected to allow a likely cheaper and surely more equitable and fair energy pro-

vision [43,52], but also to enhance local development, improving living conditions and economic activity [16], and ensuring that the benefits of the exploitation of RE resources remain in local economies [53]. But pitfalls may also arise in CRE developments, such as the uncertainty caused by frequent changes in the legal framework [54]; the absence of economies of scale [55]; the transformation of landscapes [56]; and other critical factors from a social, political, economic, and natural point of view [57]. Other disadvantages are the higher transaction costs (due to the large number of people involved) and the limited possibility of diversifying risks across several projects [58]. A tool to identify appropriate locations for the development of rural CRE projects would increase the potential of CRE to drive the SET and contribute to SRD.

2.3. Identification of CRE Appropriate Locations Through Composite Indices

Some previous research efforts have been directed to assess optimal spatial configurations of CREs [59,60]. Grimaldi and Marra [60] acknowledge that the viability and success of a CRE greatly depend on achieving energy self-sufficiency. They suggest considering proximity criteria and mapping the energy demand and supply to optimize the production and sharing of energy between districts, so that if a district cannot be self-sufficient, it can join other districts to create a larger CRE. But they only consider supply from photovoltaic facilities, and they base the estimation of demand only on technical criteria. Agliata et al. [59] propose assessing the suitability of a municipality for implementation of a CRE based on two environmental (presence of suitable areas for wind/solar facilities), two socioeconomic (population density and municipal energy consumption), and three technical factors (presence of existing wind/solar facilities and scale of the permitted wind turbines). They acknowledge that their analysis could be refined by integrating additional indicators.

Composite indices are commonly used to measure performance or assess the progress in the achievement of some specific result, such as rural development [61,62], but they have not usually been envisioned as tools to anticipate action. Some previous research has approached the analysis of suitability for the siting of stand-alone RE installations through multi-criteria decision processes and composite indices with different methodological specifications [63–65]. In this study, the proposed CRERAL index integrates a broader range of perspectives or dimensions with a specific focus on the development of CRE projects, considering that they are not only RE developments but also, and maybe more importantly, an entrepreneurial activity that demands a varied set of resources from all the capital spheres.

Romero-Castro et al. [66] note that both entrepreneurship and RE converge in the concept of CRE. Some previous literature has also independently addressed the identification of local (rural) entrepreneurial potential [67,68] and of local (rural) RE potential [65,69–72]. McKenna's [55] recognizes that environmental, economic, and technical indicators should be analyzed to assess municipalities' suitability for energy autonomy. The Resource Mobilization Theory (RMT) [73,74] provides a useful lens for understanding how collective actors strategically acquire and deploy various types of resources to advance CRE and influence broader socio-political contexts [75,76]. It departs from the analysis of the individual (and sometimes irrational) participation in social movements to put the focus on rational collective action that mobilizes resources to drive societal changes. Under the RMT, resources do not only refer to structural or material ones, but also to symbolic resources (such as legitimacy, identity, or the quest for autonomy) that play a crucial role in removing the financial, technological, and political obstacles to CRE [75]. RMT dictates that success is not guaranteed by the objective of materializing the SET, but by the ability of local actors to effectively mobilize essential inputs. By measuring five distinct capital

spheres—economic, human, social, physical, and natural—the CRERAL composite index directly operationalizes RMT.

2.4. *Preconditions for the Development of CRE in Rural Areas*

The feasibility and success of CRE initiatives depend on multiple factors that condition the deployment of CRE projects [36,77], their geographical density [14], their social acceptance [78], or the willingness to participate/invest [79,80]. They also depend on an appropriate degree of local development able to sustain local energy demand [81].

As acknowledged by Roesler [82], “not all localities are equally well configured to become a bioenergy village” (p. 273). To decrease the perceived risk and attract policy and financial support, optimal locations for rural CRE projects could be identified [32]. Based on Romero-Castro et al.’s [66] conceptualization of CRE as the convergence of rural entrepreneurship and RE, this study suggests combining previous approaches to measure the entrepreneurial local potential (e.g., [67,68]) and the RE potential (e.g., [65,69]) of specific territorial units. The success of rural CRE projects is, thus, related to several supply-side and demand-side factors that have been identified in the previous literature as preconditions of entrepreneurship or RE, grouped around five capital spheres: social, economic, human, natural, and physical.

2.4.1. Social Capital

Social capital and its components are among the most prominent factors that have gathered the attention of CRE literature [83,84], both as preconditions and as relevant outcomes [19,49]. Morrison et al. [50] stress the role of social capital in reducing the risks of CRE. Many different forms of social capital can act as facilitators or barriers of CRE: place-attachment [85], community spirit, cooperative tradition, and norms of locality [86,87], or trust and cooperation [57,88]. In addition, local governments have great potential to collaborate with CRE actors [32,89,90]. Municipal actors facilitate trust building and knowledge transfer between local actors, help to navigate through regulatory and bureaucratic aspects, and can become financial contributors to CRE projects [7,8,29].

2.4.2. Economic Capital

The economic sphere is also of paramount importance. The structure and dynamism of the population of people and companies in a specific territory influence its ability to promote entrepreneurial and community initiatives. From a demand-side perspective, successful CREs need to link the generation and provision of energy to the increase in the local demand for energy [59,60]. This demands specific policies simultaneously targeting both the development of CRE projects as well as the promotion of local economic activity, so that a virtuous circle is created where the reinforced economic activity guarantees the viability of a CRE and the CRE facilitates the local economic activity [81]. From a supply-side perspective, local CRE developments demand a robust socioeconomic system with financial capacity from individuals, companies, and municipal governments [9,91].

2.4.3. Human Capital

Human capital has also received a good deal of attention in CRE literature in relation to the analysis of the willingness to invest or participate in CRE projects [40,79,80,92]. Cohen et al. [93] compare preferences and interest in CRE investments in 31 European countries, confirming a strong heterogeneity of preferences that is not surprising considering the varied cultural, social, historical, and economic contexts considered. Many studies have also indicated that sociodemographic variables may be more explanatory of the predisposition to adopt RE than attitudinal variables [36]. Moreover, the successful implementation of a CRE depends on the qualification of its management team [84].

2.4.4. Natural and Physical Capitals

Finally, beyond financial resources, investments in RE are conditioned by access to physical and natural resources, such as infrastructures, land, and RE potential [60,94,95]. Technical aspects related to the maturity of RE technologies are also relevant [96]. Public infrastructure [97] and internet access [98] are basic elements of local development. Natural assets also support the economic growth, development, and performance of rural areas [99–101]. RE potential has been measured in different ways and contexts in the literature [69–72]. Miramontes-Viña et al. [65] suggest the development of a rural RE potential index that could assist in the identification of appropriate locations for the implementation of hybrid RE systems.

3. Data and Methods

3.1. Study Area

The sustainable energy transition should be planned at the municipal scale [5,32] to account for specific local issues [102]. The municipal level of analysis is especially appropriate in countries with a high degree of administrative decentralization [103], and with a considerable regional heterogeneity in RE natural potential from solar, wind, biomass, or hydropower [104], such as Portugal.

In Portugal, CRE initiatives have shown scarce or even absent development [105], but recent changes in the regulatory framework have opened the door to the potential development of more CRE initiatives [39,106]. Northern Portugal is among the European regions most dramatically affected by the depopulation of its rural areas [107,108], which poses serious risks to their sustainability. It has a rich capital of RE sources [109,110], which has traditionally been exploited with no community participation [105]. Northern Portugal shows the lower population dispersion and the lower proportion of scattered population centers, with only one parish having fewer than 100 inhabitants [108]. Previous literature has highlighted that the feasibility of shared energy requires enough households involved and situated close to each other [32,111], and that spatial closeness facilitates the activation of social norms in communities [112]. Thus, Northern Portugal provides a suitable ground to test a composite indicator to identify potential rural CRE locations based on statistical information about the status of its municipalities regarding different capital spheres or dimensions.

3.2. Indicators

In the context of this study, RE potential deserves separate consideration, so that natural capital is broken down into two independent components: natural capital (ecosystem services) and RE potential. Furthermore, as economic capital embraces many relevant issues, it can also be split into two separate but related dimensions, following Verheul et al.'s [113] framework for the antecedent factors of entrepreneurship [114]: demand-side economic capital (related to the market demand for goods and services that create entrepreneurial opportunities) and supply-side economic capital (enablers or facilitators of the entrepreneurial activity). In this way, seven dimensions are considered to propose a composite index to identify appropriate rural locations for rural CRE projects (CRERAL index).

Each dimension can be configured through alternative indicators to describe the status of each municipality. Based on Romero-Castro et al.'s [66] extensive review of the antecedent conditions of CRE projects, considering a quality criterion based on relevance, interpretability, and reduced redundancy [115], and accounting for the restrictions imposed by data availability, data on 56 indicators were collected for all the Northern Portugal municipalities. Acknowledging that the number of indicators per dimension should be

neither too big nor too small [116], each dimension is described through a set of at least 6 and at most 9 indicators. Since the CRERAL index is aimed at identifying appropriate rural locations for CRE projects, only those municipalities catalogued as thinly populated areas according to the EU's classification of areas by degree of urbanization [117] (three types of areas are defined, using a criterion of geographical contiguity in combination with a minimum population threshold based on grid cells and census data: densely populated areas (or cities/urban centres/urban areas), intermediate areas (or towns and suburbs), and thinly populated areas (or rural areas)). A thinly populated area has more than 50% of the population living in rural grid cells (those that are not identified as urban centres or as urban clusters) are considered [79]. These are 45 out of the 86 Northern Portuguese municipalities.

Table A1 in Appendix A.1 summarizes the list of indicators considered under each dimension and provides references to previous studies that have employed quantitative empirical methodologies to relate them to entrepreneurship, RE, or CRE developments. Based on this previous literature, the expected sign of the relationship of each indicator with the suitability of the municipality to develop rural CRE projects is defined. Appendix A.2 develops an extensive explanation of these relationships, while Appendix A.3 shows descriptive statistics on the indicators.

The Demand-Side Economic Capital (DSEC) contains 8 indicators measuring different aspects related to the drivers of demand (population, employment and firm densities, migration rate, receivers of welfare payments, change in unemployment, distance to urban centers and labor self-containment). The Supply-Side Economic Capital (SSEC) involves 7 indicators related to the investment capacity of the municipality (population growth, qualified share of contracts, gross income, net variation of companies, municipal goods and services expenditures, number of bank offices, and municipal debt). The Human Capital (HC) includes 8 indicators capturing the availability of skilled potential community members (10-year population growth, immigrant population, population between 25 and 64 years, population replacement, qualified labor force, female labor force, employment in the private sector, self-employment, and unemployment rate). Social capital (SC) includes 9 indicators measuring determinants of the essential network cohesion and trust needed to overcome collective action problems (voter turnout, cooperatives, cultural/sport/leisure centers, social service entities, healthcare centers, primary/secondary schools, healthcare personnel, clubs/associations, and native population). Physical Capital (PC) is formed by 6 indicators showing the available infrastructure (selective waste disposal, wastewater purification service, water supply, sewage systems, broadband wireless internet, and Universal Mobile Telecommunications systems). Natural Capital (NC) is represented through 8 indicators (protected land area, tourist places, cultural interest places, forest and agricultural land, second homes, controlled bath areas, burned area, and certified ecological producers). Finally, the Renewable Energy Potential (REP) employs 9 indicators to measure solar, wind, geothermal, biogas, and small-hydro energy availability.

3.3. Method

Composite indicators are powerful instruments to define complex multidimensional concepts that cannot be easily described with a single indicator. Although its use is not without criticism [118], they can contribute to visualizing or demanding attention upon important issues that require social or policy intervention [119,120] and facilitate communication between researchers, policy makers, and the public [121]. The construction of a composite indicator involves several steps [116,122]. After selection of the individual indicators, the next steps involve data collection, analysis, and preparation (normalization

and/or standardization), weighting (equal weighting or PCA), aggregation (linear/additive or geometric/multiplicative), and sensitivity or robustness analysis.

To account for the sensitivity and robustness of the CRERAL index, and following Salvati and Carlucci [119] and Tapia et al. [115], this study considers the alternative application of PCA (through the R Studio software, version 2025.05.1+513) and Equal Weighting (EW) as weighting methods, and of arithmetic average (AA) and geometric average (GA) as aggregation methods, both in the construction of each of the seven dimensions and in their combination into the final index. This yields eight possible configurations of the index. That with the highest correlation with the others will be selected [119].

3.4. Data Collection

Data for the different indicators were obtained from public statistical sources. Most indicators were directly captured from Statistics Portugal [123], with no transformation, while others needed some transformation. Most of the indicators were calculated as average values from 2014 to 2023 to avoid the effect of coincidental occurrences on a particular year [102]. Data for some indicators are taken only for the last available year due to data availability restrictions or the nature of the indicator, i.e., since indicators in the physical capital dimension are assumed to be cumulative through time, there is no sense in considering them as average values. Although the indicators selected in the present study cannot be considered an exhaustive description of the Northern Portugal context, they provide a broad picture of the economic, social, human, physical, and natural capital, including the RE potential, of its municipalities.

3.5. Index Construction

3.5.1. Standardization and Normalization of Indicators

All indicators were visually supervised for atypical values by means of box plots [115]. Different transformation methods were tested for each indicator (logarithms, square roots, square, cubic root, and quadratic root). The transformation methods that mostly reduce skewness within the distribution, if any, were selected for each indicator (see Appendix A.3). Four indicators whose atypical values and skewness were not reduced with any of the alternative transformation methods were removed from their respective dimensions, so that the final data set consists of 54 indicators.

Given the different magnitudes of the chosen indicators [116], a Min-Max standardization was needed [119,124]. Based on the positive or negative contribution of each indicator to the index (Table A1), Equations (1) and (2) are respectively applied.

$$z(x_{i,j}) = \frac{x_{i,j} - x_{minj}}{x_{maxj} - x_{minj}} \quad (1)$$

$$z(x_{i,j}) = 1 - \frac{x_{i,j} - x_{minj}}{x_{maxj} - x_{minj}} \quad (2)$$

where $x_{i,j}$, represents the value of the indicator j for a municipality i , and x_{maxj} and x_{minj} the maximum and minimum values of the indicator across all municipalities.

3.5.2. Weighting of Indicators and Dimensions

To calibrate the contribution of each indicator to each capital sphere, as well as the contribution of each capital to the final index, EW and PCA were alternatively considered. The Keiser–Meyer–Olkin (KMO) measure of sampling adequacy is used to test the suitability of the data set for the application of PCA [116,119,121], considering acceptable values above 0.5 [116]. All the dimensions show a KMO greater than 0.6 except the economic supply-side capital (0.59) and the social capital (0.5). The internal consistency of each

capital is also tested with Cronbach's, resulting in values higher than 0.5 for all capitals. As noted by Tapia et al. [115], high values for this test were not expected given the nature of the individual indicators. The physical capital dimension shows the higher KMO (0.85) and Cronbach's Alpha (0.85).

PCA was retained as an appropriate weighting method despite the moderately low KMO values for all capital spheres, since the variance accumulated by the PCs exceeded the 70% threshold (except for NC with 65.62% and REP with 69.94%), confirming that the PCA successfully captures the vast majority of the underlying information within the dataset. Moreover, Bartlett's test of sphericity proved significant across all capital components, rejecting the null hypothesis that the correlation matrix is an identity matrix and thereby confirming that sufficient correlation exists among the indicators to warrant the application of factorization techniques like PCA [125].

Three criteria are considered to extract the PCA PCs based on the correlation structure shown by the indicators (for each capital subindex) and capitals (for the final CRERAL index) [115,126]: (i) eigenvalues larger than one; (ii) individual contribution to overall variance greater than 10%, and (iii) cumulative contribution to overall variance greater than 60%. Varimax rotation, as the most common rotation method [116], was applied to minimize the number of variables with a high loading on a specific PC [121] and maximize the variance of loadings [115].

Following Tapia et al. (p. 149), PCA weights were derived from the matrix of factor loadings after rotation: "... first, square factor loadings are computed; subsequently, weighted intra-factor loadings are calculated by dividing the square factor loadings by the proportion of variance explained by each factor; then across-factor weighted loadings are generated by dividing intra-factor weighted loads by the proportion of variance explained by each factor in relation to the total cumulative variance explained by all factors; finally, those individual indicators with the highest factor loadings across all factors are selected and re-scaled to unity, as final weights. ..." [115].

3.5.3. Aggregation of Indicators and Dimensions

Since the presence of some indicators with zero values impedes the possibility of applying a GA to obtain each one of the seven sub-indices representing each one of the seven capital dimensions considered (it would cancel out a whole dimension for certain municipalities), the AA is applied. Nevertheless, to obtain the CRERAL index for each municipality through the combination of these seven sub-indices, AA and GA aggregation methods were alternatively considered. Instead of deciding a priori the weighting and aggregation method to be applied to configure the final index, a greatly subjective decision, this procedure incorporates a certain degree of objectivity and a high degree of transparency into the index construction and allows for direct dealing with the analysis of its sensitivity and robustness.

3.5.4. Index Construction Under a Sensitivity and Robustness Analysis

Eight possible configurations (A to H) of the CRERAL index are tested (Table 1).

Following Salvati and Carlucci [119], Spearman's rank correlation coefficient between the eight models is computed to select as the most stable and reliable the one that maximizes the observed pair-wise correlation coefficients.

Table 1. Alternative models for CRERAL index construction under different combinations of weighting and aggregation methods.

MODEL	DIMENSIONS/SUB-INDICES		CRERAL INDEX	
	Weighting	Aggregation Methods	Weighting	Aggregation Methods
A	PCA	AA	PCA	AA
B	PCA	AA	PCA	GA
C	PCA	AA	EW	AA
D	PCA	AA	EW	GA
E	EW	AA	EW	AA
F	EW	AA	EW	GA
G	EW	AA	PCA	AA
H	EW	AA	PCA	GA

Source: own elaboration.

4. Results

4.1. Description of Components Analysis and Weights of Indicators

Table 2 shows the factor loadings derived from a PCA for each one of the seven sub-indices related to the seven capital dimensions considered.

For the DSEC (eight indicators), four PCs are extracted, with eigenvalues larger than one and explaining 80.14% of the total variance. PC1 explains 51.55% of variance and is mainly related to Population density, Herfindahl index, Firm density, and Distance to metro area with a population of more than 50.000. PC2 explains 16.71% of variance and is related to Per capita net migration rate and Labor self-containment, Per capita GDP, Average firm size, and firm density. PC3 is related to the Share of the population with welfare payments and Unemployment change.

For the SSEC (seven indicators), four PCs that explained 71.66% of the total variance are extracted. PC1 explains 28.31% variance and is related to Share of registered contracts with higher education degrees on total registered contracts, Per capita gross income, and Number of bank offices per 1000 people. PC2 explains 25.42% of variance and is related to the Annual population growth rate, Share of goods and services expenditure in total municipalities' expenditure, and Per capita municipal debt. PC3 explains 17.92% of the variance and is related to the Change in the number of firms.

For Human Capital (nine indicators), 82.95% of the total variance is explained through three PCs. PC1 explains 51.93% of variance and is related to the Share of population between 25 and 64 years old of the total population, Population replacement index, the Female labor force participation rate, the Share of employment in the private sector, and the Share of self-employment. PC2 explains 17.76% variance and is related to the 10-year population growth rate and the Unemployment rate. PC3 explains 13.26% of variance and is related to Share of immigrant population on total population and Share of labor force with higher education.

For the Social Capital sub-index (nine indicators), four principal components that explain 70.28% of the total variance were extracted. PC1 represents 26.20% of variance and is mainly related to the Number of cultural, sport, or leisure centers per 1000 people, the Number of healthcare centers per 1000 people, the Number of primary and secondary schools to population under 16 years, and the Number of clubs and associations per 1000 people. PC2 explains 19.31% of variance and is related to Number of cooperatives per 1000 people and Number of healthcare personnel per 1000 people. PC3 explains 13.24% of the variance and is related to the Share of the population born and residing in the municipality. PC4 explained 11.54% of variance and is related to the Ratio of voter turnout

for the municipal elections to voter turnout in general elections and the Number of social services entities per 1000 people.

Table 2. PCA Factors loadings.

DSEC	Factors Loadings	PC	Factors Loadings
POP_DEN	0.006926673	POP_WAS	0.360920845
NET_MIG	0.167103409	POP_PUR	0.573534444
POP_WEL	0.323958667	POP_WAT	0.012750541
UNE_CHG	0.324516188	POP_SEW	0.013345498
HER_INX	0.033711132	POP_INT	0.013008129
FIR_DEN	0.012134454	POP_UMT	0.012454655
DIS_MET	0.018346188		
LAB_SEL	0.113303289		
SSEC	Factors loadings	NC	Factors loadings
POP_GRW_A	0.091797222	PRO_LAN	0.137121330
JOB_EDU	0.085693700	TOU_PLA	0.371127906
INC_CAP	0.097594015	CUL_INT	0.082643449
FIR_CHG	0.433494263	FOR_AGR	0.156535815
MUN_EXP	0.116352131	SEC_HOM	0.024603552
BAN_OFF	0.057921595	FOR_FIR	0.177971776
MUN_DEB	0.117147075	ECO_FIR	0.049996172
HC	Factors loadings	REP	Factors loadings
POP_GRW_10	0.182086462	POT_WIN	0.116236585
POP_INM	0.253937321	POT_SOL	0.083641134
POP_25_64	0.007838982	POT_GEO	0.046722737
POP_REP	0.007604693	POT_BGS	0.068180319
POP_EDU	0.361976151	POT_SHY	0.191510324
POP_FEM	0.008342582	PRO_LAN_RN2000	0.400504019
PRI_EMP	0.007189741	ICP_WIN	0.036134215
SEL_EMP	0.008125025	ICP_SHY	0.057070667
UNE_RAT	0.162899042		
SC	Factors loadings		
VOT_TUR	0.286808510		
COOP_No	0.088635741		
CUL_CEN	0.044305075		
SOC_SER	0.087330460		
HEA_CEN	0.027068379		
SCH_No	0.042835509		
HEA_PER	0.111787581		
ASSO_No	0.036727986		
POP_B&R	0.274500759		

Source: own elaboration.

Natural Capital (7 indicators) is represented through four PCs that explain 65.62% of the total variance. PC1 explains 27.71% variance and is related to the Number of goods of cultural interest per square km of land area, the Share of second homes, and the Share of certified ecological producers relative to the total number of firms in the agro-forestry industry. PC2 explains 20.61% variance and is related to the Share of forest and agriculture land area relative to total land area and Share of land area annually burned in forest fires. PC3 explains 17.30% of variance and is related to Share of protected land on total land area and Number of places in tourist accommodation per 1000 people.

PCA on Physical Capital (6 indicators) returns only two PCs that explain 73.05% of the total variance. PC1 explains 48.39% of variance and is related to Share of population with

wastewater purification service of total population, Share of population with water supply on total population, Share of population with sewage system on total population, and Share of population with Universal Mobile Telecommunication System on total population. PC2 explained 24.66% of the variance and is related to Share of population centers with selective waste disposal on total population and Share of population with broadband Wireless Internet on total population.

Finally, for RE Potential (eight indicators), three PCs that explain 69.94% of the total variance were extracted. PC1 explains 33.45% of variance and is related to Geothermal potential, Biogas potential, installed capacity in windparks and installed capacity in small hydro plants. PC2 explains 20.08% variance and is related to Wind potential and Small hydro potential. PC3 explains 15.84% of variance and is related to Solar potential and Share of land area included in Red Nature 2000.

4.2. Model Selection

To select the most stable CREAL index, an exploratory analysis based on the Pearson correlation coefficient was performed, as explained in Salvati et al. [119]. Table 3 illustrates the Pearson's correlation coefficient matrix between the index scores obtained from the eight models. The model that maximizes the observed pair-wise correlation coefficients is selected as the most stable and reliable one. Model E is the only one that shows correlation coefficients higher than 0.65 with the rest of the models.

Table 3. Correlation matrix (Pearson's rank coefficients) between the scores obtained in the eight alternative configurations for the CRERAL index.

	A	B	C	D	E	F	G	H
A	1.000							
B	0.979	1.000						
C	0.737	0.741	1.000					
D	0.683	0.735	0.948	1.000				
E	0.676	0.725	0.782	0.784	1.000			
F	0.671	0.733	0.776	0.815	0.987	1.000		
G	0.675	0.685	0.489	0.499	0.763	0.734	1.000	
H	0.694	0.712	0.511	0.538	0.775	0.758	0.995	1.000

Source: own elaboration.

Salvati and Carlucci [119] also suggest identifying the most stable model that minimizes the pair-wise absolute difference in ranks of each municipality under each model. Table 4 shows that model E offers the lowest values, and we confirm it as the most reliable and stable one.

Finally, it is informative to compare whether there are significant differences among the municipalities ranking higher and lower in the eight possible configurations. As Table 5 shows, there is some consistency in the first positions (ranks 1 to 3) of all the models where PCA weights are applied to construct each capital dimension (models A to D) and of those where EWs are used (models E to H). Moreover, it should be noted that the municipality of Penedono, with the first position in model E, appears among the first three positions in another four models. Regarding positions 43 to 45, the same consistency in the ranked municipalities in models A to D and E to H is verified. This confirms a certain degree of robustness of the proposed methodology for the construction of the CRERAL index. We can also conclude that the impact of deciding between EW or PCA weights in the construction of the seven sub-indices is higher than in the case of the final index configuration.

Table 4. Average pair-wise absolute difference in ranks under each alternative model for the construction of the CRERAL index.

	A	B	C	D	E	F	G	H	Average Rank Difference
A	0								8.2016
B	4.117	0							6.9760
C	8.877	6.957	0						6.1147
D	12.394	9.406	5.222	0					7.5055
E	10.485	8.757	5.402	6.637	0				5.6962
F	11.763	9.324	6.598	5.754	2.195	0			6.3244
G	8.922	8.842	8.118	10.769	6.477	7.993	0		6.5844
H	9.054	8.406	7.743	9.863	5.615	6.968	1.555	0	6.1505

Source: own elaboration.

Table 5. Municipalities ranking highest and lowest in each alternative configuration of the CRERAL index.

Rank	A	B	C	D
1	Vila Flor	Vila Flor	Vila Flor	Vila Flor
2	Valpaços	Tarouca	Tarouca	Tarouca
3	Tabuaço	Sernancelhe	Penedono	Armamar
		(...)		
43	Ponte de Barca	Mondim de Basto	Ponte de Barca	Cabeceiras de Basto
44	Mondim de Basto	Santa Marta de Penaguião	Resende	Baião
45	Santa Marta de Penaguião	Cinfães	Cinfães	Cinfães
Rank	E	F	G	H
1	Penedono	Mogadouro	Valpaços	Penedono
2	Mogadouro	Penedono	Penedono	Valpaços
3	Vila Nova de Foz Côa	Tarouca	Macedo de Cavaleiros	Macedo de Cavaleiros
		(...)		
43	Celorico de Basto	Baião	Cabeceiras de Basto	Vinhais
44	Cabeceiras de Basto	Celorico de Basto	Vinhais	Cabeceiras de Basto
45	Cinfães	Cinfães	Santa Marta de Penaguião	Santa Marta de Penaguião

Source: own elaboration.

4.3. Classification of the Northern Portugal Municipalities According to the CRERAL Index

Once that model E (AA on EW weights for each dimension and AA on EW for the final index) has been chosen as the most reliable and stable configuration for the CRERAL index, its geographical distribution and that of its seven sub-indices are represented in Figure 1. Appendix A.4 shows the scores of the CRERAL index and sub-indices for all the 45 municipalities, and Appendix A.5 shows the ordered ranking of municipalities. For the sake of simplicity and clarity, the scores were rescaled to a range between 0 and 1, with 1 corresponding to those municipalities with the greatest potential for the development of CRE projects.

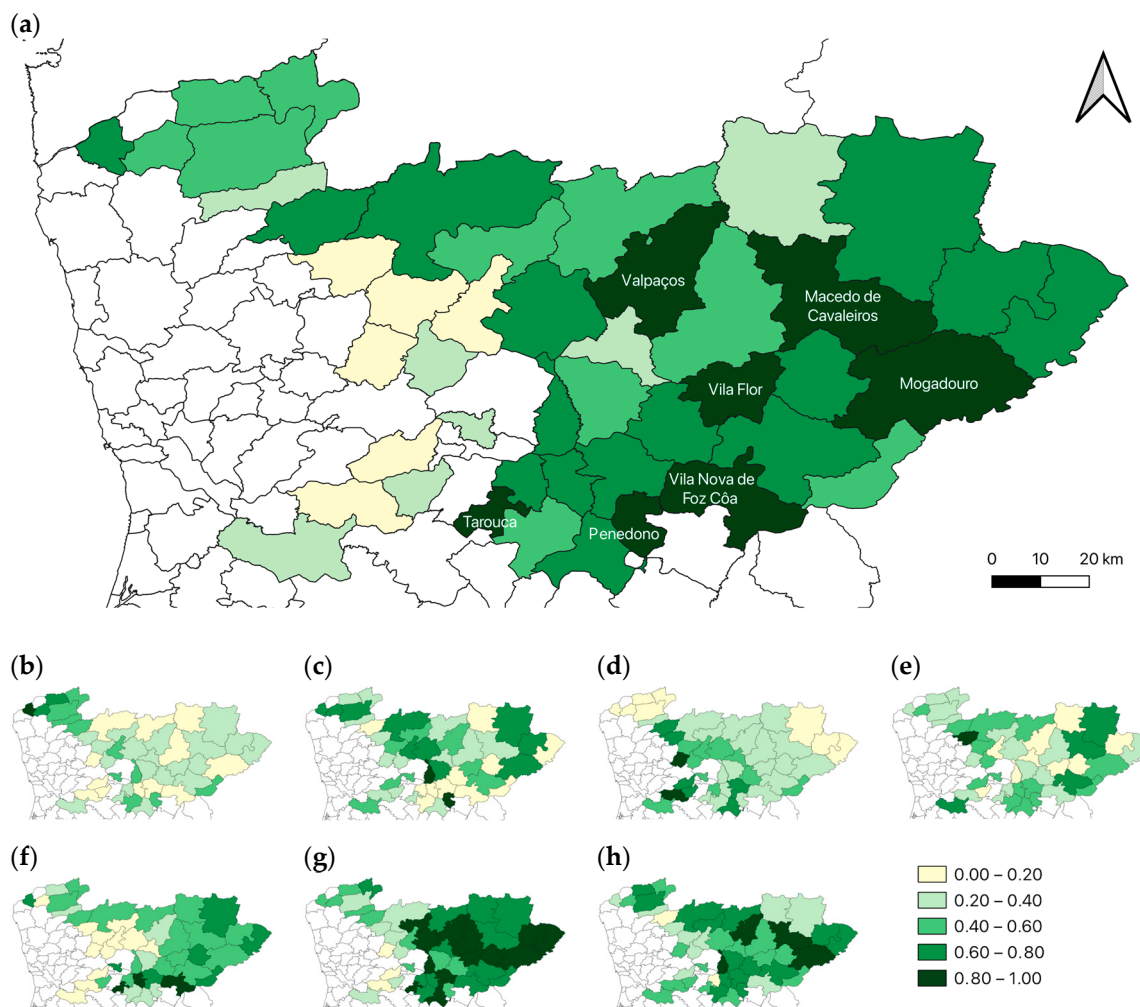


Figure 1. (a) CRERAL index; (b) Demand-side Economic Capital Index; (c) Supply-side Economic Capital Index; (d) Human Capital Index; (e) Social Capital Index; (f) Natural Capital Index; (g) Physical Capital Index; (h) RE Potential Index.

The analysis identifies 22 municipalities with a high potential (>0.6) for the development of CRE projects (Figure 1a). These municipalities are mainly concentrated in the south and southeast of Northern Portugal. 17 municipalities show a medium potential (between 0.2 and 0.6) for the development of CRE projects, and 6 municipalities a low potential (<0.2).

The analysis of the results for each dimension is also interesting. Regarding Economic DS, 3 municipalities show high potential, 30 municipalities medium potential, and only 12 municipalities a low potential (Figure 1b). In relation to Economic SS, 12 municipalities have high opportunities, 22 municipalities are classified with medium opportunities, and 11 municipalities have low potential. The Human capital dimension identifies 8 municipalities with a high value, 29 with medium potential, and 8 municipalities with low potential (Figure 1d). The social capital dimension shows 5 municipalities with high potential, 31 municipalities with medium potential, and 9 municipalities with low potential (Figure 1e). Figure 1f shows the results related to Natural Capital: 10 municipalities have high potential; 23 municipalities have medium potential, and 12 have low potential. Regarding Physical Capital (Figure 1g), 25 municipalities have high potential, 17 municipalities represent medium potential, and only 3 municipalities have low potential. Finally, the RE Potential dimension shows 18 municipalities with high values, 25 municipalities with medium values, and 2 municipalities with low values (Figure 1h).

The analysis of the decomposition of the overall index into its seven dimensions allows for a better understanding of the multidimensional nature of the suitability of a specific municipality to foster the development of a CRE initiative. As can be seen in Table 6, the municipality of Penedono, ranked in the first position of the CRERAL index, shows an outstanding position in the DSEC, SSEC, and REP dimensions. In relation to the DSEC, Penedono stands out in variables such as migration rate, share of population with welfare payments, unemployment change, and firm density, which reflect population and business dynamism. In relation to SSEC, a low municipal debt and a high number of bank offices, gross income, and annual population growth rate stand out, evidencing a robust financial and demographic structure capable of sustaining new investments. In relation to REP, Penedono gathers a solid technical foundation for CRE projects relying on solar, wind, and geothermal potential, with an already high installed capacity in small hydro plants. In the other hand, Penedono ranks low in the human capital, natural capital and physical capital, that contain fewer variables in which it performs comparatively well: within the human capital, it only exhibits relatively favorable results in share of immigrant population, share of labor force with higher education, and share of self-employment; in the natural capital, in share of second home and share of land area annually burned in forest fires; and in the physical capital, only in share of population with broadband Wireless internet. Mogadouro, which ranks second in the overall index, stands out in the physical capital and RE potential dimensions, and ranks low in the DSEC. Rather differently, the third municipality in the CRERAL index, Vila Nova de Foz Côa, is only among the first ten municipalities in the natural capital dimension, showing more modest positions on the rest of the dimensions.

Table 6. Rank in the sub-indices of the three higher and three lower ranked municipalities in the CRERAL index.

	CRERAL Index	DSEC	SSEC	HC	SC	NC	PC	REP
Penedono	1	8	1	31	13	30	30	10
Mogadouro	2	41	9	27	9	21	3	3
Vila Nova de Foz Côa	3	36	45	34	36	1	23	35
			(...)					
Celorico de Basto	43	45	32	1	21	36	43	33
Cabeceiras de Basto	44	28	16	13	7	45	41	38
Cinfães	45	44	25	2	24	42	45	24

Source: own elaboration.

Regarding the three municipalities with the lower scores in the CRERAL index, they show consistently low values across all dimensions. The cases of Celorico de Basto and Cinfães are interesting as they show good levels of human capital but humble scores in the other dimensions. If we examine in detail the last position in the CRERAL index, Cinfães, we observe that in the human capital dimension it performs well in variables such as share of labor force with higher education, unemployment rate, share of immigrant population, female labor force participation, share of employment in the private sector, and share of population between 25 and 64 years old, which reveals an active, qualified, inclusive, and diversified population, potentially able to efficiently manage CRE projects in the long term. By contrast, in the remaining capital dimensions there are no variables in which it stands out compared with other municipalities; in the physical capital dimension it occupies the last position in the CRERAL index, and variables such as share of population centers with selective waste disposal, share of population with water supply, share of population with broadband Wireless internet, and share of population with sewage system are among those with the lowest values.

This approach allows for reinforcing the idea that the development of a CRE initiative is absolutely place-dependent and needs planning and implementation strategies clearly tailored to the specific conditions of a concrete local context, i.e., attending to the stronger or weaker position of each municipality in all the capital dimensions and adapting the type and scope of CRE to this assessment. As highlighted by Herbes et al. [89], each CRE project must be aware of its specific resources. The flexible, adaptive, and diverse nature of the CRE concept (different technologies, scales, organizational and ownership structures, planning and implementation processes, or motivations) facilitates the development of CRE projects fitted to each specific local context [12]. The development of CRE projects in the municipality of Penedono should probably require previous efforts to strengthen its human capital, natural capital, and physical capital. On the contrary, the high RE potential, together with strong demand-side and supply-side economic capitals, facilitates the deployment of a more integrated and balanced RE portfolio. Mogadouro would also demand specific forms of financial support to compensate for the lack of a strong DSEC, although it has a high RE potential that would facilitate the development of CRE projects. As for Vila Nova de Foz Côa, it requires specific actions across the different capitals aimed at improving their management. On the other side, those municipalities with the lower scores would probably demand a high degree of intervention to achieve successful CRE developments with an integral positive contribution to rural development, with costs that could maybe exceed the benefits.

5. Discussion

Table 6 provides several additional, relevant insights into how different capitals interact to drive high rankings in the CRERAL index. It is, for example, interesting to see that PC is the dimension that more consistently shows high values in the higher positions of the CRERAL index and low values in its lower positions. This confirms the importance of public infrastructure as a basic element of local development, as suggested by Krakowiak-Bal et al. [97] or Avramenko and Silver [127]. The REP shows a similar, although less clear, pattern. Anyway, the possibility of combining many different RE technologies justifies the credibility of considering that a municipality ranking medium to low in REP can, anyway, foster a successful CRE if it is sustained by an outperforming position in other capitals [89]. SSEC is also one of the capital spheres where the two municipalities ranking higher in the CRERAL index stand out, while the worst performers in the index show medium values for this dimension, highlighting the relevance of a high financial capacity to support CRE investments [9,91]. A final important remark is related to the SC and HC dimensions, which show medium to low values in the municipalities ranking higher in the index. Although higher SC values should be preferred as a previous condition to launch a CRE initiative, it is also important to remember that previous literature has pointed out the great capacity of CRE for improving SC [19,49]. Moreover, previous successful CRE experiences have demonstrated the crucial role of stakeholder participation and trust building, meaning that a low SC can be counteracted with a proper CRE planning process, a role that frequently falls to the municipal government [7,8,29]. Regarding HC, previous research has also pointed out the need to provide CRE promoters with specific management skills [84] or even involving private energy companies, compensating for the lack of a qualified critical mass of potential community members.

CRE holds the key to accelerating the energy transition and achieving SRD, and CRE initiatives should expand across all types (developed and underdeveloped) of urban and rural contexts. The CRERAL index could help to identify where the first efforts to consolidate rural CRE projects should be focused. Further expansion of CRE in localities with a poorer capital base will be easier when successful initiatives can be imitated and

shared. Wüste and Schmuck [128] describe how, after the successful implementation of the Jühnde bioenergy village in 2006, the district of Goettingen initiated a follow-up project that resulted in another four bioenergy villages being realized in 2010. Cooperation between CRE projects [90] or the possibility of joining efforts between municipalities [10,60] can be crucial. Moreover, successful CRE projects can create positive spillover effects on the economic development of neighboring municipalities [129], becoming a driving force of an endogenous rural development [130] and an endogenous sustainability transition [81].

The contribution of CRE to rural development would nevertheless need a set of regional and sectoral policies simultaneously targeting the development of CRE projects and the promotion of local economic activity, supporting both energy supply and energy demand [81]. These policies should be flexible and adapt to rural communities' structural disadvantages [67] and specific features [131], embedded in the concept of countryside capital [99]. CRE can change the perception of REs as an exclusive environmental matter related to climate change mitigation to a powerful instrument of socioeconomic development, contributing to solving the unrealized synergies between SRD and REs [132]. Thus, although policy has been a barrier for CRE in many national contexts, such as the Spanish one, CRE developments could also become an enabler for better energy policy [12,133], leading to the consideration of RE as an integral and critical element of both rural development plans and energy plans [5,17].

Apart from the five capital spheres containing specific factors in specific locations at the municipal level that will configure the proposed CRERAL index, the development of CRE projects obviously depends on the policy framework [41,106,134]. To guarantee a positive contribution of CRE to SRD, an approach adapted to local conditions and focused on the competitiveness of rural areas is needed [11]. Policies pursuing the energy transition should recognize local socio-geographic important factors [78,135]. And Starick et al. [136] demand a system approach to energy planning, accounting for the interconnections of energy, landscape, and society. This should help to avoid ill-conceived energy policies with adverse impacts on land and local ecosystems [71]. Roesler and Hassler [137] and Wehbi and Kemper [1] also acknowledge the importance of complementarity of national and local/regional political support, with an increasing relevance of the municipal level [8].

A crucial issue is the decrease in the financial risk of CRE projects. Policy makers need to identify which instruments are the most effective in supporting CRE projects from the perspective of risk reduction [31]. But apart from policy support, formal and informal institutions and new business models could be determinant to the consolidation of CRE initiatives in rural areas and the reduction in their financial risk. Mey and Diesendorf [90] describe the important role of a Danish not-for-profit trading company offering fixed prices in power purchase agreements for individual and collective wind projects. Besides the relevance of establishing partnerships, Herbes et al. [84,89] also point to the necessary professionalization of the management of CRE projects to mitigate their risk. The CRERAL index could also play a relevant role as an instrument of risk mitigation, reducing the risk associated with choosing sub-optimal locations [69].

It is important to reiterate that the CRERAL index assesses potential suitability rather than realized project performance. The CRERAL index allows directing scarce public funds to the highest-ranking regions where the combination of economic feasibility, social acceptance, and natural potential guarantees the highest probability of project success. This also increases confidence from private capital.

Policy makers can also identify with the CRERAL index the limited availability of a particular capital in a specific location, and design tailored policies to improve that dimension and facilitate the positive contribution of CRE to SRD [138], i.e., a low SC may prompt investment in local cooperative support or trust-building workshops, while a low

HC may trigger new technical training programs. Thus, decision-makers can strategically elevate a region's readiness score over time.

From the alternative methodological approaches available, the CRERAL index relies on a transparent and easily understandable configuration, acknowledging as a limitation that different weighting methods can have a significant influence on the index values. Nevertheless, this can also be assumed as a strength of the proposed methodology, since the possibility of using PCA or EW as weighting methods, or even any other approach (fuzzy-TOPSIS, AHP, expert judgement) can allow the decision-makers (either policy designers or CRE promoters) to adapt the index to their preferences or previous assessment of the relevant variables or weights in a specific region or local context [139,140].

For promoters of rural CRE initiatives, the CRERAL index can help them realize that different resource configurations in different locations can condition not only project feasibility, but also project configuration (RE technologies deployed, degree of community involvement, or ownership structure).

Researchers can find in the CRERAL index an open door to suggest alternative configurations or adapt it to consider emerging RE technologies [141], integrating economic feasibility considerations [71], adding vulnerability in the assessment of rural areas [62], accounting for unsuitable areas for RE facilities [63,70], or considering the percentage of energy self-sufficiency [60,142]. Furthermore, and rather interestingly, in those countries where CRE has experienced a great development, such as Germany or Austria, the CRERAL index (with the same or an alternative specification) could be validated, testing whether those places with more successful CRE development are also those ranking higher in the index. The CRERAL index could also be applied on a yearly basis to control the progress of specific municipalities towards being optimal candidates for the location of rural CRE.

6. Conclusions

This study focused on the analysis of CRE initiatives in European rural areas, where they can contribute to stopping depopulation trends, revitalizing their economy, fighting climate change, and guaranteeing proper management of their natural resources. Given that CRE is a rather new phenomenon, and that academic research has not paid enough attention yet to the identification of the relevant preconditions for its development, this study contributes to filling an important gap in the literature.

The contributions made in this study are important from the policy, practice, and research perspectives. Policy makers could consider the CRERAL index in energy planning and base public funding decisions on the a priori assessment of at which place they could be more effective [33]. Practitioners could identify those areas with the best conditions to start the process of creating a rural CRE and gather the necessary community support [32]. Researchers concerned about SRD could orient their future research towards the study of how different forms of capital contribute to the success of CRE projects in rural contexts [66] and pay bigger attention to the analysis of their impacts, as demanded by Creamer et al. [143]. The proposed CRERAL index can also provide an appropriate framework for this purpose as a composite measure of the impacts of rural CRE projects.

Although the use of composite indicators is considered controversial due to both conceptual and methodological issues [118], they are valuable to demand and focus attention on specific topics and stimulate discussion and public interest [119,120]. The CRERAL index is not enough to decide where to launch a rural CRE project. Once a potential site is secured, comprehensive efforts must be undertaken to manage and evaluate all implementation factors, including processes for planning, achieving social acceptance, and resolving technical and financial constraints. Furthermore, the entire energy system, from production

to delivery, demands a thorough environmental, economic, and social impact assessment to ensure sustainability goals are met [144].

The primary drawbacks of this research stem from those issues common to any effort relying on aggregated indicators. Such measures risk generating misleading conclusions unless underpinned by a highly rigorous and transparent methodology [145]. While we made every attempt to minimize subjective judgments in the creation of the CRERAL index, some inherent subjectivity remains, particularly in selecting the variables and determining their expected directional relationship with the larger sub-indices. Moreover, precisely defining and quantifying abstract concepts like rural development is perpetually difficult, frequently being hindered by limited data availability. Future work should prioritize efforts to enhance data collection protocols or identify novel sources of information. Nevertheless, these limitations do not diminish the potential impact of the index. When coupled with suitable financial resources, strong partnerships, and supportive policy, the tool developed here can be a key mechanism for accelerating the expansion of CRE projects, driving sustainable energy transition, and achieving SRD. This study also leaves open an interesting future application of the CRERAL index, related to potential future validation with implemented CRE projects, and many possible adaptations, such as the integration of economic feasibility considerations.

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Abbreviations

The following abbreviations are used in this manuscript:

CRE	Community renewable energy
SD	Sustainable development
SET	Sustainable energy transition
RE	Renewable energy
SRD	Sustainable rural development
CRERAL	Community renewable energy in rural appropriate locations
PCA	Principal components analysis
RMT	Resource mobilization theory
SPAs	Special Protection Areas
EW	Equal weighting
KMO	Keiser-Meyer-Olkin
PC	Principal components
AA	Arithmetic aggregation
GE	Geometric aggregation
DSEC	Demand-side economic capital
SSEC	Supply-side economic capital
HC	Human capital
SC	Social capital

PC	Physical capital
NC	Natural capital
REP	RE potential
UMTS	Universal Mobile Telecommunications System

Appendix A

Appendix A.1. Indicators considered in each dimension of the CRERAL index.

Table A1. Indicators considered in each dimension of the CRERAL index.

Code	Indicator	Period	Sign	Related References
<i>Demand-side economic capital (DSEC)</i>				
POP_DEN	Population density (Total resident population per square km; all population figures refer to the population on the 1st of January)	2014–2023	(+)	[100,129,146–148]
NET_MIG	Per capita net migration rate (difference between the number of people entering and leaving the municipality during the year, per 1000 people)	2014–2023	(+)	[149,150]
POP_WEL	Share of population with welfare payments	2014–2022	(–)	[67]
UNE_CHG	Unemployment change	2021 census	(–)	[151]
HER_INX	Herfindahl index (sum of the squared employment shares in the main four economic sectors)	2021 census	(–)	[100,102,146]
FIR_DEN	Firm density (No firms per 1000 people)	2014–2023	(+)	[114,152,153]
DIS_MET	Distance to Metro Area with Population More Than 50,000	2024	(–)	[100,148]
LAB_SEL	Labor self-containment (share of resident workers who are employed within the boundaries of the municipality)	2021 census	(+)	[154]
<i>Supply-side economic capital (SSEC)</i>				
POP_GRW_A	Annual population growth rate	2014–2023	(+)	[102,146]
JOB_EDU	Share of registered contracts with higher education degrees on total registered contracts	2014–2023	(+)	[67,155]
INC_CAP	Per capita gross income (Gross Income/population)	2015–2022	(+)	[16,151]
FIR_CHG	Change in number of firms (ratio of net variation of companies, as difference between births and deaths, in year t, to total number of companies at the beginning of the year)	2014–2023	(+)	[100]
MUN_EXP	Share of municipal goods and services expenditures on total municipal expenditure	2014–2022	(+)	[147]
BAN_OFF	Number of bank offices per 1000 people	2014–2023	(+)	[146,148,153]
MUN_DEB	Per capita municipal debt (Municipal debt/population)	2014–2023	(–)	[29]
<i>Human capital (HC)</i>				
POP-GRW_10	10-years population growth rate (Population growth rate over a period of ten years)	2014–2023	(+)	[67,102]
POP_INM	Share of immigrant population on total population	2014–2023	(+)	[156–158]
POP_25_64	Share of population between 25 and 64 years old of total population	2014–2023	(+)	[147]

Table A1. Cont.

Code	Indicator	Period	Sign	Related References
<i>Human capital (HC)</i>				
POP_REP	Population replacement index (ratio of the elderly (ages 60–64) to the young (15–19))	2014–2023	(+)	[33]
POP_EDU	Share of labor force with higher education	2021 census	(+)	[33,100,147,152]
POP_FEM	Female labor force participation rate (percentage of the female population in the 16–64 age group)	2014–2023	(+)	[146,151]
PRI_EMP	Share of employment in the private sector (Number of employees in the private sector/Total number of employees)	2021 census	(+)	[102,147]
SEL_EMP	Share of self-employment (proportion of the self-employed among the private sector employees)	2021 census	(+)	[146]
UNE_RAT	Unemployment rate (in the 16–64 population group)	2021 census	(+)	[146–148]
<i>Social capital (SC)</i>				
VOT_TUR	Ratio of voter turnout for the municipal elections to voter turnout in general elections (Proportion of eligible voters who voted at the most recent local election, related to the proportion who voted in that same year's general election)	2021	(+)	[100,102]
COOP_No	Number of cooperatives per 1000 people	2023	(+)	Own proposal
CUL_CEN	Number of cultural, sports, or leisure centers per 1000 people	2014–2023	(+)	[148]
SOC_SER	Number of social services entities per 1000 people	2014–2023	(+)	[67,102]
HEA_CEN	Number of healthcare centers per 1000 people	2014–2023	(+)	[148]
SCH_No	Number of primary and secondary schools for the population under 16 years	2014–2022	(+)	[148]
HEA_PER	Number of healthcare personnel per 1000 people	2014–2023	(+)	[33,148]
ASSO_No	Number of clubs and associations per 1000 people	2023	(+)	[148]
POP_B&R	Share of population born and residing in the municipality relative to total population	2021 census	(+)	Own proposal
<i>Physical capital (PC)</i>				
POP_WAS	Share of population centers with selective waste disposal of total population	2023	(+)	[97]
POP_PUR	Share of population with wastewater purification service of total population	2022	(+)	[97]
POP_WAT	Share of population with water supply of total population	2022	(+)	[97]
POP_SEW	Share of population with a sewage system of total population	2022	(+)	[97]
POP_INT	Share of the population with broadband wireless internet of total population	2023	(+)	[67,98]
POP_UMT	Share of population with Universal Mobile Telecommunications System (UMTS) service of total population	2023	(+)	Own proposal

Table A1. Cont.

Code	Indicator	Period	Sign	Related References
<i>Natural Capital (NC)</i>				
PRO_LAN	Share of protected land area on total land area (Maximum area included in some protection figure: Natura 2000 Network, Special Protection Areas (SPAs) and protected areas)	2014–2022	(+)	[33,100]
TOU_PLA	Number of places in tourist accommodation per 1000 people	2014–2023	(+)	Own proposal based on Eimermann [101]
CUL_INT	Number of goods of cultural interest per square km of land area	2014–2023	(+)	Own proposal based on Korsgaard et al. [149]
FOR_AGR	Share of forest and agricultural land area relative to total land area	2015, 2019	(+)	Own proposal based on Dammers and Keiner [149]
SEC_HOM	Share of second homes	2021 census	(+)	Own proposal
BAT_QUA	Number of bath areas with quality controls per 1000 people	2014–2023	(+)	[152]
FOR_FIR	Share of land area annually burned in forest fires	2023	(−)	Own proposal
ECO_FIR	Share of certified ecological producers relative to the total number of firms in the agro-forestry industry	2019	(+)	[67,100,149]
<i>RE potential (REP)</i>				
POT_SOL	Solar potential (in W/m ²)	2024	(+)	[69,71]
POT_WIN	Wind potential (in W/m ²)	2024	(+)	[69,71]
POT_GEO	Geothermal potential (in MW/m ²)	2024	(+)	[159,160]
POT_BGS	Biogas potential (in m ³)	2019	(+)	[69,71,161]
POT_SHY	Small hydro potential (in km ²)	2024	(+)	[162]
PRO_LAN_RN2000	Share of land area included in the Red Natura 2000	2022	(−)	[69]
ICP_WIN	Installed capacity in wind parks	2024	(+)	Own proposal based on Langer et al. [161]
ICP_SOL	Installed capacity in solar plants	2024	(+)	Own proposal based on Langer et al. [161]
ICP_SHY	Installed capacity in small hydro plants	2024	(−)	Own proposal based on Corcoran et al. [162]

Source: own elaboration.

Appendix A.2. Justification of the Selection of Indicators Under Each Capital Dimension

DEMAND-SIDE ECONOMIC CAPITAL

Demand-side economic capital is related to market demand and the industrial structure at the municipality and is configured through 8 indicators. Regarding market demand, 6 indicators are considered: population density, per capita net migration, share of population with welfare payments, change in unemployment rate, labor self-containment, and distance to a metro area with a population of more than 50,000 inhabitants. A higher population density should mean higher access to both customers and inputs [129,147]. Positive net migration can have a positive impact on the socioeconomic viability of the area [149]. A low share of the population with welfare payments is considered an indication of strong local economic performance [67]. A decrease in unemployment creates entrepreneurial opportunities [151]. Kalantaridis and Bika [154] consider that the percentage of the workforce living within the same settlement where the enterprise is located

(related to labor self-containment) is a relevant market driver of rural entrepreneurship. And smaller distances to densely populated urban centers are related to higher productivity and economic activity in small rural municipalities [100]. Regarding the industrial structure, it is described through 2 indicators: the Herfindahl index (based on employment shares in the main four economic sectors) and firm density. The Herfindahl index measures the degree of concentration in the market; the closer to zero, the more intense the competition in the municipality, implying a negative relationship with new firm formation [103]. High firm density has been related to positive agglomeration and knowledge spillover effects on entrepreneurship [114,152].

SUPPLY-SIDE ECONOMIC CAPITAL

Supply-side economic capital depends on demographic characteristics of the population and their financial strength, and it is configured through 7 indicators: annual population growth rate, share of registered contracts with higher education degrees on total registered contracts, per capita gross income, change in the number of firms (birth rate—death rate), share of goods and services expenditures on total municipal expenditure, number of bank offices per 1000 people, and per capita municipal debt. Population growth may be a pull factor for entrepreneurship (placing additional strain on salaries and thereby lowering the opportunity costs for entrepreneurship), while population decline could have an adverse impact because it increases the risk of starting up a new venture [102]. A higher share of registered contracts with higher education degrees on total registered reflects a municipality's capacity to attract a qualified workforce with a stronger financial position [67,157], while greater per capita gross income implies more income available for investment [16,152]. Net firm population growth is related to a vibrant enterprise culture encouraging new firm formation [100]. A larger number of bank offices per 1000 people relates to the availability of financial resources [146,153]. Finally, contracting/outsourcing municipal activities can be seen as a direct local policy measure to promote entrepreneurship and as an indirect, inverted measure of local public employment [147], while more indebted municipalities could have limited capacity to develop local entrepreneurial policies or to commit funds to CRE projects [29].

HUMAN CAPITAL

Under the human capital dimension, nine indicators are considered: 10-year population growth rate, share of immigrant population on total population, share of population between 25 and 64 years old on total population, population replacement index, share of workforce with higher education, female workforce participation rate, share of employment in the private sector, share of self-employment, and unemployment rate. A high long-term decline in population reflects a structural limitation in the human capital resource base [130,163]. Immigrants augment the human capital available and, thus, enhance the economic development potential of rural areas [154,157,158]. Regarding population age structure, it is assumed that individuals of working age (25–64 years) have a higher propensity to start new firms compared with young people and pensioners [147], while a low population replacement index provides an indication of the potential social support requirements resulting from changes in population age structures [33]. On the other side, higher levels of education are associated with a higher potential for the emergence of new firms in fast-growing, knowledge-intensive sectors [147] and higher productivity and living conditions [33]. Although females have been traditionally considered a minority among the self-employed [146,151], and Fraune [164] finds a lower participation of women in CRE, we presume a positive relation to the CRERAL index based on Goetz and Rupasingha's [146] finding that female workforce participation is a precondition for self-employment in small rural non-adjacent counties. A higher share of public employment in total local employment can have a negative impact on new firm formation, since those privately employed

could show a higher entrepreneurial orientation [147]. Finally, Goetz and Rupasingha [146] find that the initial share of self-employed and the unemployment rate positively relate to self-employment growth.

SOCIAL CAPITAL

Previous literature related to entrepreneurship, RE, and CRE has mainly approached social capital through qualitative research. In order to gather quantitative indicators able to capture alternative social capital issues, and based on the statistical information available, we select 9 indicators for the social capital dimension of the CRERAL index. These indicators are aimed at grasping the abstract components of trust [57,88,112,165,166], cooperation [57], and place attachment [85,88] that define social capital. Previous literature has suggested that the degree of services (infrastructure, educational and medical facilities, and other public services) in a certain municipality may positively affect entrepreneurship, as they imply lower average start-up costs [102] and symbolize vitality in the countryside [167]. Deller et al. [148] employ the concentration of religious organizations, business associations, and civic and social organizations to reflect social capital and analyze its influence on business start-up rates in rural US counties. Previous community initiatives and experiences (cooperatives, associations, community land management) can be considered an expression of a strong social capital positively related to the suitability of a rural municipality to develop CRE initiatives. This motivates the inclusion of the following indicators as proxies for trust and cooperation: number of cooperatives per 1000 people, number of cultural, sport or leisure centers per 1000 people, number of social services entities per 1000 people, number of healthcare centers per 1000 people, number of primary and secondary schools to population under 16 years, number of healthcare personnel per 1000 people, number of clubs and associations per 1000 people. An additional indicator related to voter turnout is also included, as it reflects participation and involvement [100,102]. Regarding place attachment, we consider that the share of the population born and residing in the municipality relative to the total population is a good proxy.

PHYSICAL CAPITAL

The physical capital dimension is formed by 6 indicators, also limited to the available statistical data. Fuller-Love et al. [168] suggest that improvement in the physical infrastructure, particularly road networks, is necessary for enhanced economic activity. Krakowiak-Bal et al. [97] consider public infrastructure a basic element of local development, and employ five indicators related to water supply system, sewage system, gas network, communication accessibility, and illegal dumping sites. Agarwal et al. [100] analyze the influence of the length of motorways and/or dual carriageways on local development. Many authors have also acknowledged the fundamental role of information and communication technologies and broadband internet connection for rural development, as it allows rural entrepreneurs to overcome the disadvantages of being remote from urban areas [67,98,168,169]. Ultimately, infrastructure and information flows are vital for rural entrepreneurship [127]. The 6 indicators chosen are: share of population centers with selective waste disposal on total population, share of population with wastewater purification service on total population, share of population with water supply on total population, share of population with sewage system on total population, share of population with broadband wireless internet on total population, share of population with Universal Mobile Telecommunications System (UMTS) service on total population.

NATURAL CAPITAL

The natural capital dimension is configured through 8 indicators that embrace different aspects related to how countryside capital [99] or rural capital [158] contribute to rural development. The assets that configure the countryside capital are strongly related to the concept of natural capital, considered vitally important to sustain ecosystems and

human life [170] and to encourage or limit economic growth [100,149]. Natural assets and the quality of the environment are increasingly important for rural development, driving changes in agriculture (i.e., organic farming), energy production (i.e., RE generation) and, specially, in tourism and recreation [101], since the rural environment is nowadays seen as an area of consumption, and the parallel increase in green consumerism has created opportunities for farmers and entrepreneurs [100,149]. These natural assets include different perceptual or tangible natural, built, and social elements that support the economic growth, development, and performance of rural areas [99–101]. Previous literature has tried to capture these different elements through alternative indicators. As a proxy of the environmental quality of a given territory, Agarwal et al. [100] consider an index of natural beauty related to the surface catalogued as a protected area or similar figures, and Abreu et al. [33] the proportion of the Natura 2000 network area. In a similar vein, the share of protected land area on total land area is included in the natural capital dimension of the CRERAL index. An additional indicator related to the number of second homes in a municipality is considered a proxy for the natural beauty of a rural area. Moreover, since the tourism development of rural areas has been directly linked to the quality of their natural capital [101], the number of places in tourist accommodation per 1000 people is also included, as well as the number of goods of cultural interest per square km of land area, which is assumed to enable entrepreneurial opportunities [171]. Dammers and Keiner [149] acknowledge that agriculture and forestry are vital for the preservation of the rural landscape, so the higher share of forest and agricultural land area relative to total land area is assumed to positively contribute to rural entrepreneurship. Since in Galicia these assets are seriously threatened by wildfires, the share of land area annually burned in forest fires in each municipality is included as an indicator that negatively affects natural capital and rural development. Another related indicator included under this natural capital dimension is the share of certified ecological producers relative to the total number of agro-forestry firms [67,100]. Finally, natural amenities such as the number of bath areas with quality controls per 1000 people can also be relevant to represent an enhanced natural capital positively contributing to rural development [152].

RENEWABLE ENERGY POTENTIAL

Following Miramontes-Viña et al. [65], the dimension devoted to measuring the RE potential includes 9 indicators related to the potential deployment of six RE technologies: solar, onshore wind, geothermal, small hydro, and biogas. The extension of the CRERAL index to other regions would demand the integration of other technologies, such as marine or offshore wind energy. Biomass potential is also highly relevant, but information at the municipal level is not available in Portugal. The six indicators employed to measure the potential of RE generation with these five technologies are extracted from institutional databases with the support of GIS software, being their technical calculations similar to those applied in the previous literature [69,71,161,172].

RE potentials were calculated through the GIS software QGIS 3.40. To calculate each RE potential, two base layers were used: a raster layer of the potential of each RE technology in Northern Portugal, and a vector layer of the municipalities of Portugal, available in the Portuguese Public Administration Open Data service [173]. The QGIS tool “zone statistics” calculates the average of RE potential for each RE technology and municipality in Northern Portugal. Wind potential was obtained from wind energy density maps for Northern Portugal, available on the Global Wind Atlas (GWA) website [174]. Solar potential was extracted from the Global Solar Atlas for Northern Portugal, developed by The World Bank and the International Finance Corporation [175]. Geothermal potential was calculated using the Geothermal Potential Map for Northern Portugal, developed by the Energy and Geology geoPortal [176]. Small hydro potential was obtained from the surface water

maps available on the website of the National Environment Information System [177]. Finally, based on the number of bovine and porcine animals in each municipality, obtained from IGE, biogas potential was derived following the methodology proposed by Iglinski et al. [161], who estimate the amount of biogas from animal droppings. The solar, wind, and small hydro installed capacities were retrieved from the Endogenous Energies of Portugal [178].

Four additional indicators are included under this dimension, considered as enabling or limiting factors of the different RE potentials: the share of land area included in Red Natura 2000 must be incorporated as a limiting factor for any of the RE technologies considered [60,69]. Moreover, the previous small-hydro installed capacity is also considered a restriction to the deployment of new small-hydro facilities, since existing ones have already altered the flow rate [162]. On the contrary, the existence of previously installed capacity in wind and solar energy is considered as an enabling factor, since there are no evident restrictions to the installation of more turbines or panels, and, instead, a positive predisposition of the population to new facilities is assumed [179].

Appendix A.3. Descriptive Statistics

Table A2. Descriptive statistics of the indicators in the database.

	Mean	SD	Min	Max
<i>Demand-Side Economic Capital (DSEC)</i>				
POP_DEN	41.230	26.878	8.827	103.176
NET_MIG	2.619	4.152	−6.016	12.494
POP_WEL	331.262	276.574	63.600	1215.200
UNE_CHG	308.822	242.166	59.000	1212.000
HER_INX	0.392	0.049	0.337	0.481
FIR_DEN	166.078	45.941	89.190	246.618
DIS_MET	138.663	48.438	69.985	259.350
LAB_SEL	0.874	0.137	0.580	1.290
<i>Supply-Side Economic Capital (SSEC)</i>				
POP_GRW_A	−0.008	0.005	−0.016	0.003
JOB_EDU	14.499	3.610	5.620	27.290
INC_CAP	6275.950	808.910	5081.976	9063.640
FIR_CHG	0.017	0.012	−0.006	0.046
MUN_EXP	29.309	7.084	16.589	43.511
BAN_OFF	0.376	0.126	0.180	0.709
MUN_DEB	783.081	807.158	23.100	3986.313
<i>Human Capital (HC)</i>				
POP-GRW_10	0.466	1.753	−0.810	7.505
POP_INM	15.165	11.081	4.976	55.558
POP_25_64	0.496	0.027	0.437	0.549
POP_REP	1.843	0.441	1.159	2.966
POP_EDU	0.068	0.019	0.042	0.157
POP_FEM	0.294	0.022	0.244	0.340
PRI_EMP	0.753	0.040	0.649	0.835
SEL_EMP	0.202	0.063	0.084	0.408
UNE_RAT	7.407	1.543	4.600	10.040
<i>Social Capital (SC)</i>				
VOT_TUR	1.871	0.240	1.504	2.579
COOP_No	0.009	0.029	0.000	0.152
CUL_CEN	0.344	0.225	0.056	0.877

Table A2. *Cont.*

	Mean	SD	Min	Max
<i>Social Capital (SC)</i>				
SOC_SER	1.106	1.361	0.196	9.480
HEA_CEN	0.488	0.119	0.315	0.942
SCH_No	0.008	0.003	0.004	0.014
HEA_PER	8.951	5.898	4.604	39.334
ASSO_No	4.282	2.335	0.000	12.990
POP_B&R	0.869	0.023	0.795	0.918
<i>Physical Capital (PC)</i>				
POP_WAS	46.369	17.346	20.000	99.200
POP_PUR	78.622	17.637	40.500	100.000
POP_WAT	52.550	17.998	17.961	98.241
POP_SEW	71.835	23.552	22.111	100.000
POP_INT	0.200	0.025	0.146	0.268
POP_UMT	39.468	4.335	28.969	47.942
<i>Natural Capital (NC)</i>				
PRO_LAN	11.244	18.732	0.000	61.900
TOU_PLA	33.203	39.651	1.703	265.823
CUL_INT	0.052	0.041	0.006	0.202
FOR_AGR	1.054	0.129	0.819	1.339
SEC_HOM	0.381	0.068	0.218	0.536
BAT_QUA	0.046	0.085	0.000	0.380
FOR_FIR	0.942	1.316	0.000	4.660
ECO_FIR	1.519	1.886	0.000	9.600
<i>RE Potential (REP)</i>				
POT_SOL	4.108	0.141	3.825	4.328
POT_WIN	251.824	85.255	108.489	475.144
POT_GEO	189.587	18.000	156.938	213.667
POT_BGS	13.530	17.723	0.050	100.725
POT_SHY	44,662.845	35,863.562	4434.251	155,923.755
PRO_LAN_RN2000	22.489	25.022	0.000	94.800
ICP_WIN	22.677	45.090	0.000	198.800
ICP_SOL	1.096	7.302	0.000	48.990
ICP_SHY	2.627	6.405	0.000	30.000

Source: own elaboration.

Appendix A.4. Data Analysis and Transformation

Table A3. Data analysis and transformation.

	Asymmetry (Before Transformation)	Transformation Method	Asymmetry (After Transformation)
<i>Demand-Side Economic Capital (DSEC)</i>			
POP_DEN	0.757	Logarithm	−0.066
NET_MIG	0.010	No transformation	
POP_WEL	1.690	Logarithm	0.240
UNE_CHG	1.907	Logarithm	0.341
HER_INX	0.457	Reverse square	−0.196
FIR_DEN	0.210	Square root	0.017
DIS_MET	0.490	Fourth root	0.048
LAB_SEL	0.377	Square root	0.020

Table A3. Cont.

	Asymmetry (Before Transformation)	Transformation Method	Asymmetry (After Transformation)
<i>Supply-Side Economic Capital (SSEC)</i>			
POP_GRW_A	0.427	No transformation	
JOB_EDU	0.893	Cube root	−0.054
INC_CAP	1.068	Reverse square	0.053
FIR_CHG	0.096	No transformation	
MUN_EXP	0.315	Fourth root	−0.013
BAN_OFF	1.050	Logarithm	0.002
MUN_DEB	2.751	Fourth root	0.523
<i>Human Capital (HC)</i>			
POP-GRW_10	2.465	Reverse	0.736
POP_INM	1.899	Reverse	0.539
POP_25_64	−0.358	Quadratic	−0.015
POP_REP	0.501	Logarithm	0.100
POP_EDU	2.431	Reverse	−0.110
POP_FEM	−0.255	Cube	0.044
PRI_EMP	−0.390	Quadratic	−0.046
SEL_EMP	0.777	Fourth root	0.106
UNE_RAT	−0.007	No transformation	
<i>Social Capital (SC)</i>			
VOT_TUR	1.112	Reverse square	−0.063
COOP_No	3.639	Fourth root	2.339
CUL_CEN	0.701	Cube root	0.023
SOC_SER	5.325	Logarithm	0.720
HEA_CEN	1.344	Reverse	0.185
SCH_No	0.909	Reverse	0.289
HEA_PER	3.624	Reverse	−0.202
ASSO_No	1.615	Square root	−0.136
POP_B&R	−0.716	Cube	−0.510
<i>Physical Capital (PC)</i>			
POP_WAS	0.761	Logarithm	−0.056
POP_PUR	−0.559	Cube	−0.077
POP_WAT	0.271	Square root	−0.187
POP_SEW	−0.614	Cube	0.057
POP_INT	0.277	Fourth root	−0.012
POP_UMT	−0.663	Cube	−0.079
<i>Natural Capital (NC)</i>			
PRO_LAN	1.467	Fourth root	0.661
TOU_PLA	4.661	Logarithm	−0.427
CUL_INT	1.843	Logarithm	−0.044
FOR_AGR	0.467	Reverse	0.004
SEC_HOM	0.012	No transformation	
BAT_QUA	2.283	Fourth root	0.763
FOR_FIR	1.562	Fourth root	−0.107
ECO_FIR	2.405	Fourth root	−0.448
<i>RE Potential (REP)</i>			
POT_SOL	−0.527	Quadratic	−3.980
POT_WIN	0.756	Fourth root	0.295
POT_GEO	−0.535	Quadratic	−0.180

Table A3. Cont.

	Asymmetry (Before Transformation)	Transformation Method	Asymmetry (After Transformation)
<i>RE Potential (REP)</i>			
POT_BGS	2.976	Fourth root	0.005
POT_SHY	1.318	Logarithm	−0.124
PRO_LAN_RN2000	0.852	Fourth root	0.162
ICP_WIN	2.507	Fourth root	0.784
ICP_SOL	6.482	No transformation	
ICP_SHY	3.350	Fourth root	1.101

Source: own elaboration.

Dropped indicators: Number of bath areas with quality controls per 1000 people from the natural capital dimension, and installed capacity in solar parks from the RE potential dimension.

Appendix A.5. Scores of the CRERAL Index and Sub-Indices for the 45 Northern Portugal Municipalities

Table A4. Scores of the CRERAL index and sub-indices for the 45 Northern Portugal municipalities.

Municipalities	CRERAL	DSEC	SSEC	HC	SC	NC	PC	REP
Arcos de Valdevez	0.4958	0.0875	0.0841	0.0512	0.0642	0.0513	0.0777	0.0797
Melgaço	0.4935	0.0863	0.0626	0.0475	0.0584	0.0843	0.0788	0.0756
Monção	0.4792	0.0892	0.0704	0.0520	0.0589	0.0592	0.0617	0.0878
Paredes de Coura	0.4960	0.0934	0.0852	0.0551	0.0713	0.0678	0.0513	0.0719
Ponte de Barca	0.4522	0.0798	0.0668	0.0589	0.0602	0.0600	0.0659	0.0607
Vila Nova de Cerveira	0.5139	0.1092	0.0863	0.0480	0.0606	0.0676	0.0826	0.0596
Terras de Bouro	0.5011	0.0866	0.0605	0.0859	0.0724	0.0648	0.0791	0.0519
Cabeceiras de Basto	0.4320	0.0686	0.0743	0.0731	0.0737	0.0387	0.0417	0.0620
Vieira do Minho	0.4476	0.0699	0.0670	0.0812	0.0934	0.0405	0.0524	0.0653
Mondim de Basto	0.4696	0.0761	0.0717	0.0750	0.0684	0.0412	0.0487	0.0665
Arouva	0.4615	0.0755	0.0798	0.0698	0.0778	0.0370	0.0478	0.0737
Boticas	0.4953	0.0699	0.0722	0.0660	0.0631	0.0911	0.0508	0.0822
Chaves	0.4893	0.0626	0.0668	0.0636	0.0687	0.0736	0.0745	0.0795
Montalegre	0.4979	0.0658	0.0896	0.0674	0.0747	0.0460	0.0677	0.0866
Ribeira de Pena	0.4469	0.0799	0.0827	0.0738	0.0483	0.0538	0.0491	0.0593
Valpaços	0.5220	0.0710	0.0798	0.0605	0.0568	0.0917	0.0598	0.1024
Vila Pouca de Aguiar	0.5037	0.0710	0.0834	0.0702	0.0599	0.0887	0.0522	0.0783
Celorico de Basto	0.4359	0.0552	0.0654	0.0978	0.0657	0.0326	0.0523	0.0687
Baião	0.4376	0.0659	0.0724	0.0825	0.0695	0.0289	0.0536	0.0631
Cinfães	0.4236	0.0556	0.0690	0.0917	0.0637	0.0192	0.0481	0.0763
Resende	0.4600	0.0571	0.0702	0.0871	0.0539	0.0471	0.0744	0.0701
Carraceda de Ansiães	0.5165	0.0703	0.0577	0.0727	0.0656	0.0667	0.0715	0.0839
Freixo de Espada à Cinta	0.4784	0.0797	0.0566	0.0736	0.0661	0.0802	0.0836	0.0710
Torre de Moncorvo	0.5015	0.0720	0.0735	0.0662	0.0755	0.0802	0.0671	0.0820
Vila Nova de Foz Côa	0.5398	0.0651	0.0533	0.0593	0.0576	0.0731	0.1045	0.0656
Alijó	0.4884	0.0684	0.0846	0.0616	0.0610	0.0551	0.0654	0.0795
Murça	0.4540	0.0728	0.0636	0.0713	0.0502	0.0711	0.0479	0.0771
Sabrosa	0.5114	0.0854	0.0916	0.0621	0.0556	0.0924	0.0674	0.0912
Santa Marta de Penaguião	0.4579	0.0778	0.0727	0.0743	0.0733	0.0597	0.0805	0.0732
Armamar	0.5109	0.0722	0.0536	0.0691	0.0618	0.0876	0.0691	0.0446

Table A4. Cont.

Municipalities	CRERAL	DSEC	SSEC	HC	SC	NC	PC	REP
Moimenta da Beira	0.4756	0.0793	0.0604	0.0645	0.0706	0.0817	0.0614	0.0817
Penedono	0.5458	0.0816	0.0997	0.0605	0.0709	0.0600	0.0643	0.0822
São João de Pesqueira	0.4997	0.0623	0.0553	0.0786	0.0666	0.0882	0.0865	0.0801
Sernancelhe	0.5193	0.0742	0.0693	0.0778	0.0737	0.0938	0.0653	0.0776
Tabuaço	0.5176	0.0614	0.0612	0.0591	0.0666	0.0718	0.0936	0.0878
Tarouca	0.5316	0.0705	0.0679	0.0588	0.0626	0.1053	0.0997	0.0750
Alfândega de Fé	0.5099	0.0685	0.0570	0.0672	0.0566	0.0971	0.0843	0.0792
Bragança	0.5195	0.0696	0.0863	0.0541	0.0783	0.0872	0.0826	0.0615
Macedo de Cavaleiros	0.5232	0.0674	0.0683	0.0603	0.0807	0.0733	0.0711	0.1022
Mirando do Douro	0.5050	0.0670	0.0556	0.0510	0.0579	0.0978	0.0865	0.0893
Mirandela	0.4859	0.0632	0.0689	0.0623	0.0587	0.0907	0.0701	0.0720
Mogadouro	0.5449	0.0608	0.0836	0.0630	0.0733	0.0984	0.0702	0.0955
Vila Flor	0.5231	0.0669	0.0809	0.0648	0.0485	0.1051	0.0790	0.0779
Vimioso	0.5042	0.0722	0.0817	0.0538	0.0477	0.0951	0.0736	0.0800
Vinhais	0.4544	0.0624	0.0602	0.0654	0.0548	0.0733	0.0782	0.0601

Source: own elaboration.

Appendix A.6. Ranking of the 45 Northern Portugal Municipalities

Table A5. Ranking of the 45 Northern Portugal municipalities.

	CRERAL	DSEC	SSEC	HC	SC	NC	PC	REP
1	Penedono	Vila Nova de Cerveira	Penedono	Celorico de Basto	Vieira do Minho	Vila Nova de Foz Côa	Tarouca	Valpaços
2	Mogadouro	Paredes de Coura	Sabrosa	Cinfães	Macedo de Cavaleiros	Tarouca	Vila Flor	Macedo de Cavaleiros
3	Vila Nova de Foz Côa	Monção	Montalegre	Resende	Bragança	Tabuaço	Mogadouro	Mogadouro
4	Tarouca	Arcos de Valdevez	Bragança	Terras de Bouro	Arouca	São João de Pesqueira	Mirando do Douro	Sabrosa
5	Macedo de Cavaleiros	Terras de Bouro	Vila Nova de Cerveira	Baião	Torre de Moncorvo	Mirando do Douro	Alfândega de Fé	Mirando do Douro
6	Vila Flor	Melgaço	Paredes de Coura	Vieira do Minho	Montalegre	Alfândega de Fé	Vimioso	Monção
7	Valpaços	Sabrosa	Alijó	São João de Pesqueira	Cabeceiras de Basto	Freixo de Espada à Cinta	Sernancelhe	Tabuaço
8	Bragança	Penedono	Arcos de Valdevez	Sernancelhe	Sernancelhe	Vila Nova de Cerveira	Sabrosa	Montalegre
9	Sernancelhe	Ribeira de Pena	Mogadouro	Mondim de Basto	Mogadouro	Bragança	Valpaços	Carraceda de Ansiães
10	Tabuaço	Ponte de Barca	Vila Pouca de Aguiar	Santa Marta de Penaguião	Santa Marta de Penaguião	Santa Marta de Penaguião	Boticas	Penedono
11	Carraceda de Ansiães	Freixo de Espada à Cinta	Ribeira de Pena	Ribeira de Pena	Terras de Bouro	Terras de Bouro	Mirandela	Boticas

Table A5. Cont.

	CRERAL	DSEC	SSEC	HC	SC	NC	PC	REP
12	Vila Nova de Cerveira	Moimenta da Beira	Vimioso	Freixo de Espada á Cinta	Paredes de Coura	Vila Flor	Vila Pouca de Aguiar	Torre de Moncorvo
13	Sabrosa	Santa Marta de Penaguião	Vila Flor	Cabeceiras de Basto	Penedono	Melgaço	São João de Pesqueira	Moimenta da Beira
14	Armamar	Mondim de Basto	Arouca	Carrazeda de Ansiães	Moimenta da Beira	Vinhais	Armamar	São João de Pesqueira
15	Alfândega de Fé	Arouca	Valpaços	Murça	Baião	Arcos de Valdevez	Bragança	Vimioso
16	Mirando do Douro	Sernancelhe	Cabeceiras de Basto	Vila Pouca de Aguiar	Chaves	Chaves	Melgaço	Arcos de Valdevez
17	Vimioso	Murça	Torre de Moncorvo	Arouca	Mondim de Basto	Resende	Moimenta da Beira	Chaves
18	Vila Pouca de Aguiar	Armamar	Santa Marta de Penaguião	Armamar	Tabuaço	Vimioso	Torre de Moncorvo	Alijó
19	Torre de Moncorvo	Vimioso	Baião	Montalegre	São João de Pesqueira	Carrazeda de Ansiães	Freixo de Espada á Cinta	Alfândega de Fé
20	Terras de Bouro	Torre de Moncorvo	Boticas	Alfândega de Fé	Freixo de Espada á Cinta	Macedo de Cavaleiros	Chaves	Vila Pouca de Aguiar
21	São João de Pesqueira	Valpaços	Mondim de Basto	Torre de Moncorvo	Celorico de Basto	Mogadouro	Vinhais	Vila Flor
22	Montalegre	Vila Pouca de Aguiar	Monção	Boticas	Carrazeda de Ansiães	Mirandela	Macedo de Cavaleiros	Sernancelhe
23	Paredes de Coura	Tarouca	Resende	Vinhais	Arcos de Valdevez	Armamar	Vila Nova de Foz Côa	Murça
24	Arcos de Valdevez	Carrazeda de Ansiães	Sernancelhe	Vila Flor	Cinfães	Montalegre	Tabuaço	Cinfães
25	Boticas	Vieira do Minho	Cinfães	Moimenta da Beira	Boticas	Sabrosa	Murça	Melgaço
26	Melgaço	Boticas	Mirandela	Chaves	Tarouca	Torre de Moncorvo	Paredes de Coura	Tarouca
27	Chaves	Bragança	Macedo de Cavaleiros	Mogadouro	Armamar	Ponte de Barca	Vila Nova de Cerveira	Arouca
28	Alijó	Cabeceiras de Basto	Tarouca	Mirandela	Alijó	Alijó	Carrazeda de Ansiães	Santa Marta de Penaguião
29	Mirandela	Alfândega de Fé	Vieira do Minho	Sabrosa	Vila Nova de Cerveira	Sernancelhe	Terras de Bouro	Mirandela
30	Monção	Alijó	Chaves	Alijó	Ponte de Barca	Penedono	Penedono	Paredes de Coura

Table A5. Cont.

	CRERAL	DSEC	SSEC	HC	SC	NC	PC	REP
31	Freixo de Espada á Cinta	Macedo de Cavaleiros	Ponte de Barca	Penedono	Vila Pouca de Aguiar	Monção	Ponte de Barca	Freixo de Espada á Cinta
32	Moimenta da Beira	Mirando do Douro	Celorico de Basto	Valpaços	Monção	Moimenta da Beira	Santa Marta de Penaguião	Resende
33	Mondim de Basto	Vila Flor	Murça	Macedo de Cavaleiros	Mirandela	Valpaços	Monção	Celorico de Basto
34	Arouca	Baião	Melgaço	Vila Nova de Foz Côa	Melgaço	Baião	Alijó	Mondim de Basto
35	Resende	Montalegre	Tabuaço	Tabuaço	Mirando do Douro	Vieira do Minho	Ribeira de Pena	Vila Nova de Foz Côa
36	Santa Marta de Penaguião	Vila Nova de Foz Côa	Terras de Bouro	Ponte de Barca	Vila Nova de Foz Côa	Celorico de Basto	Arcos de Valdevez	Vieira do Minho
37	Vinhais	Mirandela	Moimenta da Beira	Tarouca	Valpaços	Vila Pouca de Aguiar	Resende	Baião
38	Murça	Chaves	Vinhais	Paredes de Coura	Alfândega de Fé	Paredes de Coura	Montalegre	Cabeceiras de Basto
39	Ponte de Barca	Vinhais	Carrazeda de Ansiães	Bragança	Sabrosa	Boticas	Mondim de Basto	Bragança
40	Vieira do Minho	São João de Pesqueira	Alfândega de Fé	Vimioso	Vinhais	Ribeira de Pena	Vieira do Minho	Ponte de Barca
41	Ribeira de Pena	Tabuaço	Freixo de Espada á Cinta	Monção	Resende	Mondim de Basto	Cabeceiras de Basto	Vinhais
42	Baião	Mogadouro	Mirando do Douro	Arcos de Valdevez	Murça	Cinfães	Arouca	Vila Nova de Cerveira
43	Celorico de Basto	Resende	São João de Pesqueira	Mirando do Douro	Vila Flor	Murça	Celorico de Basto	Ribeira de Pena
44	Cabeceiras de Basto	Cinfães	Armamar	Vila Nova de Cerveira	Ribeira de Pena	Arouca	Baião	Terras de Bouro
45	Cinfães	Celorico de Basto	Vila Nova de Foz Côa	Melgaço	Vimioso	Cabeceiras de Basto	Cinfães	Armamar

Source: own elaboration.

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