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Research article

Is social cohesion decisive for energy cooperatives existence? A quantitative analysis

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A R T I C L E I N F O

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A B S T R A C T

Energy Cooperatives (ECoops), the most prominent example for Energy Communities, are attributed great importance for the energy transition both through the engagement of energy end-consumers and the increase of local renewable energy sources. We conducted an exploratory (spatial) data analysis to study which indicators of the European Social Progress Index and Quality of Life Index co-occure with the presence of ECoops. Results show that these indexes and most of their sub-components present values significantly better at the regions where the ECoops are located compared to all EU regions. While correlation and regression coefficients between the number of ECoops per region and the indexes are relatively small, the individual indicator "Life-long learning" reaches the highest correlation and explanatory values. Additionally, Global moran statistics show that the concentration of ECoops and their relation to the indexes in space are rather random but a local analysis shows clusters emerging throughout the continent.

1. Introduction

By mobilizing citizens and communities to invest in renewable energy technologies in rural and urban areas, Energy Cooperatives (ECoops) contribute to the goals of the European Energy roadmap. ECoops are defined as jointly owned and democratically controlled (social) enterprises that unite voluntary members who follow the same economic, social, and/or environmental goals (ILO, 2013). ECoops are built on the shared values of "voluntary and open membership, democratic member control, economic participation and direct ownership, autonomy and independence, education, training and information, and environmental concern" (ILO, 2001). The new directives on renewable energy and electricity of the European Commission (European Commission, 2018; 2019) show that Energy Communities, which most often take the legal form of ECoops (Hewitt et al., 2019), fulfill not only an environmental and economic purpose but also a social one. ECoops are a source of innovation and a mean to transform the centralized energy system towards a more local and decentralized one (Arentsen and Bellekom, 2014). Wierling et al. (2018) confirmed statistically that ECoops contribute to the European energy transition and Berka and Creamer (2018a) summarized their positive social impacts, such as the creation of social capital, support of renewables, and behaviour change. As prosumer and prosumer groups invest in decentralized and co-owned renewable energy technology, such as rooftop solar, geothermal installation, and community wind turbines, ECoops and the

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relating cooperative energy sector are expected to grow economically while reducing the expenditure of businesses and governments to achieve the global limit of 1.5 °C average temperature rise.

The increasing consent that ECoops contribute positively to the energy transition, both environmentally and socially, have made the analysis of why ECoops emerge in specific areas and countries highly relevant (Bauwens, 2016). Most studies researching this phenomenon build on qualitative research methods (i.e., interviews) and less research has been conducted applying quantitative or model based approaches (Berka and Creamer, 2018a). The majority of studies focused on single or a few European countries and did not take socio-geographic data into account. Recent work from Punt et al. (2021) addressed this shortcoming by applying an ecological organization approach to assess the effects of "nstitutional relatedness" on the emergence of ECoops in Germany. However, this study is an exception to the rule and still has a limited geographical coverage. With the present study, we aim to further enrich the understanding of the emergence of ECoops by adding a quantitative socio-geographic perspective to the current state of the art. Conducting an exploratory (spatial) data analysis, we aim to explore the role of a range of socio-demographic aspects capturing social cohesion, measured by the Quality of Life (QoL) Index and the European Social Progress Index (SPI) shaping the diffusion of ECoops. The SPI and QoL indexes measure the societal development using indicators for progress on nutrition, access to medical care, water and sanitation, shelter, personal security, access to basic knowledge, information and communication, health and wellness, environmental quality, personal rights, freedom of choice, tolerance and inclusion, and access to advanced education.

We understand social cohesion as a process of a society that brings about a sense of belonging and collaboration for mutual benefits (Maillé and Saint-Charles, 2012). Existing literature that links social cohesion with the development of community energy often uses social cohesion as an umbrella term that leads to collaboration, but without giving a clear definition of the term. Due to the ambiguity of social cohesion, we aim to analyze social cohesion from the perspective of its building blocks as measured by the SPI and QoL. By following the research question, *"Does social cohesion benefit the presence of ECoops and, if yes, which indicators of social cohesion are beneficial for the development of ECoops?"*, we highlight which factors could contribute to foster ECoops on an EU scale.

Since many Energy Communities currently take the form of ECoops (Frieden et al., 2019; Gancheva et al., 2018), our results can potentially improve and fasten the policy response to, among others, the national transposition of the recast of the Renewable Energy Directive (RED II) addressing Energy Communities in the EU. Because although the deadline for transposition on the national state level has passed in June 2021, several member states have not delivered or encountered challenges to make an effective and just transposition (Hoicka et al., 2021). This study gives insight into which factors influence the diffusion of ECoops beyond single case studies applying quantitative methods to large geographic areas and highlights where results differ or align to qualitative case studies. The findings extend the understanding of why in some European regions more ECoops emerge and exist and provide insights into how ECoops can be fostered in these areas and beyond the borders of the EU.

1.1. ECoops as actors in socio-technical transitions

Taking a socio-technical systems perspective, not only the development or availability of technology but also the social context, encompassing actors, networks, knowledge, resources, and institutional settings influence the development, diffusion, and use of innovations (Geels, 2004). We see ECoops as social innovations embedded in place and space related socio-technical systems. Depending on the stage of development, ECoops may be seen as niche developments while countries in which ECoops have a long tradition, such as in Germany or Denmark, may be considered as well-established entities that already partly transformed the socio-technical system (Hufen and Koppenjan, 2015). The intertwining of socio-technical factors on different levels (niche, regime, and landscape) influencing the development and diffusion of ECoops remained understudied over a long time, especially when looking at social factors (Wittmayer et al., 2020). By analyzing factors such as the history of cooperatives (Sperling, 2017), trust in investors and local policy makers (Leiren et al., 2020) or a broad range of individual motivations (Bauwens, 2016), the understanding of the social context of ECoops has been extended.

However, the emergence of ECoops is not equal across time and space and requires not only a socio-technical perspective, but also a geographical one (Coenen and Truffer, 2012). Also Ponte and Birch (2014) highlighted that transition pathways of different socio-technical innovations (e.g., ECoops) are bound to the geographical environment. The geographies of transitions, conceptualized by Bridge et al. (2013), can be described by six main components, namely the location (actual location and the relational proximity to transition), the landscape (as a result of social processes), territoriality (social and political power over specific territories), geographical differences (spatial differentiation and uneven development of transitions), scaling (size and areal scope of the transition), and spatial embeddedness and path dependency (transitions are embedded in specific spaces and are subject to transition pathways resulting from their geography). Following these components, we aim to add a geographical perspective to the analysis of the emergence of ECoops. Rather than studying the political and economic factors, this study places its focus on social factors contributing to their emergence on the local and regional level using quantitative and exploratory spatial analysis, adding new insights to the place-related development of ECoops.

1.2. Conditions for the emergence and existence of ECoops

The successful emergence of ECoops has been tied to various socio-economic factors. During the establishment of ECoops, beneficial institutional and policy settings concerning financial, legal, and procedural set-up of ECoops were found to be influential (Mirzania et al., 2019; Warbroek and Hoppe, 2017). For example, supportive and reliable governance structures on the promotion of renewable energy, and macro-economic trends affecting the development and price fluctuations of electricity benefit the development of ECoops (Boon and Dieperink, 2014; Warbroek and Hoppe, 2017). Klagge and Meister (2018) showed that the emergence of ECoops is also affected by the degree of market decentralization. Bomberg and McEwen (2012) distinguish influencing factors into structural resources (the broader political context) and symbolic resources (place attachment, collective identity and shared normative goals). Their study stresses the importance of symbolic resources for the successful mobilization of ECoops' participants. Among the identified beneficial pre-conditions leading to the emergence of ECoops are social norms and positive attitudes affecting the acceptance of local renewable energy (Bauwens and Devine-Wright, 2018; Ribeiro et al., 2018). Kalkbrenner and Roosen (2016) found that social norms, trust, environmental concern and community identity are the most decisive factors that affect the willingness to participate in community energy schemes including ECoops.Walker et al. (2010a) showed that trust among ECoop members and towards other key actors is needed for their successful implementation. A successful implementation of ECoops can lead to increased environmental awareness and changed behaviour, participation, uptake of renewable energy technologies, and local benefits, such as project revenue (Berka and Creamer, 2018b; Rogers et al., 2012).

The ECoop of Samsø island is considered a prime example for a successful social and technical integration of a renewable energy community achieved through, among others, a joint vision and plan for transitioning, local participation and sense of ownership, social networks and entrepreneurial actors (Sperling, 2017). Mundaca et al. (2018) have highlighted that a strong social cohesion was beneficial for the development and success of the energy island. Also case studies in Scotland and the United Kingdom connected social cohesion with the success of initiatives for community energy (Haggett and Aitken, 2015). All case studies showed that various factors were beneficial for the success of the initiatives, such as trust, legislation, and the mobilization of community members. Many of the mentioned factors relate to social cohesion, but it remains unclear which aspects of social cohesion, which is a broader social concept and cannot be defined or measured by a single indicator, were beneficial for the case studies and, with extension to the European Union (EU), could be favorable for other existing ECoops and their diffusion. Moreover, Maillé and Saint-Charles (2012) who studied social cohesion in the context of a wind farm development stressed the importance to specify clearly what aspects are considered when analyzing social cohesion.

Social cohesion is not a novel social concept and has many different definitions and conceptualizations. Recent definitions align in describing social cohesion as a process (Jupp et al., 2007) that aims "to consolidate plurality of citizenship by reducing inequality and socioeconomic disparities and fractures in the society. It reflects people's needs for both personal development and a sense of belonging and links together individual freedom and social justice, economic efficiency and the fair sharing of resources, and pluralism and common rules for resolving all conflicts" (Manca, 2014, p.6026). Social cohesion can be assessed from three levels; individual, community, and institutional (Fonseca et al., 2019). These levels address, among others, aspects of sense of belonging, inclusion, participation, and legitimacy, trust, common goals and behaviour, life satisfaction, voting, and reduction of inequalities covering the aspects of basic human needs, well-being, and social opportunities (Manca, 2014). This has become the theoretical base of measurement frameworks for societal progress, e.g., in Europe and Australia (Greve, 2017). Societies with stronger social cohesion create mutual benefits through collaboration and social networks. Many of the factors captured by social cohesion, and social capital are influential for the emergence of collective actions and local initiatives (Maillé and Saint-Charles, 2012; Poortinga, 2006). This led to the assumption of this study that social cohesion relates with the existence of ECoops.

Social cohesion has a geographic dimension. Spatial considerations are prerequisite for the achievement of social justice and cohesion among and between individuals and state actors, therefore, social cohesion on the individual level, is closely linked with spatial equality (Martin, 2009). In previous studies, several aspects of social cohesion have shown to be influential for the development of ECoops. With this study, we research which aspects of social cohesion relate with the emergence of ECoops and provide a spatial perspective.

2. Material and methods

2.1. Hypotheses

This study follows an exploratory research design applying a statistical and spatial analysis to study the connection between the spatial distribution of ECoops and socio-demographic indicators. We adapted the study design of Nicolosi et al. (2018) conducting a spatial analysis of the emergence of sustainable grassroot innovations in the United States. To assess which socio-demographic reasons affect the emergence and presence of ECoops, we explore the connection between the SPI and QoL index of the European Union with the spatial distribution of ECoops. We use the European SPI, and the related but spatially more detailed QoL, which operationalizes, with an explicit focus, the societal progress within the EU (Annoni and Bolsi, 2020). As social cohesion compromises various of the beneficial social factors for the development of ECoops, we use the SPI and QoL indexes as proxys for the quantitative evaluation of social cohesion. Using the database on ECoops in the EU provided by the organization Renewable Energy Sources Cooperatives (REScoop), we compiled an overview of 698 European ECoops and supplemented the entries with socio-geographic data from the European SPI and QoL indexes. The data set includes community energy initiatives that take the legal and organisational form of cooperatives. Other legal entities, such as limited liability companies or charitable funds, are not captured in the data set. We conducted an exploratory (spatial) data analysis to gain insight into which of the indexes and indicators foster the emergence of ECoops and provide a regional perspective. The database covers most of the EU countries and, as a result, extends the current scope of analyzed countries where ECoops emerged.

The spatial aggregation of the indexes is defined by Nomenclature of Territorial Units for Statistics (NUTS) regions. NUTS are territorial units to generalize statistical and regional studies across the EU (Eurostat, 2021a). While there are multiple particularities depending on e.g. the countries' size, usually the NUTS1 regions represent states or groups of states in a country, the NUTS2 regions cover government regions or provinces, and NUTS3 regions embody districts or counties. Based on the available data and structure of

Table 1
SPI Index.

Component	Domain	Indicator
Basic Human Needs	Nutrition and basic medical care	Premature mortality (before 65), Infant mortality, Unmet medical needs, Insufficient food
	Water and sanitation	Satisfaction with water quality, Lack of toilet in dwelling, Uncollected sewage, Sewage treatment
	Shelter	Burdensome cost of housing, Satisfaction with housing, Housing quality - dampness, Housing quality - darkness, Overcrowding, Lack of adequate heating
	Personal Security	Homicide rate, Traffic deaths, Crime, Safety at night, Money stolen, Assaulted/Mugged, Traffic deaths and injuries
Foundation of well-being	Basic Knowledge	Pre-primary education, Upper-secondary enrolment rate (age 14–18), Lower-secondary completion only, Early school leavers
	Information and Communication	Internet at home, Broadband at home, Online interaction with public authorities,Internet access
	Health and Wellness	Life expectancy, Subjective health status, Standardised cancer death rate, Standardised heart disease death rate, Standardised alcohol consumption death rate, Leisure activities, Unmet dental needs, Satisfaction with air quality, Traffic deaths
	Environmental Quality	Carbon intensity, Air pollution NO_2, Air pollution Ozone, Air pollution pm2.5, Air pollution pm10, Pollution, grime, or other environmental issues, Noise pollution, Natura 2000
Opportunity	Personal rights	Trust in the national government Trust in the legal system, Trust in the police, Active citizenship, Female participation in regional assemblies, Institution quality index
	Freedom of choice	Freedom over life choices Job opportunities, Involuntary part-time/ temporary employment, Teenage pregnancy, Young people not in education, employment or training, NEET gender gap, Gender pay gap, Institutions corruption index
	Tolerance and inclusion	Institution impartiality index, Tolerance towards immigrants, Tolerance towards minorities, Tolerance towards homosexuals, Making friends, Trust in others, Safety net, Volunteering, Tolerance towards disabilities, Gender employment gap
	Advanced Education	Tertiary education attainment, Tertiary enrolment, Lifelong learning, Accessibility to university, Lifelong learning - female

the SPI and QoL indexes, we propose the following hypotheses: ECoops are more likely to be found in areas where i) the overall SPI and QoL index, ii) components, domains, indicators of the SPI, and iii) components, domains and sub-domains of the QoL index perform significantly better than the respective average values on NUTS regions. Furthermore, we foresee iv) high correlations between the number of ECoops per NUTS region and the values of each index and their components, domains, sub-domains/indicators. We also expect that there is spatial auto-correlation for the location of ECoops i.e. NUTS regions with high number of ECoops are neighbouring other NUTS regions with high number of ECoops, and between the indexes (SPI and QoL) and the distribution of ECoops i.e. areas in which the indexes and their components are performing high are neighboring NUTS2 and NUTS3 regions with a higher number of ECoops. Our hypotheses focus on the context in which ECoops emerge rather than attitudes, drivers, motivations of individuals who join ECoops. By correlating regional social cohesion data to ECoops, we consider the average regional data as an indication for the level of social cohesion in the respective NUTS2 and NUTS3 regions. Considering social cohesion as a mobilizing factor for social capital and collaboration for mutual benefits in the society, we analyze if this is affecting the emergence and existence of ECoops. The hypothesis that ECoops are more likely to exist where the overall SPI and QoL are higher (hypothesis i) is tested using the total SPI and QoL indexes. Hypotheses that focus on the components, domains, subdomains, and indicators of the SPI and QoL are tested using the domains, components and the indicators for the SPI and the components, domains and sub-domains of the QoL index. The hypothesis for the high correlation between the number of ECoops per NUTS region and the values of each index (hypothesis iv) is tested by calculating correlations between all items of the indexes and the number of ECoops per NUTS region as well as linear regressions for a subset of them. Finally, testing the hypothesis concerning the auto-correlation between the location of ECoops and the SPI and QoL indexes (hypothesis v) is tested using the Global Moran's I and Local Indicators for Spatial Association (LISA) in the univariate version for the ECoops and, in the bivariate version, using the number of ECoops and the indexes in the neighbouring NUTS.

2.2. Data

Four data sets are necessary to test the hypotheses. These include the geographic location of the ECoops, the SPI database, the QoL index database and base maps to geolocate the SPI and QoL index databases. To obtain an geographic overview of ECoops in Europe, we used the database on ECoops by ReScoop (REScoop, 2021). The data is publicly available on its website from where we extracted the name, address and, if provided, the coordinates of the geographic location of each ECoop. ReScoop is the representing federation of the network of European ECoops and provides various services such as training, legal guidance, and networking opportunities to existing and developing energy communities. Although not all ECoops are registered in this network, ReScoop provides an extensive overview of ECoops in the EU. Other studies on ECoops also rely on this database, Heras-Saizarbitoria et al. (2018) for example, researched Spain's ECoop developments and Wierling et al. (2018) explored statistically, if ECoops are significantly contributing to the European energy transition.

To study the connection between the emergence and presence of ECoops with aspects of social cohesion, we use the SPI as a proxy for the quantitative evaluation of social cohesion. The SPI builds on Eurostat data and assesses the social progress in the European area encompassing the overall index, three domains, each with four components and a total of 50 indicators. Table 1 summarizes the SPI

Table 2
QoL Index.

Component	Domain	Subdomain
QoL Enablers	Personal (B1)	Housing and Basic Utilities (b11)
		Health (b12)
		Education (b13)
	Socio-Economic (B2)	Transport (b21)
		Digital Connectivity (b22)
		Work (b23)
		Consumption (b24)
		Public Spaces (b25)
		Cultural assets (b26)
	Ecological (B3)	Green Infrastructure (b31)
		Protected areas (b32)
Life Maintenance	Personal health and safety (M1)	Personal Health (m11)
		Personal safety (m12)
	Economic and societal health (M2)	Inclusive economy (m21)
		Healthy society (m22)
	Ecological health (M3)	Healthy environment (m31)
		Climate change (m32)
Life flourishing	Personal flourishing (F1)	Self-esteem (f11)
		Self-actualisation(f12)
	Community flourishing (F2)	Interpersonal trust, societal belonging (f22)
		Institutional trust, good governance (f21)
	Ecological flourishing (F3)	Biodiversity wealth (f31)

framework, with its three main domains ("basic human needs", "foundation of well-being", and "opportunity") divided into four component with a varying number of corresponding indicators. The first domain "basic human needs" includes indicators to assess access to financial resources and to health. The "foundation of well-being" includes components to assess education and human capital, access to technology and, in addition, considers environmental indicators, that can affect human health conditions. The last domain "opportunity" covers indicators of trust, participation, access to economic activity, cultural acceptance and tolerance, and education.

This alignment shows that the SPI is suitable to assess social cohesion for the European context. The SPI database is publicly available (European Commission, 2021) in common formats (e.g. xls, csv), for the NUTS2 regions. The SPI database used for this study was calculated for 2016 and therefore still includes data for the United Kingdom. The more recent version (2020) does not include this data. As many ECoops in our database are registered in the UK, the SPI 2016 allows for more reliable results.

To obtain a more detailed geographic insight, we also included the QoL index in our analysis. The QoL also entails similar data as the SPI but on the NUTS3 regions, see Table 2).

The QoL index is composed of three components ("QoL Enablers", "Life Maintenance", "Life Flourishing"), each with three corresponding domains addressing personal, socio-economic, and then ecological aspects which are further assessed via several subdomains. In contrast to the SPI, the QoL does not include data for the single indicator level. The QoL is also publicly available in common data formats (e.g., xls, csv) and was calculated for the year 2020 encompassing data from various years (ESPON, 2019; 2021).

The basis maps with the NUTS2 and NUTS3 for Europe are retrieved from EUROSTAT in geoJSON format (Eurostat, 2021b). These also correspond to the year 2016 in order to match the SPI data.

2.3. Methods

Data cleaning was necessary to conduct the analysis. The ECoops data set, with a total of 749 ECoops, had location entries for some of the ECoops based either on address or World Geodetic System (WGS84) coordinates, or had missing values in both cases. Entries in the database without any location data were verified via their website (based on name or provided link), and were completed with an address, where available, and deleted when not available/not operational anymore. The corrected database with 698 ECoops was then geo-located using geocoder for python (Dennis Carriere, 2021) and using arcgis as provider. Based on the addresses, a map was created with the determined geographical location for each ECoop. The SPI and QoL databases were geo-located on NUTS 2 and 3 regions, respectively. We used an attribute join based on the NUTS identifications (IDs) available in the base maps and the individual databases. The NUTS2 join presented some minor inconsistencies due to different NUTS2 IDs between data sets, which were manually corrected. Two additional maps were created using a spatial join. One map counts the number of ECoops on the NUTS2 regions entailing the SPI data, the other counts the number of ECoops on the NUTS3 regions and includes the QoL data. The map of ECoops, the maps with the SPI on NUTS2 and the QoL on NUTS3 as well as the two derived maps with the number of ECoops for NUTS2 and NUTS3 regions build the data foundation on which we performed the exploratory (spatial) data analysis. The analysis was conducted using Python libraries such as numpy (van der Walt et al., 2011), geopandas (Jordahl, 2014), pandas (McKinney and others, 2010), scipy (Jones et al., 2015), statsmodel (Seabold and Perktold, 2010) and PySAL (Rey and Anselin, 2007).

We follow a four step approach to assess the data: (1) By conducting a spatial join between the ECoops map and the maps with the SPI and QoL data, we assigned to each ECoop the data available for its location from each of the SPI and QoL maps. We calculate descriptive statistics for each indicator associated to the ECoops and compare them to the distribution of the entire set of NUTS. This on

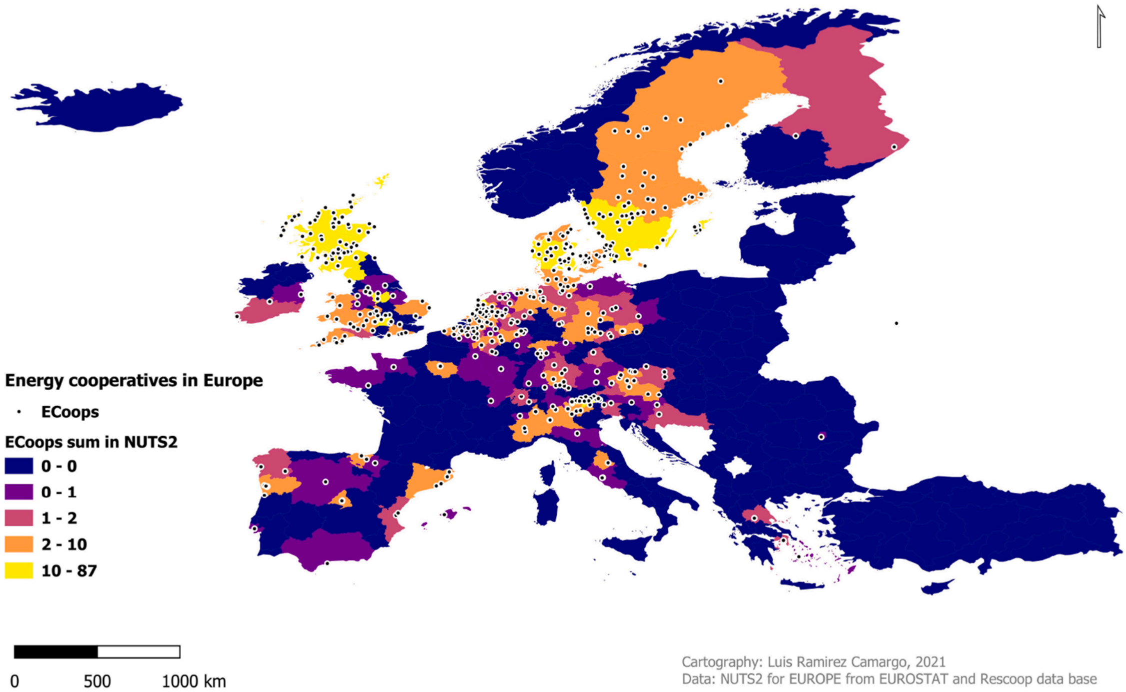

Fig. 1. Distribution of ECoops across Europe.

NUTS2 regions when working with SPI and on NUTS3 regions for the QOL. We calculate mean, standard deviation and quartiles, create box plots and run a *t*-test for each indicator. With this we aim to understand how the indicator an indexes associated to each ECoop perform in comparison to the statistics of all administrative areas in the EU, and, in addition, we want to evaluate if there is a significant difference between them. (2) By using the derived maps with the cumulative number of ECoops per administrative unit, we calculate correlations between all indicators and components and the number of ECoops per administrative unit. This maintains the original differentiation between NUTS2 and NUTS3 of the underlying data sets. (3) By running ordinary least squares regressions between indexes, components, domain and indicators as independent variables and the number of ECoops as depended variable, we aim to understand if some of the variables are good predictors for the existence of ECoops. Considering the large number of possible combinations of independent variables, we follow a successive approach where we discard independent variables to include in the regression based on their R^2 and explanatory significance. We start with models that explain the number of ECoops merely based on the indexes (SPI and QoL separately). If these have explanatory value, we move to the lower level of aggregation to create a new model which is then evaluated again. This following the order domain, component and indicator for SPI and domain, component and subdomain for QoL. If levels or components are not significant as explanatory variable we discard them and continue creating models until we reach the lowest explanatory level. (4) By conducting an exploratory spatial data analysis, we aim to understand better the spatial distribution of ECoops and the spatial correlations with the SPI and QoL. The applied types of LISAs describe similarities or dissimilarities between a specific unit of analysis (here NUTS2 for the SPI and NUTS3 for the QoL) with its neighboring spatial units. Firstly, we calculate the global Moran's I to understand the spatial distribution of ECoops. The Moran's I ranges from values of -1 to 1 whereas -1 indicates perfect clustering of dissimlar values, 0 indicates complete randomness, and 1 signifies perfect clustering of similar values. Secondly, we use LISAs to differentiate the types and location of the spatial correlations. We analyze if clusters of High-High (HH), High-Low (HL), Low-High (LH), Low-Low (LL) of ECoop values exist. First as an univariate analysis using the variable number of ECoops, which studies values for number of ECoops in neighboring spatial units. Then, in addition, we conduct a bivariate analysis between ECoops and SPI/QoL. For this the analysed spatial unit is assessed with the value for number of ECoops and compared with the value of the neighboring spatial unit for the SPI and QoL, respectively. We visualize the results with a Moran's I scatterplot (global, local), LISA cluster map, and choropleth map.

3. Results

3.1. Results of spatial join analysis

Fig. 1 shows the distribution of ECoops across Europe on NUTS2 regions, it indicates that there are higher concentrations of ECoops in central and northern European countries (such as the Sweden, Denmark, Belgium, the Netherlands and Germany), as well as in the former EU member state the United Kingdom (yellow and orange areas). Fewer ECoops are found, for example, in France, in Eastern European countries and South East of Europe (blue areas).

Table 3
Summary statistics SPI.

Social Progress Index									
Count	Mean	Std	Min	25%	50%	75%	max	*t*-test	*p*-value
651.0	73.588	5.458	52.03	72.06	73.57	78.48	82.33	14.621	1.045e – 43
276.0	**76.639**	**10.726**	**42.46**	**70.6975**	**79.915**	**84.553**	**90.34**		
Basic Human Needs									
651.0	82.865	5.093	52.03	79.21	83.18	86.58	90.34	11.971	8.373e – 31
276.0	**62.058**	**6.872**	**42.26**	**57.22**	**63.97**	**66.92**	**76.07**		
Foundation of Well-being									
651.0	66.887	4.471	48.49	65.54	67.42	69.39	75.95	12.686	4.111e – 34
276.0	**62.058**	**6.872**	**42.26**	**57.22**	**63.97**	**66.92**	**76.07**		
Opportunity									
651.0	71.613	9.036	39.01	67.165	72.25	77.87	87.02	14.145	2.877e – 41
276.0	**61.4914**	**11.868**	**31.12**	**52.305**	**62.54**	**70.068**	**87.02**		

Table 4
Summary statistics QoL.

Quality of Life Index									
Count	Mean	Std	Min	25%	50%	75%	max	*t*-test	*p*-value
1440.0	0.505	0.094	0.13	0.45	0.53	0.57	0.68	11.607	3.101e – 30
668.0	**0.549**	**0.045**	**0.33**	**0.52**	**0.55**	**0.58**	**0.66**		
Good Life Enablers									
1440.0	0.498	0.096	0.21	0.43	0.5	0.57	0.75	1.977	0.048
668.0	**0.507**	**0.071**	**0.3**	**0.46**	**0.5**	**0.55**	**0.71**		
Life Maintenance									
1440.0	0.527	0.154	0.0	0.44	0.56	0.64	0.95	5.892	4.443e – 09
668.0	**0.564**	**0.072**	**0.27**	**0.52**	**0.55**	**0.61**	**0.8**		
Life flourishing									
1440.0	0.502	0.094	0.23	0.45	0.5	0.57	0.79	18.737	1.411e – 72
668.0	**0.583**	**0.089**	**0.24**	**0.53**	**0.59**	**0.64**	**0.77**		

Fig. 2. Correlation heatmap of SPI components.

The geolocated ECoops occur in only 18.2% of the NUTS3 regions. After accumulating the ECoops on the NUTS2 regions, the 46% of the NUTS2 contain ECoops. The values refer here to a changing basic population depending on the availability of the indicators. When considering all NUTS including those without available data on indicators, the coverage of ECoops goes down to 15% on NUTS3 regions and to 38% on NUTS2 regions.

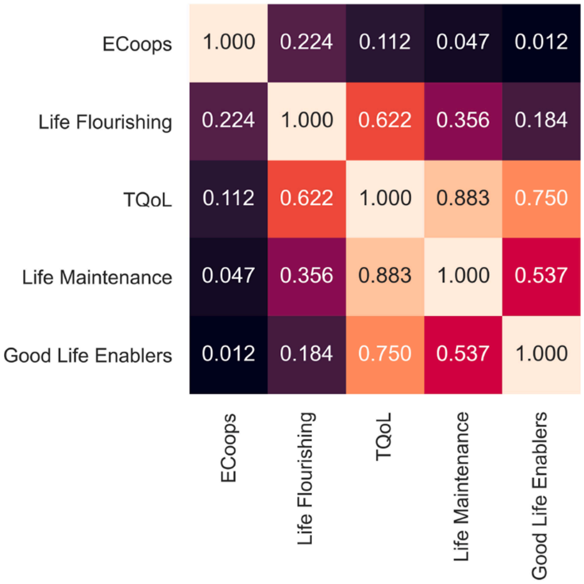

Fig. 3. Correlation heatmap of the QoL components.

Table 5
Regression results for the SPI.

Variable	Beta	Std error	t	$P > \|t\|$	R^2
SPI	0.039	0.006	6.291	0.000	0.126
Components					0.172
Basic Human Needs	− 0.072	0.064	− 1.121	0.263	
Foundation of Well-being	− 0.109	0.081	− 1.336	0.183	
Opportunity	0.2383	0.058	4.129	0.000	
Opportunity	0.043	0.007	6.602	0.000	0.137
Domain					0.218
Nutrition and Basic Medical Care	− 0.172	0.096	− 1.786	0.075	
Water and Sanitation	0.146	0.047	0.307	0.759	
Shelter	0.0334	0.075	0.444	0.657	
Personal Safety	− 0.0688	0.069	− 0.996	0.320	
Access to Basic Knowledge	− 0.0723	0.035	− 2.092	0.037	
Access to Information and Communication	− 0.0910	0.068	− 1.348	0.179	
Health and Wellness	0.1525	0.110	1.391	0.165	
Environmental Quality	0.0478	0.046	1.038	0.300	
Personal Rights	0.0448	0.051	0.873	0.384	
Personal Freedom and Choice	0.1222	0.086	1.416	0.158	
Tolerance and Inclusion	0.0122	0.099	0.123	0.902	
Access to advanced education	0.075	0.030	2.513	0.013	
Single Domain					
Advanced education	0.0416	0.006	6.842	0.000	0.145
Access to basic knowledge	0.0316	0.006	5.525	0.000	0.100
Advanced education and access to basic knowledge combined					0.172
Advanced education	− 0.0544	0.019	− 2.943	0.004	
Access to basic knowledge	0.0984	0.020	4.871	0.000	
Indicators for access to basic knowledge					0.214
Secondary enrolment rate	1.7978	0.562	3.200	0.002	
Lower secondary completion only	− 0.0076	0.025	− 0.303	0.762	
Early school leaving	0.0156	0.061	0.255	0.799	
Indicator for advanced education					0.343
Tertiary education attainment	0.0257	0.023	1.135	0.258	
Tertiary enrolment	− 20.043	10.341	− 1.938	0.054	
Lifelong learning	0.1852	0.040	4.661	0.000	
Best single indicators					
Secondary enrolment rate	1.7981	0.230	7.803	0.000	0.214
Lifelong learning	0.1867	0.018	10.536	0.000	0.331
Secondary enrolment rate and lifelong learning combination					0.332
Secondary enrolment rate	− 0.2140	0.384	− 0.557	0.578	
Lifelong learning	0.2015	0.032	6.293	0.000	

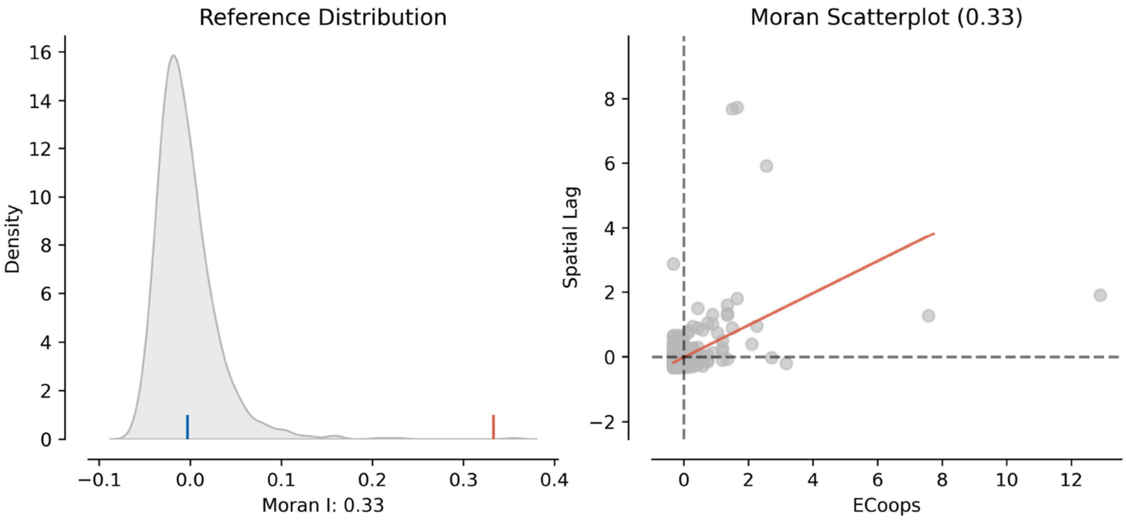

Fig. 4. Moran global on NUTS2 regions.

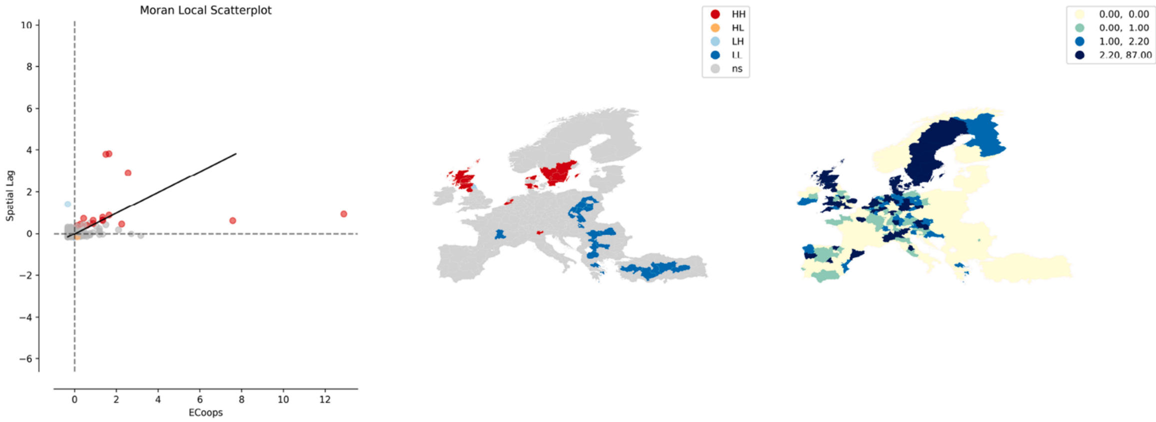

Fig. 5. Moran local on NUTS2 regions.

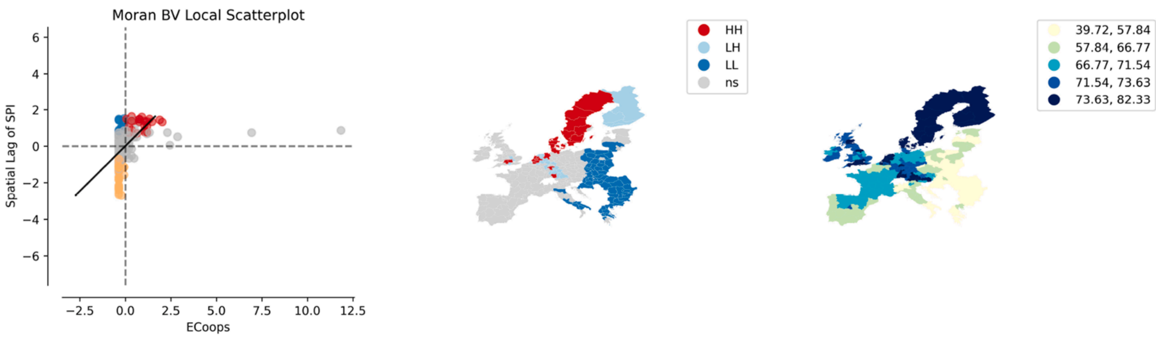

Fig. 6. Bivariate local moran statistics ECoops and SPI.

3.1.1. Statistics for SPI

Table 3 shows the summary statistics for the SPI index and its components, the values for the ECoops are highlighted in bold. The component 'Basic Human Needs' includes domains and indicators that assess basic requirements for living. The 'Foundation of well-being', in contrast to the basic human needs, assesses the degree of the citizens' and communities' ability and resources to maintain and further enhance their quality of life. 'Opportunity' assesses if citizens and communities have the chance to reach and realize their

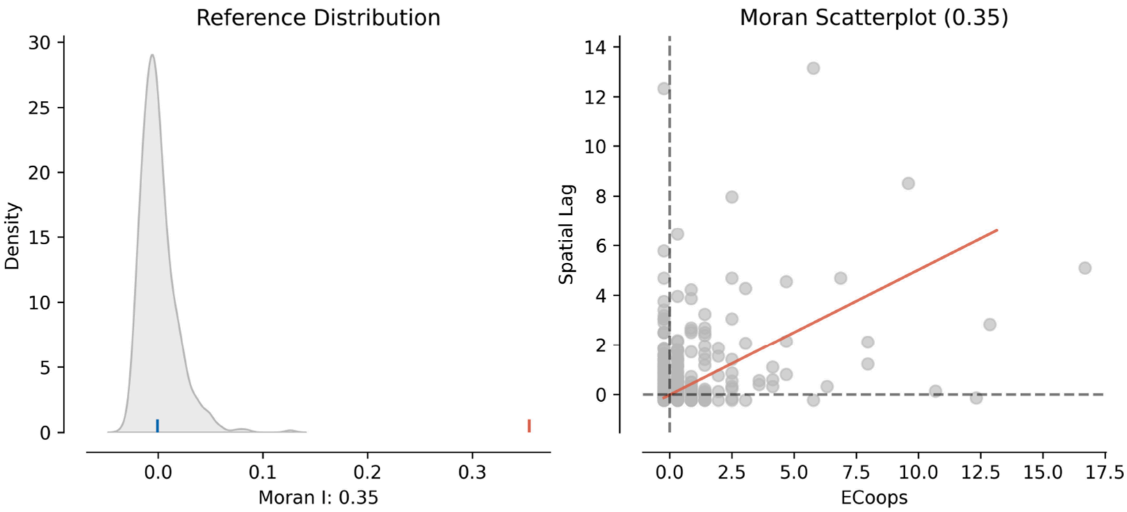

Fig. 7. Moran global on NUTS3 regions.

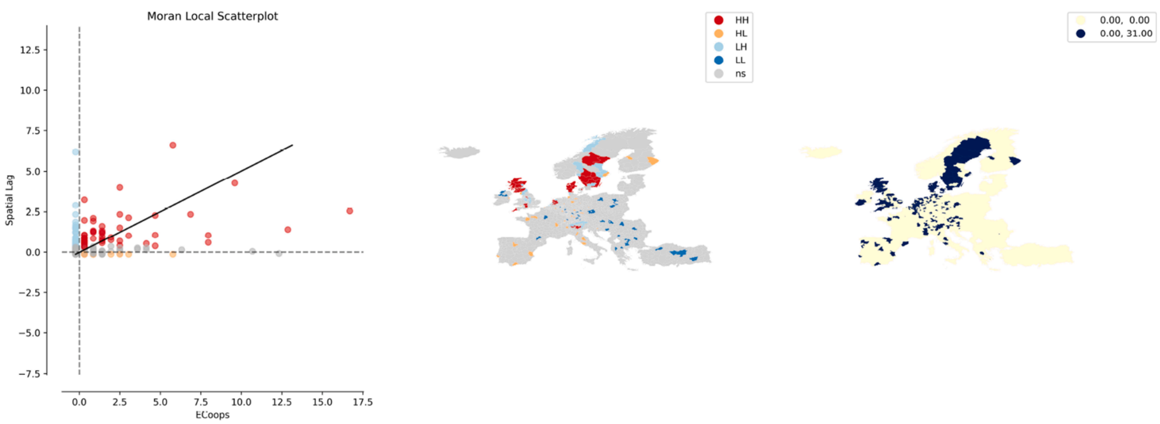

Fig. 8. Moran local on NUTS3 scale.

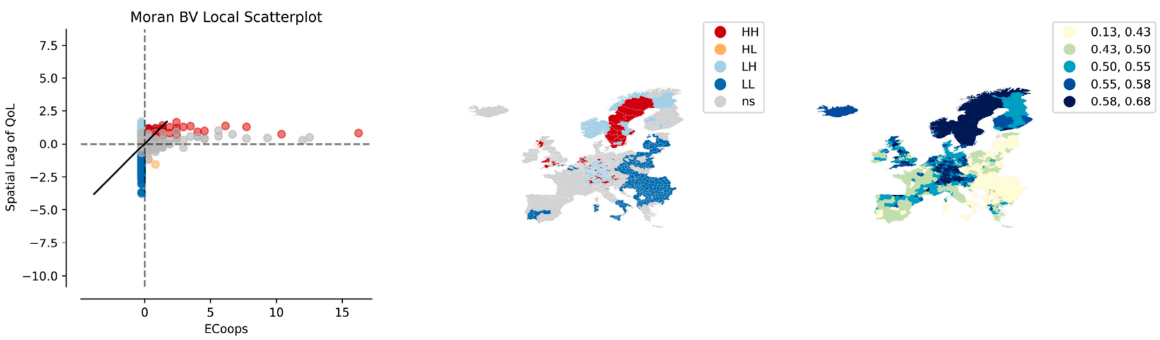

Fig. 9. Moran bivariate local statistics ECoops and QoL.

full potential concerning their personal rights, freedom and choice,tolerance and inclusion, and advanced education. The *p*-values for the *t*-statistic of the SPI and its components are all significant, concluding that the values for the SPI and its domains are all significantly better (higher when higher indicator values are better and lower when a lower indicator values are better) on the NUTS2 regions where ECoops exist, compared with the NUTS2 regions average. This confirms the first hypothesis that ECoops are more likely to be found in areas where the overall SPI is higher. This situation also holds for all domains in the components of the index but not for the domain “Indicators for access to basic knowledge” (see Appendix Tables A1–A3). On the single indicator level, solely “Secondary enrolment rate", "Secondary enrolment rate - CAPPED", "Tertiary enrolment - CAPPED", "Sewage treatment" and "Teenage pregnancy" were found not significantly different (see Appendix Tables A4 and A5). This reveals that hypothesis ii), which looks at the components, domains, and indicators of the SPI does not hold in all cases.

3.1.2. Statistics for QoL

Table 4 shows the summary statistics for the QoL index and its components, the values for the ECoops are highlighted in bold. All components of the QoL are also significantly different where ECoops exist compared to the NUTS3 regions average. This supports the first hypothesis that the ECoops are more likely to be found in the NUTS3 regions where the QoL index is higher.

On the domain level, only "Ecological flourishing" and the "Socio-economic enablers" are not found significantly different (see Appendix Table A6). On the sub-domain level, the results show greater differences. The sub-domains of "Education", "Transport", "Consumption opportunities", "Climate change", "Ecosystem services and biodiversity wealth" and "Green infrastructure" are not significantly different (see Appendix Table A7). Therefore, hypotesis iii), where domains and sub-domains are expected to perform significantly better than the respective average values on NUTS3 regions, does not apply in all cases.

3.2. Results for the correlation analysis

The correlation analysis showed that among the different components of the SPI, "Opportunity" receives the highest correlation coefficient value (see Fig. 2). Within "Basic Human Needs", the domains of "Shelter", and "Personal Safety", correlate the highest with the presence of ECoops (see Appendix Fig. B.1). On the single indicator level, "Satisfaction with housing" correlates with the highest positive coefficient value while the indicators of "Overcrowding" and "Burdensome Cost of Housing" have the highest negative coefficient value with the existence of ECoops. ECoops seem less likely to be found in places where housing costs are perceived as a heavy financial burden and where people live in dwellings exceeding their capacity. In contrast, where people feel satisfied with their housing situation, ECoops are more likely to be found. Building on Magnani and Osti (2016), this could be explained because citizens who have no disposable income are less likely to be able to invest (e.g., in membership fees of ECoops). In highly populated urban areas, the installment of co-owned renewable energy technology has also been accompanied by various challenges caused by the lack of space, higher costs and restrictive rental agreements (Chen, 2015).

Within "Foundation of Well-Being", the domain of "Access to Information and Communication" correlates the highest with the presence of ECoops (see Appendix Fig. B.2). Further down on the indicator level, indicators related to the access to information and communication, namely internet at home, broadband at home, and online interaction with public authorities, have the highest correlation. The domains of "Health and Wellness", "Access to basic knowledge" as well as "Environmental Quality" and their indicators correlate less. Šahovi and da Silva (2016) has stressed that communication via websites are the main channel for distribution of information for initiatives promoting renewable energy. Also, Hyysalo et al. (2018) have studied the transition potential of energy internet forums, and discovered that forums on renewable energy facilitate faster exchange and community building for the uptake of local renewable energy resources. A reliable network to share information with citizens is important to mobilize, engage, and educate potential members for ECoops.

Within "Opportunity", the highest correlation coefficient for a domain is found for "Personal Rights", followed by the domain for "Personal Freedom and Choice" (see Appendix Fig. B.3). On the indicator level, "Lifelong learning" (0.383), "Quality and accountability of government services" (0.371) and "Corruption" (0.352) correlate the highest with the presence of ECoops. "Corruption" is measured with the institutions corruption index, the higher the value the cleaner are institutions from corruption. Therefore, ECoops correlate with perceived lower corruption. "Lifelong learning" has the highest correlation with ECoops among all indicators of all domains.

The correlation values for QoL and the number of ECoops are considerably lower than for the SPI index, the component of "Life flourishing" received the highest correlation coefficient value across all components, domains, and subdomains (0.224) (Fig. 3).

The component "Life flourishing" entails similar aspects as the component of "Opportunity" of the SPI assessing the fulfilment of personal aspirations, community flourishing and ecological flourishing. On the domain level, "Community Flourishing", assessing both social belonging and good governance aspects, showed the highest correlation values (see Appendix Fig. B.6).

Within the domain of "Good Life Enablers", the correlation coefficient value for the sub-domain "Digital connectivity" is the highest (see Appendix Fig. B.4), also the sub-domain of "Institutional trust" receives a higher correlation value within the domain of "Life flourishing". However, the overall correlations values are low (see also Appendix Fig. B.5). The correlations of the QoL confirm similar findings as the SPI. A high value for "Life flourishing", similar to "Opportunity" of the SPI, occurs most with a higher number of ECoops. Among which "Institutional trust", comparably with the indicators "Quality and accountability of government services" and "Corruption" of the SPI, indicate that the institutional setting influences the emergence and existence of ECoops also on NUTS3 regions. Chen (2015) also stressed that strong leadership and government support are important for the development of ECoops. Our study also found a connection between trust in public authorities (police, policy-makers, other public services) and interaction with public authorities both on NUTS2 and NUTS3 regions with the existence of ECoops. Leiren et al. (2020) and Walker et al. (2010b) have studied the aspect of trust among civic groups and into national and regional policy makers and highlighted that increased trust fostered the development of community energy. Also, Chan et al. (2017) highlighted that financial and policy support by local authorities are vital for the success for local renewable energy projects. Similar to studies of Punt et al. (2021), further research on specific policy support and institutional pre-conditions, and their impact on the regional development of ECoops could be insightful.

The result for the sub-domain "Digital connectivity" shows the importance of access to information and communication also on the NUTS3 regions. This result relates to the domain of "Access to Information and Communication" of the SPI which also received a comparably high correlation coefficient value. These results indicate that the hypothesis assuming a high correlation between the number of ECoops per NUTS3 and the values for each index does not hold. The correlations are in general low and from a wide range of options only few items present correlations larger than +/− 0.3.

3.3. Results for the regression analysis

The linear regression models using each index, SPI and QoL, as independent variable to explain the number of ECoops show positive significant relations but the resulting R^2 values are low (see Table 5 and Appendix Table C.1), confirming that the hypothesis on the high correlation between the number of ECoops per NUTS region and the values for each index and their components, domains, subdomains/indicators can be rejected. Especially for the QoL, the R^2 value only reaches 0.065. By iterating through the different levels of aggregation of the index, we see that this value only gets slightly higher. A model considering all components as independent variable shows that the highest R^2 reaches 0.092 while all other alternative models show lower values (see Appendix Table C.1). For the SPI the R^2 is higher (see Table 5). The model including solely the SPI has a R^2 of 0.126. In the regression model that includes the components of the index, only the aspect of "Opportunity" received a significant result. The R^2 increases for the model with the single component "Opportunity" as independent variable. The next regression model includes the domain level, in which both "Access to Basic Knowledge" and "Access to Advanced Education" showed a significant result. A model combining the two domains has a better R^2 than the model for the index, while models for each of these two domains separately show better results for "Advanced education". Next, the regression model for the indicators of "Access to basic knowledge" shows a significant result for "Secondary enrolment rate". The regression model for the indicators for advanced education shows a significant result for the indicator of "Lifelong learning" which also received the highest explanatory value. The model encompassing solely "Lifelong learning" receives the highest explanatory value for a single indicator and outperforms all other models reaching a R^2 of 0.343. Compared to the "Access to Basic Knowledge", "Advanced education" seems to play a greater role for the development and existence of ECoops. Šahovi and da Silva (2016) mentioned that training, education on renewable energy (e.g. via community events or excursions), and strong collaboration with citizens are the best practice to foster the development of ECoops. Also, Vallecha et al. (2021) considers educational training and events as an important enabler for successful energy initiatives. Going back to the conceptualization of the SPI, the aspects under "Opportunity" seem most decisive for the development of ECoops providing citizens with needed resources (specified training). Connecting the findings with the concept of socio-technical systems, we found that the development of ECoops is connected with place-based conditions, such as trust in government, access to information and communication, access to advanced education, and satisfaction with the housing situation. The results for the regression analysis of the QoL index and components have only very low explanatory value and therefore are not presented in detail here (see Appendix Table C.1).

3.4. Results spatial analysis

The spatial analysis includes the results for the global and local univariate Moran's I for ECoops and then the bivariate Moran's I for the spatial correlation of ECoops with the SPI and the QoL.

3.4.1. Spatial analysis on NUTS2 regions

The results of the Moran's I indicate a slight positive auto-correlation between the existence of ECoops in neighboring NUTS2 with a significant difference from a fully random, reference distribution (Fig. 4). This indicates that NUTS regions with a particular number of ECoops are surrounded by NUTS regions with a similar number of ECoops.

As the global Moran's I does not account for the location of correlations, we present the distribution of the local spatial auto-correlations using LISA in Fig. 5. The scatterplot on the left allows to differentiate between the specific type of auto-correlation. On the bottom left it shows LL correlations, upper left shows LH, upper right shows HH, and the bottom right shows HL correlations. The scatterplot shows that there are several HH correlations and some outliers. The figure in the middle shows the LISA cluster map. The red areas on NUTS2 regions show the HH auto-correlations between ECoops for neighboring NUTS2 regions. This indicates that there are several areas where NUTS2 regions with a high number of ECoops are located next to another NUTS2 unit with a high number of ECoops. HH clusters are mainly located in the United Kingdom and Denmark. In contrast, the blue areas show LL auto-correlations, which are mainly found in Eastern European countries. The figure on the right shows the choropleth map. Darker areas in the choropleth map show higher values for ECoops while lighter areas indicate lower values. This is an alternative presentation of Fig. 1. and emphasizes the high concentration of ECoops reported in the United Kingdom, Sweden, and Denmark (coloured dark blue) and the absence of ECoops in most parts of Eastern European countries (light coloured).

To understand the spatial connection between the SPI and the distribution of ECoops, the bivariate Moran's I is conducted. The results of the bivariate global Moran's I with the variable of ECoops and the spatial lag of the SPI also show a slight positive auto-correlation ($I = 0.27$, see Appendix Fig. D.1). This indicates mainly that NUTS regions with high numbers of ECoops are surrounded by regions with high SPI. The local bivariate Moran's I statistics are shown in Fig. 6. Here we see that NUTS2 regions with high SPI values are neighbours of NUTS regions with high number of ECoops in Sweden and Denmark while eastern european countries present mostly LL relations betwen SPI values and number of ECoops. The combined case, LH, occours maninly in Finland where the number of ECoops of individual NUTS regions is rather low but the SPI of neighbouring NUTS regions is rather high.

3.4.2. Spatial analysis on NUTS3 regions

The Global Moran's I for the NUTS3 regions shows a slight positive auto-correlation among the existence of ECoops with $I = 0.35$ with a significant difference from a fully random, reference, distribution (Fig. 7), which is completely aligned with the results for the NUTS2 regions.

Fig. 8 shows the different clusters of ECoops between neighboring NUTS3 regions. The scatterplot on the left shows various HH units with several HH outliers, it also indicates the presence of LH clusters. The LISA cluster map shows several LL correlations across Central and Eastern European countries and HH clusters in Denmark, the United Kingdom, and some in Sweden. Several LH clusters can be found across Spain, France, and Finland. The choropleth map also displays higher spatial correlation for the existence of ECoops in Sweden, Denmark and the United Kingdom. The choropleth map only shows two extremes, the NUTS3 regions with multiple ECoops and NUTS3 with no ECoops. This contrasts with the case of the NUTS2 where multiple classes in-between these two extremes could be identified.

To get more insight into the spatial connection between ECoops and the QoL, bivariate Moran's I statistics are also assessed. The bivariate Moran's I for ECoops and the spatial lag of the QoL is $I = 0.14$, showing a very small positive auto-correlation (see Appendix Fig. D.2). Fig. 9 shows the LISA results. The scatterplot shows that various LL, HH, and LH clusters were found. The LISA cluster map specifies their location: Again there are HH clusters found in Sweden, some across the United Kingdom and Germany, LH clusters are located across Germany and Northern European countries, while LL clusters are located mainly in Eastern European countries.

Comparing the results for the SPI and QoL, they both show similar results. For the univariate analysis of the number of ECoops on NUTS2 and NUTS3 regions, HH correlations occure in Northern European countries, while LL are predominantly found in Eastern European countries. The local correlations of ECoops are more diverse on the NUTS3 regions showing also HL and LH correlations, in contrast to only HH and LL correlations on NUTS2 regions.

The bivariate analysis also shows similar correlations for the SPI and QoL on NUTS2 and NUTS3 regions. However, in Germany on NUTS3 regions several LH correlations are found which are not found on the NUTS2 regions using the SPI. Further, the resulting HH correlations from the bivariate analysis occuring in Denmark for the SPI on NUTS2, are not emerging on NUTS3 regions using the QoL. But, several HH correlations occure in the United Kingdom on NUTS3 regions that cannot be found on the NUTS2 regions.

The different LH, HH, HL, LL correlations depend highly on our used dataset, but the results confirm existing studies which highlight a stronger cooperative culture in the mentioned countries: Germany, Denmark and United Kingdom (Klagge and Meister, 2018; Lehtonen and de Carlo, 2019; Mundaca et al., 2018). Further, it shows that within countries there can be regional differences in the spatial distribution of ECoops shown by the LH and HL spatial correlations. It also builds on other studies which confirmed a very low number of ECoops and community energy project in Eastern European countries and connected it with factors affecting social cohesion such as e.g., institutional trust (Capellán-Pérez et al., 2020). The study also stresses that the dataset of ECoops and initiatives for community energy in Eastern European countries is less documented which could lead to distorted results. In general the spatial analysis contributes to reject hypothesis v) which was postulating a spatial auto-correlation for the location of ECoops, between the indexes and the distribution of ECoops from a global perspective. This hypothesis can, however, be accepted from the local perspective since in each single case it is possible to identify clusters.

4. Discussion

This study sheds light on the connection between some socio-demographic conditions and the emergence and existence of ECoops. While there are limitations in the coverage of the ECoops dataset and the indicators of the exploratory spatial data analysis do not show very strong trends (e.g., relatively low correlation factors), the findings of this study strengthen some conclusions of existing studies that were conducted in a qualitative way.

In general, our findings indicate that ECoops develop in areas that perform better on social cohesion. This shows that ECoops as social innovations co-occure with higher social cohesion, which was also found by Evers and Ewert (2015). The studies of Bauwens and Eyre (2017) and Yildiz et al. (2014) on the membership structures of ECoops also stress that most members of ECoops are characterized by a high energy consumption pattern and belong to social groups with higher income, and higher education. While ECoops can be a means to implement procedural energy justice, the distribution and recognition justice, so questions of who benefits from ECoops and can access their membership can further reinforce social inequality (Jenkins et al., 2016). From a spatial perspective, our study showed that there is an unequal distribution of ECoops across space. Martin (2009) showed that social inequalities measured on an individual level coincide with inequalities measured on a regional level, this calls for further caution on just transition considerations both socially and spatially. To counteract this divergence, the provision of specified training for and outreach to vulnerable social groups could be addressing the barriers to a just transition on the individual level.

Concerning the geography of ECoops, we have fostered the understanding of their location, spatial development, and scaling. Future studies could address the relational proximity, territoriality, and path dependency of this transition phenomenon. To study the impact and geographies of regional cohesion policy and proximity to industrial clusters could be specifically interesting in this context.

In addition to the reflections on our findings and existing research, we want to highlight some remarks on the conducted research. The present study is dependent on the available data on ECoops and the SPI and QoL. The SPI and QoL are indexes measuring the societal development using social and environmental indicators while excluding traditional progress indicators such as the gross domestic product and income. This aligns with our conceptualization and focus on social cohesion but traditional economic indicators were not considered in our regression analysis. This may have led to a larger error variance. Future studies should include also economic indicators to foster the understanding of the connection between societal and economic progress in the context of ECoops.

Moreover, although the ECoops database provides a very extensive overview of renewable ECoops in Europe, not all ECoops are covered by this dataset. Countries well connected with the ReScoop network, or countries with a longer tradition of ECoops are more likely to be represented in the dataset while other countries that are not, or have different, more prominent legal entities (not co-operatives) aiming for community renewable energy, are not included in this analysis. A thorough data acquisition of ECoops and other forms of community energy initiatives is vital to conduct future research and to develop credible policy solutions to foster their development. Similar to the database that is developed by the ReScoop network, we stress that a nuanced and European wide data acquisition on Energy Communities and the different forms they can take (e.g. ECoops, grassroot initiatives, renewable energy and citizen energy comunities), is needed.

Further, we want to note that the socio-demographic information for the NUTS2 and NUTS3 units does not have to apply to the member of ECoops themselves. To avoid an ecological fallacy, our unit of analysis were the NUTS2 and NUTS3 regions and not an individual one. However, previous studies have shown that some of our findings relate to qualitative findings on the individual level. Bringing together insights from both qualitative and quantitative research may foster an holistic understanding of the emergence and existence of ECoops and other forms of renewable energy initiatives. In that way, individual and community drivers and facilitating factors on the system level can be assessed.

5. Conclusion

By applying an exploratory (spatial) data analysis of ECoops in Europe associated to the socio-demographic indexes SPI and QoL, this study aimed to explore the connection of specific socio-demographic factors with the existence of ECoops. The study highlighted that factors such as access to advanced education, access to information and communication, satisfaction with housing and authorities correlate with the existence of ECoops. Further, the study showed where ECoops emerge more (Sweden, Denmark, United Kingdom) and where less (Eastern Europe, South Eastern Europe) concluding that there is a positive but limited spatial correlation between the SPI and QoL and the presence of ECoops.

By providing insights into which aspects are beneficial for the existence of ECoops, our results facilitate the development of measures to foster the creation of ECoops in regions where they are currently low in numbers. Investing in improving relatively easy to modify indicators such as long-life learning can contribute to boost the creation of further ECoops.

This study represents a starting point for future research fostering the understanding of the spatial emergence of ECoops, and the connection with socio-demographic conditions. While our study focused on the Qol and SPI, further indicators on economic and technical aspects should be studied for which we provided a replicable methodological approach.

CRediT authorship contribution statement

Maria Luisa Lode: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization. **Thierry Coosemans:** Resources, Project administration, Funding acquisition. **Luis Ramirez Camargo:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing – original draft, Writing – review & editing, Visualization, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Summary statistics SPI and QoL

Table A2.

A1. Summary statistics for domains in components in SPI

Table A1
Summary statistics basic human needs.

Indicators for nutrition and basic medical care									
Count	Mean	Std	Min	25%	50%	75%	max	*t*-test	*p*-value
651.0	85.542	3.589	57.99	82.9	85.55	88.67	94.56	11.335	5.621e − 28
276.0	**79.937**	**11.356**	**31.32**	**78.6**	**83.795**	**86.555**	**94.56**		
Indicators for water and sanitation									
651.0	89.128	10.017	46.68	76.83	94.87	97.92	99.49	6.347	3.430e − 10
276.0	**83.819**	**14.799**	**24.22**	**76.0025**	**86.4**	**96.72**	**99.49**		
Indicators for shelter									
651.0	76.124	7.340	40.33	74.86	75.73	80.2	87.56	13.685	5.876e − 39
276.0	**66.488**	**13.994**	**34.13**	**53.6275**	**74.86**	**75.758**	**87.56**		
Indicators for personal Security									
651.0	81.233	4.798	59.92	78.675	83.35	84.53	87.06	8.695	1.564e − 17
276.0	**77.526**	**8.008**	**41.37**	**72.475**	**80.175**	**83.66**	**92.92**		

Table A2
Summary statistics foundation of well-being.

Indicators for access to basic knowledge									
Count	Mean	Std	Min	25%	50%	75%	max	*t*-test	*p*-value
651.0	71.277	10.687	38.45	60.19	71.54	80.08	92.2	− 0.574	0.566
276.0	**71.749**	**13.126**	**24.13**	**63.762**	**73.075**	**82.1725**	**99.11**		
Indicators for access to information and communication									
651.0	70.022	10.214	42.77	66.16	67.68	75.74	92.71	7.278	7.253e − 13
276.0	**64.249**	**12.792**	**33.4**	**55.01**	**66.43**	**74.17**	**92.71**		
Indicators for health and wellness									
651.0	75.548	3.52	44.21	74.15	75.59	78.31	81.05	14.865	5.592e − 45
276.0	**69.186**	**9.495**	**35.29**	**65.8675**	**72.815**	**75.4225**	**81.05**		
Indicators for environmental quality									
651.0	53.127	11.833	21.87	44.44	52.58	59.62	72.91	8.095	1.801e − 15
276.0	**46.361**	**11.157**	**20.59**	**38.823**	**45.13**	**52.7575**	**91.08**		

A2. Summary statistics for the QoL

Table A3
Summary statistics opportunity.

Indicators for personal rights									
Count	Mean	Std	Min	25%	50%	75%	max	*t*-test	*p*-value
651.0	55.938	11.951	19.38	51.83	51.83	67.86	78.93	10.829	8.180e − 26
276.0	**46.127**	**14.056**	**14.02**	**34.7675**	**44.25**	**55.03**	**83.67**		
Indicators for personal freedom of choice									
651.0	77.255	7.205	50.61	72.685	75.7	84.05	87.78	11.632	2.754e − 29
276.0	**69.826**	**11.967**	**28.62**	**62.44**	**71.77**	**79.6225**	**91.93**		
Indicators for tolerance and inclusion									
651.0	76.792	5.827	49.12	74.94	79.2	80.58	83.71	14.941	2.227e − 45
276.0	**68.676**	**10.588**	**40.84**	**58.698**	**73.6**	**77.455**	**86.11**		
Indicators for access to advanced education									
651.0	78.765	17.689	26.86	66.81	85.7	91.76	100.0	11.315	6.838e-28
276.0	**64.160**	**18.616**	**20.11**	**50.698**	**62.335**	**79.2925**	**100.0**		

Table A4
Summary statistics for the indicators of SPI (1).

Indicator	Count	Mean	Std	Min	25%	50%	75%	max	*t*-test	*p*-value
Mortality rate before age 65	651.0	0.12	0.02	0.08	0.10	0.12	0.14	0.23	− 7.39	0.00
	275.0	0.14	0.05	0.08	0.11	0.12	0.15	0.30		
Infant mortality	651.0	3.45	0.75	1.25	2.90	3.65	4.10	5.80	− 5.51	0.00
	276.0	3.89	1.69	0.00	2.95	3.53	4.30	11.45		
Unmet medical needs	651.0	1.66	1.05	0.27	1.48	1.48	1.77	11.62	− 11.12	0.00
	276.0	3.24	3.24	0.20	1.48	1.77	3.20	17.29		
Insufficient food	651.0	6.11	2.93	0.59	2.78	7.65	7.65	23.83	− 10.53	0.00
	276.0	10.36	9.27	0.19	6.46	7.69	11.59	62.85		
Lack of toilet in dwelling	561.0	0.47	0.62	0.03	0.22	0.22	0.64	10.61	− 7.27	0.00
	257.0	2.83	7.65	0.03	0.25	0.64	1.44	51.35		
Uncollected sewage	651.0	0.10	0.93	0.00	0.00	0.00	0.00	22.14	− 7.18	0.00
	276.0	2.75	9.31	0.00	0.00	0.00	0.20	65.79		
Sewage treatment	649.0	64.41	39.27	0.00	13.43	90.54	99.09	100.00	1.84	0.07
	274.0	59.25	38.39	0.00	18.24	72.03	96.17	100.00		
Burdensome cost of housing	651.0	24.60	12.62	6.06	12.75	30.67	30.67	62.57	− 9.35	0.00
	276.0	33.89	16.35	6.06	19.06	30.67	44.54	77.87		
Satisfaction with housing	651.0	47.90	12.33	0.81	40.15	52.97	52.97	64.99	13.16	0.00
	276.0	34.60	17.52	0.81	16.95	33.54	52.79	64.99		
Overcrowding	651.0	8.42	5.84	1.29	6.69	7.35	8.01	49.26	− 11.35	0.00
	276.0	16.29	15.27	1.29	6.69	7.88	24.07	59.09		
Lack of adequate heating	651.0	6.28	4.03	0.67	2.85	6.29	8.41	27.25	− 9.34	0.00
	276.0	10.41	9.43	0.67	5.06	8.06	11.28	54.24		
Homicide rate	481.0	1.06	0.54	0.23	0.74	0.94	1.23	3.20	− 3.48	0.00
	268.0	1.25	0.97	0.00	0.78	1.09	1.40	8.09		
Traffic deaths	651.0	46.49	20.98	12.22	30.36	41.76	65.95	161.99	− 8.25	0.00
	276.0	60.68	29.84	3.90	38.81	59.10	77.05	164.85		
Secondary enrolment rate	651.0	0.93	0.05	0.85	0.91	0.93	0.97	1.02	− 1.26	0.21
	269.0	0.94	0.04	0.83	0.91	0.95	0.97	1.02		
Lower secondary completion only	651.0	22.43	8.70	3.33	17.97	20.33	25.00	68.53	− 3.65	0.00
	272.0	25.20	13.95	3.33	14.92	22.77	31.00	76.47		
Early school leaving	649.0	13.65	6.78	4.97	8.53	11.77	15.30	29.87	2.22	0.03
	268.0	12.58	6.09	2.63	8.45	11.40	15.33	37.90		
Internet at home	651.0	86.77	7.38	48.00	86.00	87.00	92.00	98.00	13.76	0.00
	276.0	77.49	12.94	41.00	69.00	80.00	88.00	98.00		
Broadband at home	574.0	83.40	6.86	47.00	83.00	85.00	87.00	94.00	13.35	0.00
	268.0	74.54	12.32	40.00	67.00	77.00	85.00	94.00		
Online interaction with public authorities	651.0	49.89	19.82	11.00	32.00	45.00	73.00	88.00	5.36	0.00
	276.0	42.46	18.09	3.00	30.00	43.00	52.25	88.00		

Table A5
Summary statistics for the indicators of SPI (2).

Indicator	Count	Mean	Std	Min	25%	50%	75%	max	*t*-test	*p*-value
Life expectancy	646.0	80.80	1.42	76.10	79.80	80.95	81.80	84.20	4.57	0.00
	274.0	80.21	2.49	72.95	79.66	80.95	81.90	84.20		
General health status	651.0	73.30	5.45	46.70	70.97	75.32	75.32	83.12	11.37	0.00
	276.0	68.21	7.79	45.02	65.05	67.81	75.32	83.12		
Premature deaths from cancer	477.0	75.24	10.49	52.30	66.50	75.60	82.20	125.90	− 8.75	0.00
	266.0	85.04	20.04	52.30	72.15	80.20	91.60	165.20		
Premature deaths from heart disease	477.0	37.29	9.50	21.60	32.70	35.90	43.00	112.70	− 10.20	0.00
	266.0	55.09	35.92	21.60	33.53	40.70	55.05	206.10		
Unmet dental needs	651.0	3.10	1.81	0.83	2.43	2.43	3.63	12.43	− 8.84	0.00
	276.0	4.62	3.39	0.83	2.00	3.75	5.40	19.30		
Air pollution-pm10	651.0	16.62	6.19	6.12	12.17	17.23	20.59	38.62	− 9.97	0.00
	269.0	21.05	5.99	6.12	17.30	20.40	24.56	40.92		
Air pollution-pm2_5	651.0	11.48	4.69	4.63	8.09	11.87	14.71	29.06	− 10.23	0.00
	269.0	14.97	4.74	4.63	11.98	14.52	17.63	31.24		
Air pollution-ozone	651.0	100.36	13.96	82.08	89.21	96.79	107.08	148.89	− 9.89	0.00
	269.0	110.12	12.78	82.08	100.54	113.29	118.96	148.89		
Pollution, grime or other environmental problems	651.0	11.69	5.53	4.37	9.35	9.35	12.66	42.70	− 4.54	0.00
	276.0	13.55	6.12	2.84	9.35	11.66	17.38	42.70		
Protected land (Natura 2000)	649.0	14.71	9.47	0.23	5.92	12.19	20.29	51.05	− 5.75	0.00
	270.0	19.02	12.23	0.10	9.61	16.58	27.15	56.94		
Trust in the political system	651.0	54.71	16.65	11.65	49.52	51.63	71.06	85.35	9.65	0.00
	276.0	42.97	17.58	10.99	29.48	45.94	51.63	86.47		

(*continued on next page*)

Table A5 (*continued*)

Indicator	Count	Mean	Std	Min	25%	50%	75%	max	*t*-test	*p*-value
Trust in the legal system	651.0	36.11	15.60	5.12	27.72	27.72	53.31	63.45	6.52	0.00
	276.0	28.72	16.21	2.47	13.60	27.72	43.62	74.24		
Trust in the police	649.0	70.81	9.87	34.05	67.45	68.65	78.67	93.80	11.57	0.00
	274.0	61.34	14.33	15.32	53.42	65.22	68.65	95.82		
Quality and accountability of government services	651.0	0.74	0.51	− 2.85	0.56	0.70	1.14	1.83	13.07	0.00
	274.0	0.11	0.93	− 2.85	− 0.50	0.43	0.70	2.69		
Teenage pregnancy	651.0	1.22	0.72	0.31	0.57	0.86	2.05	2.66	− 1.64	0.10
	276.0	1.31	1.01	0.29	0.66	0.98	1.62	8.54		
Young people not in education, employment or training	651.0	10.15	3.85	3.53	7.20	10.20	13.65	22.57	− 8.07	0.00
	268.0	12.80	5.83	3.47	8.23	12.39	15.58	34.77		
Corruption	651.0	0.82	0.59	− 2.36	0.72	0.77	1.05	1.68	13.27	0.00
	274.0	0.12	0.98	− 2.66	− 0.70	0.37	0.88	2.21		
Impartiality of government services	651.0	0.75	0.54	− 1.65	0.76	0.76	1.07	1.45	12.74	0.00
	274.0	0.12	0.96	− 3.17	− 0.56	0.39	0.90	2.54		
Attitudes toward people with disabilities	649.0	8.25	0.64	5.80	7.60	8.60	8.60	9.10	11.75	0.00
	274.0	7.63	0.93	5.40	7.10	7.60	8.30	9.10		
Gender gap	651.0	− 8.34	3.02	− 20.90	− 10.13	− 7.67	− 7.13	− 0.87	9.40	0.00
	276.0	− 10.85	4.98	− 29.73	− 12.81	− 10.27	− 8.09	− 0.73		
Tertiary education attainment	651.0	33.80	8.78	13.73	28.43	33.83	41.50	61.03	9.85	0.00
	272.0	27.46	9.25	11.10	19.72	27.02	33.54	61.03		
Tertiary enrolment	651.0	0.03	0.01	0.01	0.03	0.03	0.04	0.11	− 2.63	0.01
	276.0	0.04	0.02	0.00	0.03	0.03	0.04	0.13		
Lifelong learning	651.0	15.71	7.05	1.47	9.20	16.20	17.50	35.87	11.28	0.00
	271.0	10.09	6.49	0.83	5.85	9.00	13.97	35.87		
Secondary enrolment rate - CAPPED	651.0	0.93	0.04	0.85	0.91	0.93	0.97	1.00	− 1.51	0.13
	276.0	0.94	0.04	0.83	0.91	0.95	0.97	1.00		
Air pollution-pm10 - CAPPED	651.0	16.62	6.19	6.12	12.17	17.23	20.59	38.62	− 9.97	0.00
	269.0	21.04	5.98	6.12	17.30	20.40	24.56	40.00		
Air pollution-pm2_5 - CAPPED	651.0	11.44	4.53	4.63	8.09	11.87	14.71	25.00	− 10.52	0.00
	269.0	14.89	4.51	4.63	11.98	14.52	17.63	25.00		
Air pollution-ozone - CAPPED	651.0	99.29	11.50	82.08	89.21	96.79	107.08	120.00	− 11.70	0.00
	269.0	108.94	11.08	82.08	100.54	113.29	118.96	120.00		
Protected land (Natura 2000) - CAPPED	649.0	14.62	9.19	0.23	5.92	12.19	20.29	40.00	− 5.62	0.00
	270.0	18.64	11.38	0.10	9.61	16.58	27.15	40.00		
Tertiary education attainment - CAPPED	651.0	32.43	7.24	13.73	28.43	33.83	38.80	38.80	10.41	0.00
	272.0	26.82	7.98	11.10	19.72	27.02	33.54	38.80		
Tertiary enrolment - CAPPED	651.0	0.04	0.01	0.01	0.03	0.03	0.04	0.06	0.04	0.97
	276.0	0.04	0.01	0.00	0.03	0.03	0.04	0.06		
Lifelong learning - CAPPED	651.0	13.76	4.23	1.47	9.20	16.20	17.42	17.42	13.36	0.00
	271.0	9.43	5.03	0.83	5.85	9.00	13.97	17.42		

Table A6
Summary statistics for the domains of QoL .

Domain	count	mean	std	min	25%	50%	75%	max	*t*-test	*p*-value
Personal Enablers (B1)	668.000	0.558	0.173	0.160	0.450	0.600	0.680	0.920	− 2.347	0.019
	1440.000	0.577	0.167	0.080	0.460	0.590	0.690	0.920		
Socioeconomic Enablers (B2)	668.000	0.449	0.113	0.200	0.380	0.450	0.530	0.700	1.183	0.237
	1440.000	0.443	0.118	0.130	0.350	0.450	0.540	0.760		
Ecological Enablers (B3)	668.000	0.512	0.175	0.000	0.390	0.510	0.630	0.890	4.013	0.000
	1440.000	0.476	0.198	0.000	0.350	0.490	0.610	1.000		
Personal Health and Safety (M1)	668.000	0.619	0.153	0.160	0.450	0.630	0.750	0.940	4.638	0.000
	1403.000	0.574	0.227	0.000	0.500	0.620	0.730	1.000		
Economic and Societal Health (M2)	668.000	0.646	0.095	0.160	0.600	0.640	0.690	0.900	10.364	0.000
	1428.000	0.564	0.193	0.040	0.450	0.610	0.700	0.900		
Ecological Health (M3)	668.000	0.428	0.165	0.070	0.290	0.460	0.550	0.890	− 3.152	0.002
	1440.000	0.456	0.196	0.000	0.310	0.485	0.610	1.000		
Personal Flourishing (F1)	668.000	0.734	0.177	0.040	0.628	0.780	0.840	1.000	14.035	0.000
	1393.000	0.600	0.215	0.000	0.510	0.600	0.730	1.000		
Community Flourishing (F2)	668.000	0.630	0.095	0.140	0.600	0.600	0.700	1.000	14.591	0.000
	1440.000	0.523	0.179	0.000	0.470	0.590	0.610	1.000		
Ecological Flourishing (F3)	668.000	0.384	0.159	0.010	0.270	0.360	0.483	0.820	− 0.424	0.672
	1440.000	0.388	0.199	0.010	0.230	0.360	0.523	0.990		

Table A7
Summary statistics for the subdomains of QoL .

Subdomain	Count	Mean	Std	Min	25%	50%	75%	Max	*t*-test	*p*-value
Housing basic utilities (b11)	668.000	0.658	0.183	0.130	0.490	0.630	0.850	1.000	9.497	0.000
	1440.000	0.559	0.236	0.080	0.380	0.580	0.760	1.000		
Healthcare (b12)	668.000	0.406	0.204	0.010	0.270	0.410	0.500	1.000	− 15.834	0.000
	1440.000	0.557	0.204	0.010	0.420	0.550	0.710	1.000		
Education (b13)	668.000	0.612	0.275	0.000	0.410	0.640	0.840	1.000	− 0.192	0.848
	1439.000	0.614	0.272	0.000	0.410	0.640	0.840	1.000		
Transport (b21)	666.000	0.594	0.306	0.000	0.473	0.670	0.820	1.000	− 1.519	0.129
	1363.000	0.614	0.277	0.000	0.425	0.670	0.840	1.000		
Digital connectivity (b22)	668.000	0.578	0.167	0.190	0.460	0.590	0.680	1.000	18.410	0.000
	1440.000	0.442	0.153	0.080	0.350	0.420	0.510	1.000		
Work opportunities(b23)	668.000	0.350	0.290	0.000	0.060	0.260	0.560	0.980	− 6.066	0.000
	1422.000	0.434	0.301	0.000	0.150	0.415	0.670	1.000		
Consumption opportunities(b24)	668.000	0.409	0.275	0.000	0.200	0.390	0.590	1.000	0.556	0.579
	1439.000	0.402	0.292	0.000	0.170	0.370	0.600	1.000		
Cultural assets (b26)	668.000	0.316	0.194	0.000	0.170	0.290	0.460	0.930	− 2.507	0.012
	1440.000	0.338	0.185	0.000	0.210	0.320	0.500	0.930		
Green infrastructure (b31)	668.000	0.424	0.225	0.000	0.260	0.470	0.570	1.000	− 1.571	0.116
	1434.000	0.442	0.236	0.000	0.290	0.460	0.600	1.000		
Protected areas (b32)	668.000	0.599	0.268	0.000	0.410	0.580	0.840	1.000	6.868	0.000
	1440.000	0.513	0.270	0.000	0.320	0.520	0.720	1.000		
Personal Health (m11)	668.000	0.632	0.212	0.140	0.460	0.630	0.790	1.000	2.715	0.007
	1400.000	0.599	0.281	0.000	0.460	0.610	0.810	1.000		
Personal Safety (m12)	668.000	0.606	0.175	0.010	0.530	0.600	0.650	1.000	5.191	0.000
	1393.000	0.553	0.234	0.000	0.420	0.590	0.680	1.000		
Inclusive Economy (m21)	668.000	0.688	0.109	0.040	0.640	0.690	0.750	0.910	10.498	0.000
	1427.000	0.592	0.226	0.000	0.450	0.640	0.770	0.910		
Healthy Society (m22)	668.000	0.606	0.123	0.150	0.530	0.560	0.700	0.920	8.466	0.000
	1428.000	0.537	0.192	0.000	0.440	0.550	0.680	0.980		
Healthy Environment (m31)	668.000	0.489	0.303	0.000	0.268	0.520	0.763	1.000	− 3.988	0.000
	1380.000	0.547	0.315	0.000	0.270	0.605	0.820	1.000		
Climate Change (m32)	668.000	0.367	0.186	0.000	0.230	0.355	0.460	0.920	− 1.047	0.295
	1440.000	0.377	0.194	0.000	0.270	0.370	0.470	1.000		
Self-esteem(f11)	668.000	0.734	0.177	0.040	0.628	0.780	0.840	1.000	14.035	0.000
	1393.000	0.600	0.215	0.000	0.510	0.600	0.730	1.000		
Interpersonal Trust (societal belonging)(f21)	665.000	0.548	0.079	0.180	0.510	0.530	0.620	0.730	7.844	0.000
	1390.000	0.501	0.144	0.030	0.490	0.510	0.620	0.790		
Institutional Trust (good governance)(f22)	668.000	0.714	0.157	0.110	0.680	0.700	0.850	1.000	15.546	0.000
	1440.000	0.544	0.263	0.000	0.320	0.680	0.740	1.000		
Ecosystems services and Biodiversity wealth(f31)	668.000	0.384	0.159	0.010	0.270	0.360	0.483	0.820	− 0.424	0.672
	1440.000	0.388	0.199	0.010	0.230	0.360	0.523	0.990		

Appendix B. Correlation results

B1. Correlation results for the SPI

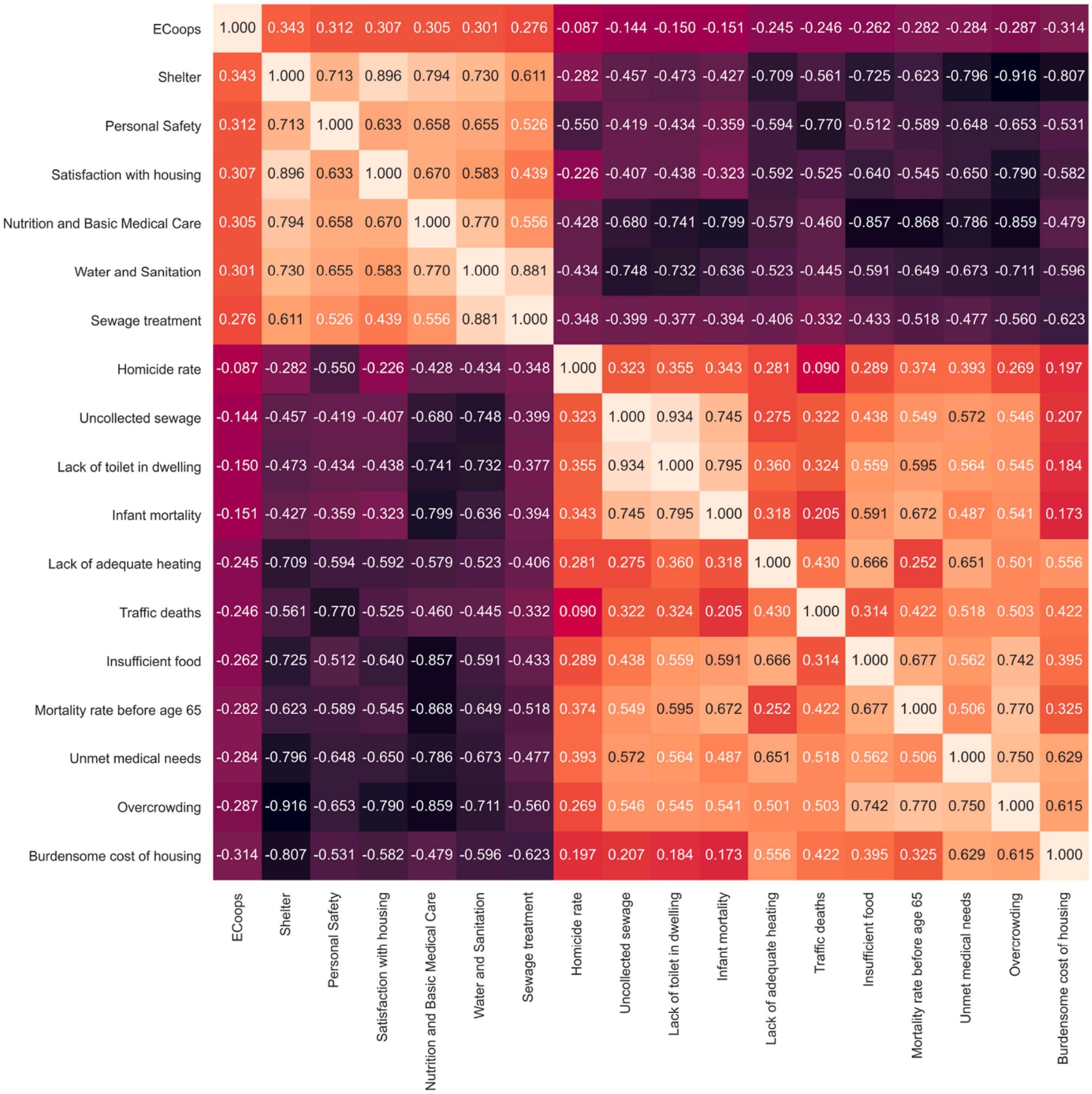

Fig. B1. Correlation of basic human needs.

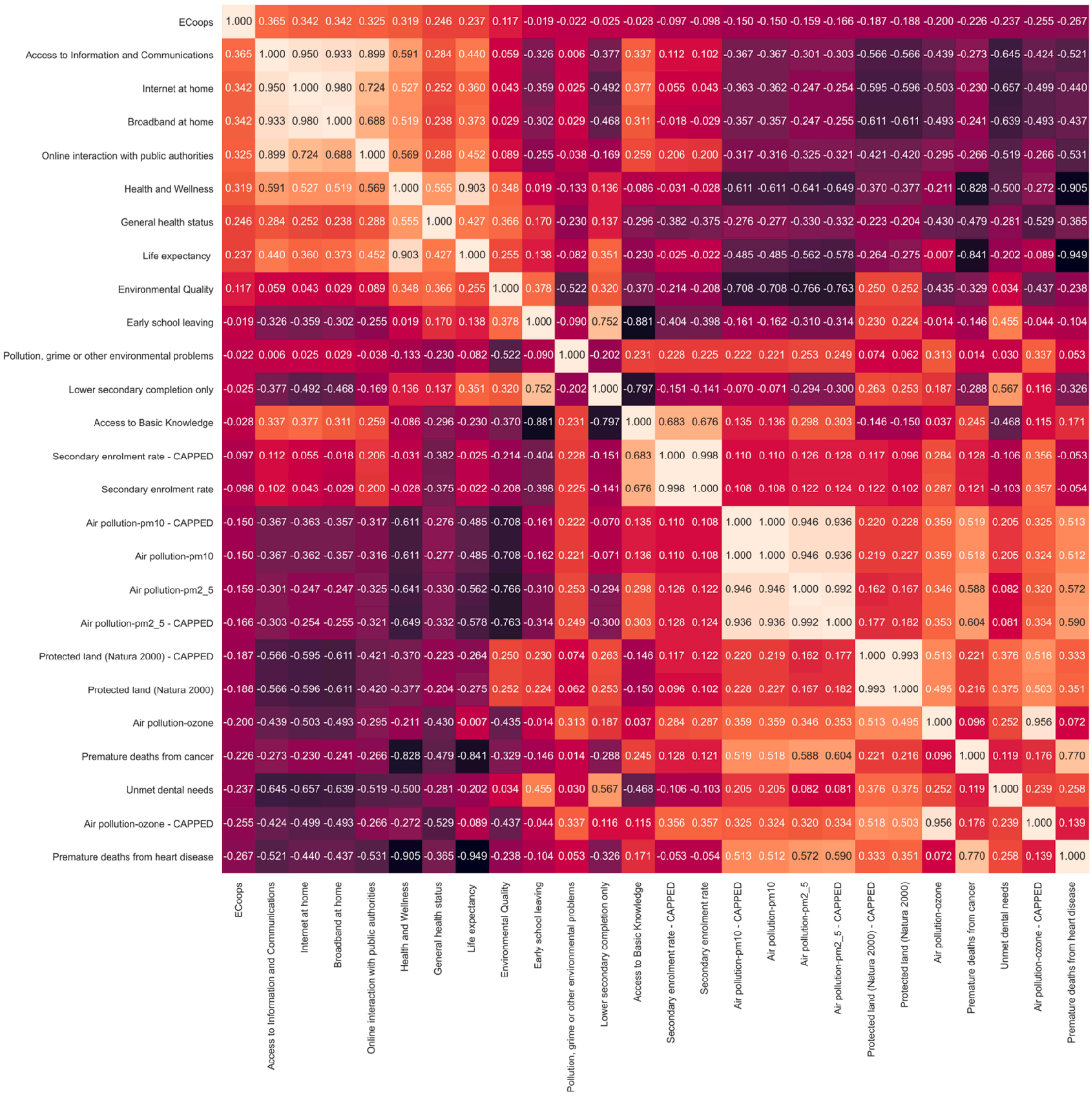

Fig. B2. Correlation of foundation of wellbeing.

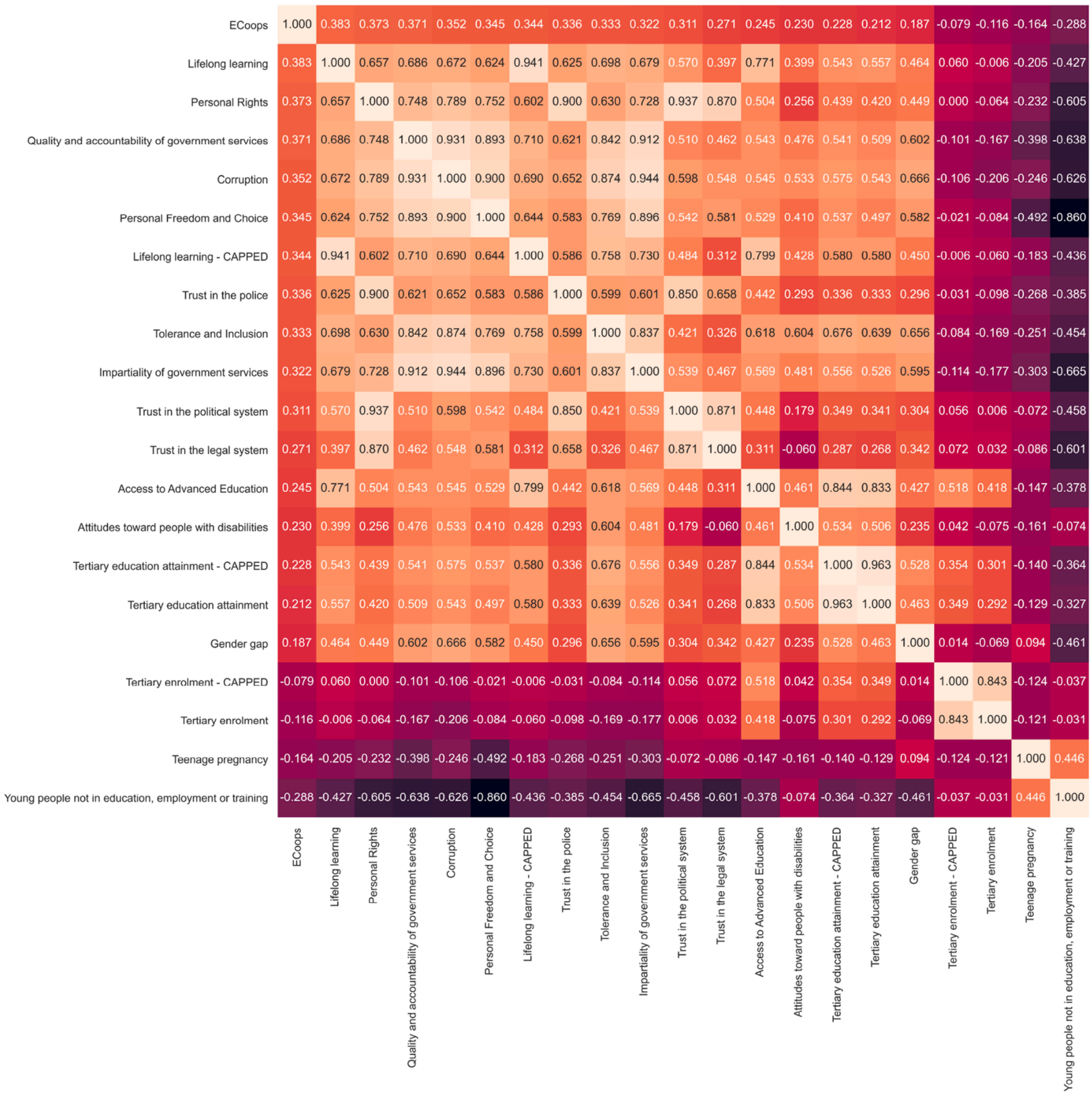

Fig. B3. Correlation of opportunity.

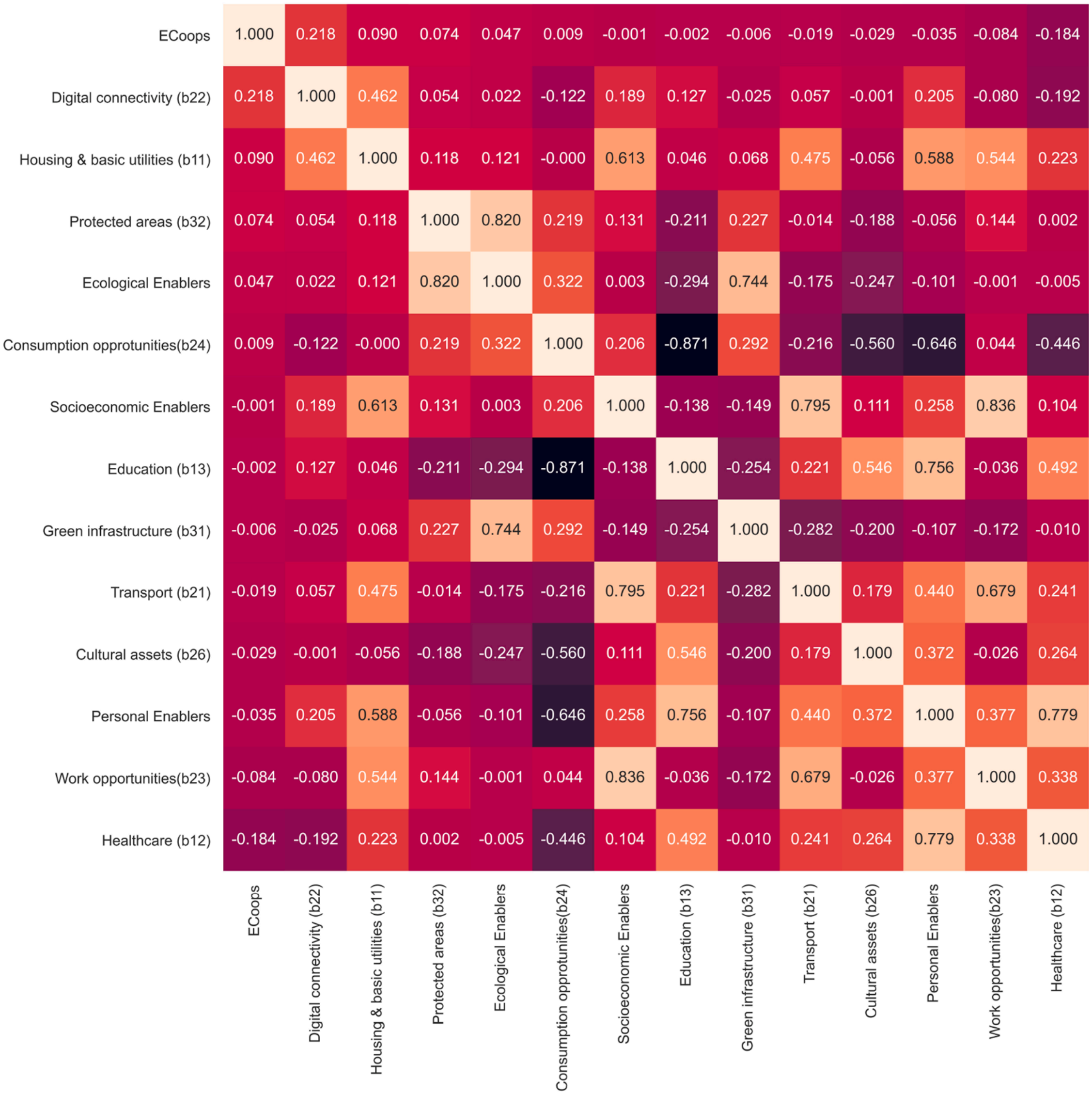

Fig. B4. Correlation within the component good life enablers.

B2. Correlation results for the QoL

Fig. B.5.

Fig. B5. Correlation within the component life maintenance.

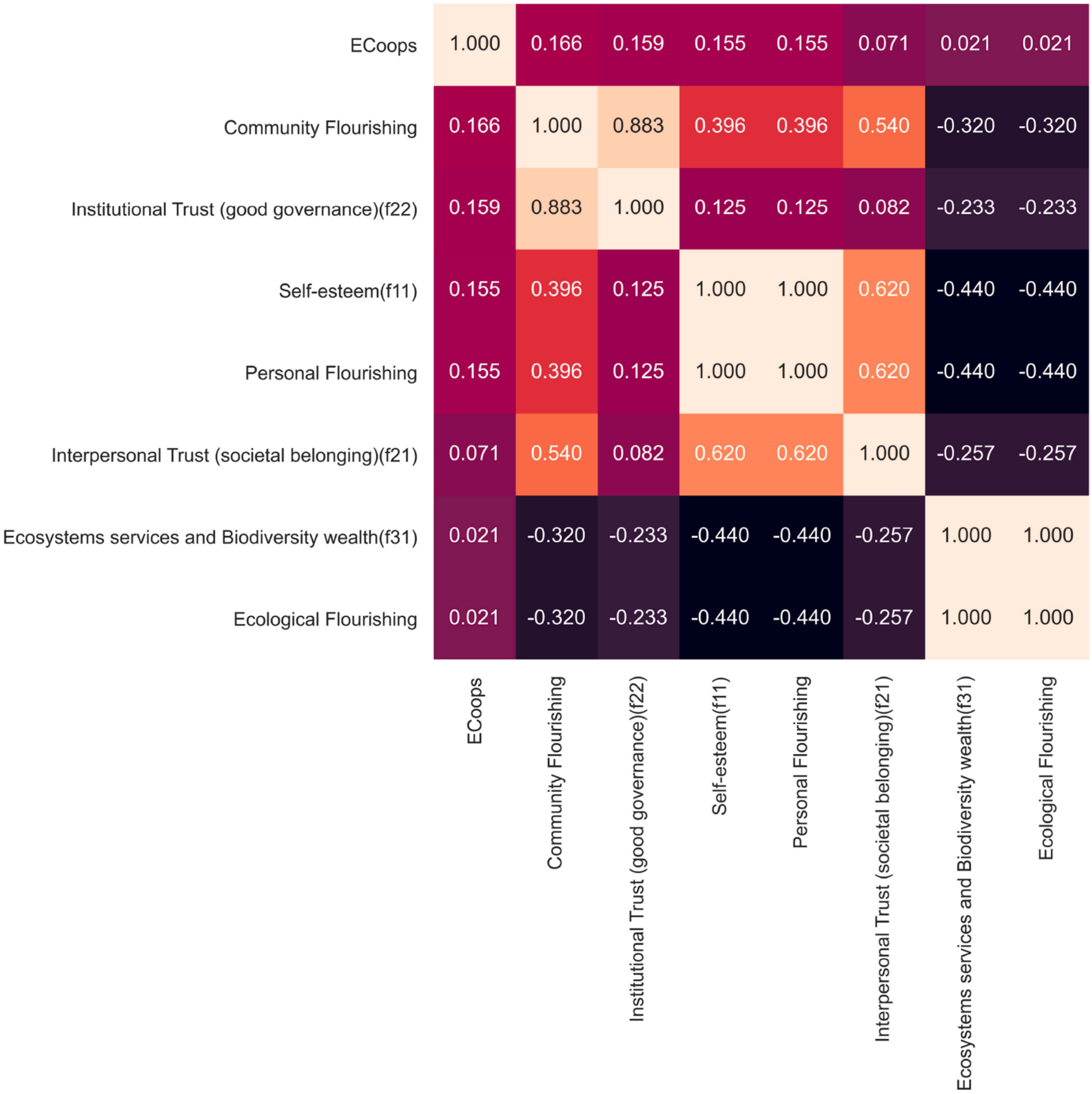

Fig. B6. Correlation within the component life flourishing.

Appendix C. Regression results QoL

Table C1
Regression results QoL.

Variable	Beta	Std error	*t*	*Pt*	R^2
QoL	1.022	0.106	9.630	0.000	0.065
Components					0.092
Good Life Enablers	− 1.966	0.571	− 3.443	0.001	
Life Maintenance	− 0.359	0.493	− 0.728	0.467	
Life Flourishing	3.4052	0.502	6.783	0.000	
Single Component					
Good Life Enablers	0.9692	0.108	8.969	0.000	0.057
Life Flourishing	1.1146	0.107	10.420	0.000	0.076
Domains of Life Flourishing					0.078
Personal	0.5284	0.266	1.987	0.047	
Community	0.4624	0.342	1.351	0.177	
Ecological	− 0.0271	0.236	− 0.115	0.909	
Single Domain					
Personal Flourishing	0.8920	0.085	10.488	0.000	0.077

Appendix D. Spatial analysis

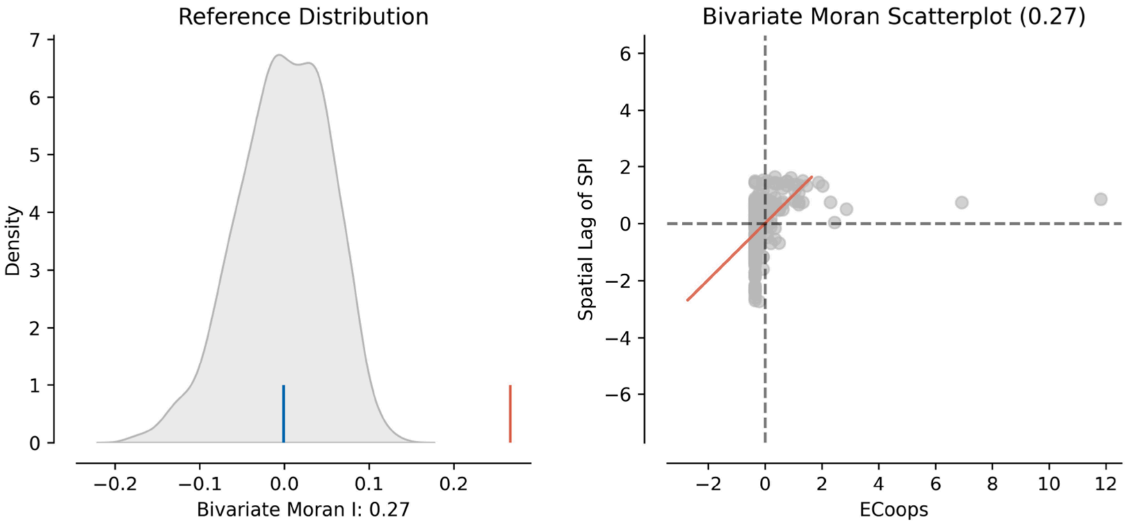

Fig. D1. Bivariate global moran statistics SPI.

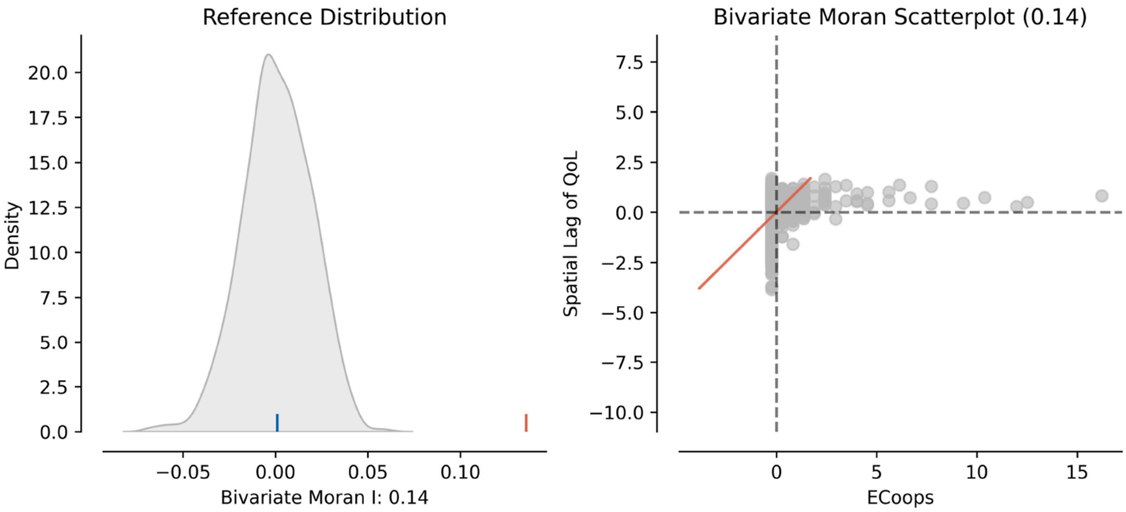

Fig. D2. Moran bivariate global QoL.

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