



Innovation, researcher and creativity: A complex indicator for territorial evaluation capacity

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ABSTRACT

Innovation, research, and creativity are crucial elements to guarantee countries' competitiveness and promote sustainable economic and social progress. The evolution of these elements influences and guides the strategic choices of policymakers to develop potential improvements. Measures of economic and social well-being are widely studied in the literature as essential tools for understanding and promoting more equitable, sustainable and inclusive social and economic progress; they provide a more complete and holistic view of people's well-being, enabling more informed policies and decisions that meet a country's needs.

Investments in scientific research and innovation, the human capital available for knowledge economy processes and the diffusion of Information and Communication Technologies are fundamental elements of social well-being and economic development. The literature highlights the need for indicators that analyze the efficiency levels of innovation, research and creativity activities to guide policies that promote better resource use. In light of this, the study aims to formulate a composite index that summarizes the "Innovation, research and creativity" dimension of the Equitable and Sustainable Wellbeing (BES) Report. The analysis focuses on Italy and provides a detailed measure of the situation in research, creativity, and innovation, which are indirect determinants of well-being but fundamental to social and economic progress. The authors propose an index for classifying Italian Regions by utilizing indicators from the BES and the Agenda 2030 and employing hierarchical clustering analysis associated with an algorithm based on the P2 distance method.

From a broader perspective, the work provides a robust tool that combines various measures into a single value. This offers a more comprehensive view of a complex situation and allows for the identification of general trends or changes over time. Furthermore, this enables a more targeted assessment of goal achievement than analysing isolated individual variables.

The results show the goodness and robustness of the proposed index. Therefore, the proposed index is a valuable tool capable of providing a comprehensive view of the situation, identifying trends, regional or national patterns, and information essential for governments to formulate strategies.

1. Introduction

A State's economic and social well-being is a crucial measure of its citizens' prosperity and quality of life. It goes beyond the simple evaluation of Gross Domestic Product (GDP) and is based on a set of indicators that reflect material well-being, economic equality, social security, and access to essential services [1].

To assess economic well-being, GDP is often used as the main indicator. However, more than GDP alone is needed to provide a complete picture of the situation as it does not consider other important factors

such as income and wealth distribution [2]. An unequal distribution can create social disparities, widespread poverty, and a lack of opportunities for a significant portion of the population. Therefore, measuring economic well-being should also consider equity in the distribution of resources.

Additional indicators are needed to measure social well-being, such as education, health, access to essential services, and the environment. The Human Development Index (HDI) is a widely used indicator that combines GDP per capita with life expectancy, education level, and standard of living [3]. This index provides a more comprehensive

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perspective on social well-being by considering factors such as access to education and healthcare that impact people's quality of life.

Alongside these, other aspects contribute to the economic and social well-being of a state, such as political stability, efficiency of the judicial system, access to essential services like clean water and energy, public safety, employment, social protection, and access to decent housing [4]. These factors are all interconnected and mutually influence a nation's overall well-being level. Policies to improve economic and social well-being focus on investment in social infrastructure, education, healthcare and reducing economic inequality (Klarin et al., 2023 [5]). These measures can create a more equitable, just, and sustainable society with greater social cohesion, political stability, and citizen happiness and satisfaction.

A state's economic and social well-being is based on a comprehensive assessment of its citizens' prosperity and quality of life. It incorporates a wide range of indicators that reflect material well-being, economic equality, social security, access to essential services, and the environment. Promoting economic and social well-being requires policies to improve resource distribution, ensure access to education and healthcare, promote environmental sustainability, and protect fundamental human rights.

In Italy, currently, to assess equitable and sustainable well-being, an indicator called "Indice di Benessere Equo e Sostenibile" (IBES) has been developed. The BES project was introduced in 2010 by Istat (the Italian Institute of Statistics) and Cnel (the Italian Council for Economics and Labour). The project's primary objective was to create a dashboard of well-being metrics that considered the two fundamental ideas of equality and sustainability [6]. One hundred thirty-four fundamental indicators were identified and grouped into 12 domains: Health, Education and training, Work and life balance, Economic well-being, Social relationships, Politics and Institutions, Security, Subjective well-being, Landscape and cultural heritage, Environment, Innovation, research and creativity and Quality of services. Due to its complexity, each dimension is defined through a comprehensive set of indicators and requires an overall understanding that cannot be achieved by considering individual elements separately. It needs to be approached through a synthesis effort, with the awareness that a similar approach should not aim to reduce complexity but rather to stylize reality (Brodny et al., 2023 [7], [8,9]). COVID-19 has highlighted the relevance of research, innovation, and creativity (Alghamdi et al., 2022 [10]). In detail, the literature review shows that we need indicators that analyze the levels of efficiency of activities in Innovation, research and creativity to guide policies that promote better use of the resources used ([11]; Chen et al., 2011).

The literature highlights a research gap in the creation of a reliable index. The proposed composite indicators (Jolliffe and Cadima, 2016; Mazziotto et al., 2019 [12]) point out, in the study of sustainable well-being measures, critical issues related to polarity and the arbitrary assignment of weights to variables (Maggino et al., 2012 [13]).

In light of this need, the present study aims to propose a tool that provides a synthetic measure of the overall trend of the considered domain while referring to individual indicators for specific in-depth analyses.

The analysis focuses on Italy and provides a detailed measure of the situation in research and innovation, which are indirect determinants of well-being but fundamental to social and economic progress. The authors propose an index for classifying Italian Regions by utilizing indicators from the BES Report and the Agenda 2030 and employing hierarchical clustering analysis associated with an algorithm based on the P2 distance method defined by Pena [14]. The proposed analysis would address aspects in this area that still need to be extensively covered.

This paper is a novel contribution to the literature by presenting a tool for identifying a robust synthetic indicator that can provide a comprehensive understanding of a complex situation, enabling the identification of general trends or changes over time.

The benefits derived from this operation would be manifold. Firstly, it would simplify the understanding and communication of results, enabling a clearer and more immediate overview. This would help engage the general public and promote greater awareness of innovation and creativity issues. Having a single indicator would allow a focus on the outcomes and specific goals to be achieved and identify areas that require prioritized interventions [15]. This would guide the orientation of public policies, provide a concise performance overview, and contribute to identifying sectors or areas that need increased investment or corrective actions. In detail, our research focused on proposing an innovative composite index for the dimension "Innovation, research and creativity" of the BES.

The authors propose a composite index synthesising the available information on innovation, research and creativity. For constructing complex indexes, we used data available on Bes Report 2022 and 2021 SDGS Report and applied mixed methods research. Specifically, we will make use of an approach of feature selection to eliminate redundancies and to obtain a smaller number of variables and then apply an algorithm based on the P2 distance method defined by Pena [14] to build a composite indicator allowing classification of the Italian regional areas (NUTS 2) providing a clearer view of differences in innovation, research and creativity sector.

The results will help compare regions' output, allowing policymakers to identify key areas of improvement. The index can support policymakers' and companies' choices regarding innovation, research, and creativity. It represents a valuable tool for allocating resources to support innovation and creativity effectively.

The following research contributes to the relationship between innovation, research and creativity. The results provide valuable information to authority over measures that improve economic development and citizens' well-being; methodologically, we propose an index synthesising different variables, allowing for a quicker and simplified understanding of the considered phenomenon.

The paper is organized as follows. Section 2 illustrates the "Innovation, research and creativity" dimension. Section 3 describes the methodology. The results are shown in Section 4. Section 5 provides findings and discussion, and section 6 concludes the work along with research implications and future research.

2. "Innovation, research and creativity" dimension

Research and innovation are indirect determinants of well-being and the basis of social and economic progress. It's crucial to monitor the measurement of the creation, application and diffusion of knowledge. Indeed, research, creativity and innovation favour intelligent and technologically advanced solutions to help the country and promote the well-being of society.

Innovation, research, and creativity are essential elements for the progress and development of a nation (Phillis, Kouikoglou and Verdugo, 2017 [16]; D'Urso and Vitale, 2020 [17]; Gargano and Ofria, 2022). These factors significantly contribute to various dimensions of society and the economy. From an economic perspective, innovation fosters the creation of new technologies, products, and services. This stimulates economic growth by opening new job opportunities, increasing productivity, and enhancing business competitiveness [18,19]. Moreover, investment in research and development leads to more efficient processes, cost reduction, and adaptability to evolving market needs. From a social standpoint, innovation and research are crucial in social progress [20,21]. Scientific and technological advancements positively impact healthcare, education, energy, transportation, and other sectors. Innovative solutions help address social challenges and improve people's quality of life. For instance, advancements in medical technologies can enhance healthcare, while innovation in education can promote access to learning and skills development. Additionally, innovation plays a critical role in sustainable development [22,23]. Investing in research and innovation enables the development of eco-friendly

technologies, renewable energy sources, and sustainable practices. This contributes to environmental impact reduction, resource management, and climate change mitigation.

Research and creativity are vital for knowledge creation and dissemination ([24]; Yu et al., 2023 [25]). Universities, research centres, and creative industries are key drivers of generating new ideas, discoveries, and advanced skills. The dissemination of knowledge is crucial for societal progress, innovation, and the development of highly skilled human resources. Furthermore, innovation, research, and creativity contribute to promoting culture and national identity (Deng et al., 2023 [26]; Lu et al., 2023). Through art, literature, design, and other creative forms, cultural heritage is preserved, cultural diversity is celebrated, and social cohesion is fostered.

Overall, innovation, research, and creativity are pivotal for a nation's social and economic progress. These dimensions drive economic growth, address social challenges, foster sustainable solutions, and preserve and promote culture and national identity.

To improve society well-being, it is necessary to have a holistic view of the various R&D investments and interventions by analyzing them through the lens of sustainability [27].

Digitalization is a powerful instrument for increasing public awareness of climate change, obtaining additional financial assistance from the government, and stimulating investment in environmental innovation [28]. The challenges arising from the economic and health crises have compelled governments to allocate resources towards innovation and digitalization to enhance residents' quality of life and encourage sustainable habits, which aligns with the goals outlined in the 2030 Agenda. Indeed, to obtain a competitive edge and foster economic development, digitization has become essential for businesses and the nation ([29]; Kucera et al., 2022 [30]). As a result of digitalization, businesses and society at large are adopting new technology. Investing in digitalization improves citizens' well-being and quality of life [31]. The European Union has been pushing measures since 2014 to boost infrastructure development and expand access to the utilization of new technology. For instance, the Horizon Europe initiative (2021–2027) has a bigger budget than prior programs and funds researchers through grants, awards, and public contracts (European Commission, 2021 [32]).

The research carried out by Ha et al. [33] demonstrates how the digital shift safeguards and enhances public health while advancing environmental sustainability (Guaita-Martinez et al., 2022). In order to attain digital competitiveness in the global market, new and contemporary digital technologies are necessary ([34]; Martinovic, [35]). All facets of society have seen an explosion in digitalization; scientists are working very hard to assess the effects of this new mode of communication and work to assist policymakers in concentrating on the factors that will promote this trend.

Governments must promote wealth, employment, research, and infrastructure investment to enhance innovative and technological development in their countries [28].

In Italy, the Innovation, research and creativity domain records widespread delays compared to Europe. Although in 2020, the majority of member countries had not reached their national target in terms of share of GDP invested in R&D, the value for Italy (1.51 %) stood at significantly lower levels than the EU27 average (2.31 %) [36].

The allocation of resources for research and development is one of the variables that influences a country's innovation capacity and readiness.

Italy ranks 28th in the "Global Innovation Index 2022" ranking. Italy is penalized by its performance in terms of infrastructure, policies to support business investments, market capitalization and the number and value of venture capital investments. However, better performances are recorded regarding innovation in the industry, where Italy ranks first for industrial diversification. The ranking sees Switzerland in first place (with a score of 64.6), followed by the USA (61.8), Sweden (61.6), Great Britain (59.7), Holland, South Korea (57.8), Singapore (57.3), Germany

(57.2), Finland (56.9) and Denmark (55.9). France is twelfth with a score of 55.0 [37].

From what emerges from the BES Report, between 2018 and 2020, only 50.9 % of industrial and service companies with ten or more employees carried out innovative activities, a share that fell by approximately five percentage points compared to the three years 2016–2018. Among the causes of the suspension or reduction of innovation was the health emergency, indicated by 64.8 % of companies with innovative activities, especially the smaller ones. The contraction in investments in innovation due to the pandemic crisis affected all companies, regardless of their size.

In particular, the regions that have invested the most in introducing innovations in the production process are the Marche, Piedmont and Liguria (BES, 2022).

If, on the one hand, the crisis associated with the health emergency has reduced the propensity of companies to innovate, on the other, it has pushed the adoption of new organizational models with the introduction of new digital technologies in the work organization to intelligent working. Furthermore, in recent years, more companies have reformulated their strategic vision to undertake low-environmental impact actions and invest in innovation.

Businesses need to focus their operations on implementing environmentally friendly practices that minimize consequences through cutting-edge technologies [38]. According to this viewpoint, digitalization accelerates business operations and fosters automation, which modifies interactions and corporate roles [39]. Despite expansion and urbanization deteriorating the various layers of the biosphere, Ahmed et al. [40] show that Information and Communication Technologies (ICT) and globalization have a favourable impact on CO₂ emissions. Virtual activities that lower energy consumption and emissions replace traditional goods and services [41]. In fact, with an effective use of resources, digital transformation will guarantee company continuity and sustainable production and consumption (Martinez et al., 2022).

In Italy, between 2018 and 2020, 37 % of innovative companies introduced eco-sustainable innovations through lower energy consumption and reduced CO₂ emissions in production processes (BES, 2022).

As shown BES report (2022), the COVID-19 pandemic has negatively impacted research intensity, business innovation and cultural and creative employment and stunted the growth of knowledge workers. The indicator relating to the flow of young Italian graduates abroad signals an improvement for 2021 as net losses have decreased through the increase in repatriations and the decrease in expatriations. Starting from 2020, there is an acceleration of the digital transition. The number of businesses active in web sales continues to grow. Trust in scientists is confirmed high enough, with over half (52.4 %) of Italian citizens (<14 years) assigning at least a vote of confidence equal to 8 points. The National Recovery and Resilience Plan (PNRR) has allocated 13.4 billion euros for the 4.0 Transition Plan to support the digital transformation of businesses by incentivising private investment through the recognition of tax credits. The PNRR encourages the R&D of smaller and newly established companies, who often need help finding sources of financing. Italy has a lower research intensity and is sixteenth in the European ranking. Driving R&D investments is the private sector (65.8 %), followed by universities (22.0 %) and the public sector (11.6 %). The health crisis has generated a sharp decline in innovation in companies, recording the most significant penalties in industry and for companies' small businesses. In 2022, workers in scientific-technological professions with education were 17.8 % of the total employed persons. Between 2021 and 2022, the number of employed people grew by an average of over half a million (+545,000, +2.4 %), and that of knowledge workers by just over 100 thousand units (+0.3 %). In 2022, cultural and creative employment represented 3.5 % of total employment.

The research uses the eleven "Innovation, research and creativity" indicators of the BES report which are integrated with the nine indicators of the theme of innovation, research and creativity found in

Goal 9 of the 2030 Agenda "Industry, innovation and infrastructure" [42]. This operation was deemed necessary because the two sets of indicators are complementary and partially overlapping. It allows for an even more comprehensive indication of the situation of the analyzed phenomenon. For a detailed analysis of research, innovation, and creativity" in Italy, as highlighted in the reports considered (BES and Agenda 2030), it is therefore necessary to consider several key elements:

- Research and Development (R&D) investments: An essential indicator of a society's commitment to innovation and research.
- Number of patents and scientific publications: Provides a measure of the output of research and innovation activities. This can indicate the quantity of discoveries, technologies, or knowledge produced by a particular society or country.
- Technology transfer and collaborations: Indicators of an environment favourable to innovation and creativity, such as collaborations between research institutions, universities, and industries.
- Economic impact indicators: Indicators like the percentage of employment in cultural and creative professions, the percentage of highly educated individuals in Science and Technology-related occupations, or the percentage of companies that have introduced product and process innovations can be considered to assess the economic effects of these activities.

The need to measure the performance of these interventions arises [43]. A synthetic measure of the performance of a society or a State in this field would enable the creation of rankings and comparisons at the national and European levels, thus supporting policymakers' planning phases ([16]; D'Urso and Vitale, 2020).

3. Method

Investments in scientific research and technological innovation, the human capital available and effectively employed in the processes of the knowledge economy and the diffusion of ICT technologies are fundamental drivers of social welfare and economic development (Perifanis et al., 2023 [44]). To rank Italian regional-areas (NUTS 2), obtaining a single measure of their degree of innovation, research and creativity is necessary.

In this work, we used data available on BES Report 2022 and the 2021 SDGS Report (statistical information for the 2030 agenda in Italy). Since we are working with 20 variables, we used a feature selection approach to obtain fewer variables. Then, we applied an algorithm based on P2 distance to build a composite indicator allowing a classification.

As one step to understand the underlying structure of our data and identify the presence of outliers, using the Analysis ToolPak in Microsoft Excel, they calculated various statistics such as mean, median, standard deviation, and correlation matrix of all 20 variables for the 20 Italian regional-areas (Berk et al., 2009 [45]). The outliers were identified as those with a distribution having an absolute skewness greater or less than one ([46]; Groeneveld et al., 1984 [47]). The variables found to be skewed were transformed using the maximum likelihood method (Box et al., 1964 [48]).

Next, we normalized our data. This step prevents any one variable from overpowering the others [49,50]. To normalize the data, we utilized each variable's minimum and maximum values, ensuring that each variable's values fall between 0 and 1 [51].

3.1. Variable selection

The BES Report 2022 and the 2021 SDGS Report identify 20 simple indicators to describe the phenomenon considered (Table 1). These variables could be strongly correlated, making it unnecessary to consider all of them in determining the complex index. Unnecessary variables would only increase complexity and make the index

Table 1
BES Report 2022 and 2021 SDGS Report indicators.

Variables	Source
R&D intensity	Istat - R&D survey in companies; R&D survey in non-profit organizations; Survey on R&D in public bodies
Patent propensity	Oecd - Database Regpat
Impact of knowledge workers on employment	Istat - Labour force survey
Innovation rate of the national productive system	Istat - Cis (Community Innovation Survey)
Intellectual property products (as part of gross fixed capital formation)	Istat - National Accounts
Cultural employment (% of total employment)	Istat - Labour Force Survey
Brain circulation (italians, 25–39 years old)	Istat - Registrations and cancellations from the registry for residence transfer and Permanent census of population.
Regular internet users	Istat - Survey on the use of ICT in the Households and by individuals
Availability of at least one computer and Internet connection in the household	Istat - Survey on the use of ICT in the Households and by individuals
Municipalities with online services for families	Istat - Survey on information and communication technology in public administrations
Enterprises with at least 10 persons employed with web sales to end customers	Istat - Survey on information and communication technology in enterprises
Employed persons with basic or above basic overall digital skills (20–64 years)	Istat - Survey on the use of ICT in the Households and by individuals
Manufacturing value added as a proportion of GDP and per capita	Istat - National Accounts
Manufacturing employment as a proportion of total employment	Istat - National Accounts
Proportion of small-scale industries in total industry value added	Istat - Territorial FRAME Information system
Proportion of small-scale industries with a loan or line of credit	Istat - Permanent census of enterprises
Research and development expenditure as a proportion of GDP	Istat - R&D survey in companies; R&D survey in non-profit organizations; Survey on R&D in public bodies; National Accounts; Italian innovation survey
Researchers (in full-time equivalent) per million inhabitants	Istat - R&D survey in companies; R&D survey in non-profit organizations; Survey on R&D in public bodies; Labour Force Survey
Proportion of medium and high-tech industry value added in total value added	Istat - Territorial FRAME Information system
Proportion of population covered by a mobile network, by technology	Istat - Survey on Aspects of daily life; Survey on information and communication technology in enterprises; Survey on information and communication technology in enterprises

challenging to interpret and use (Horvat et al., 2020 [52]).

For this purpose, a feature selection technique was employed. This is a process of choosing a relevant set of features for use in models or data analysis, aiming to reduce complexity and enhance performance (Oye-wole et al., 2023 [53]).

The variables were initially grouped into homogeneous clusters through cluster analysis (Punj et al., 1983 [54]). Then, the "low-variance filter" [55] was applied to reduce the dimensionality of the clusters, i.e., eliminating variables that do not provide informative contributions.

In literature (Husson et al., 2010), cluster analysis identifies a set of statistical techniques used to group statistical variables based on the similarity of their characteristics. The resulting groups should be characterized by a high degree of internal homogeneity and a high degree of variability between the groups.

In this work, not knowing a priori, the suitable number of groups to consider, among the plethora of classification methods, we preferred to apply the hierarchical agglomerative clustering, whose logic can be

summarized through the following steps:

1. Each variable forms a separate cluster.
2. The two variables, which have minimum distance, are merged. For the distance calculation, the Ward method, based on the decomposition of the total deviance into deviance between groups and deviance within groups, was used.
3. We calculate the distance between the new cluster (group) and all the other units.
4. Steps two and three are repeated until a configuration is reached where only one group exists.

The clustering process can be graphically represented through a dendrogram (see Fig. 1), from which it is also possible to read the aggregation index and appreciate how much a group is separated from the others. Of course, the aggregation index can be used to identify the suitable number of clusters: cutting the cluster tree after the fusions that correspond to low values of the aggregation index and before those corresponding to high values of the aggregation index (Ghergi and Lauro, 2010).

Next, we applied the “low-variance filter”, a methodology that allows the dimensionality reduction of the parameters of a cluster, ensuring that only the variables that contain adequate information remain. In each cluster, the variables, depending on the value of the variance, are arranged in descending order until the sum of the variances considered reaches a specific threshold. The remaining variables are discarded.

3.1.1. Composite indicator construction

According to McGregor [56] and Bache [57], for measuring the performance of a State/Region is necessary a solid indicator.

From a technical standpoint, different methods exist for aggregating and normalizing input variables to craft valid and robust composite indicators. These methods aim to streamline multidimensional analyses based on either a formative or reflective measurement model, where elementary indicators represent the latent variable’s causes or effects [58].

Principal Component Analysis (PCA) and Categorical Principal

Components Analysis (CATPCA) are commonly employed for metric and categorical variables to reduce multidimensionality across various sectors, including economic development and quality-of-life analyses for a country. However, in constructing a composite indicator, the use of PCA or CATPCA, while prevalent, is considered unsuitable primarily due to their disregard for polarities and the arbitrary assignment of weightings within the synthetic indicator (Jolliffe et al., 2016). Another critical aspect in building a reliable index is selecting the measurement model and determining whether the relationships between the latent variable (composite phenomena) and elementary indicators are articulated through a formative or reflective form (Mazziotta et al., 2019).

Sustainable well-being measures rely on objective indicators such as health, services, or environmental quality, necessitating formative models wherein latent measures are derived from elementary indicators (Maggino et al., 2012 [13]). In alignment with the considerations above, the primary objective of this paper is to construct a composite indicator using a methodology that addresses the previously articulated issues.

At this aim, to quantify the degree of innovation, research and creativity of Italian regions, we designed an indicator focused on the distance P2 (DP2), defined by Pena [14]. This methodology, widely used in areas related to social well-being (Somarriba et al., 2016 [59]; [60]) and quality of life (Rodríguez et al., 2018; [61]; [62]), summarizes a set of elementary variables that describe different aspects of the phenomenon under test. Somarriba and Pena [63] state that this metric exhibits desirable properties. These include non-negativity, commutativity, triangular inequality, existence, determination, monotonicity, transitivity, neutrality, and invariance to origin and/or scale changes. Furthermore, this metric effectively resolves challenges such as aggregating variables measured in different units, incorporating arbitrary weights, and avoiding duplication of information.

The DP2 indicator measures the difference that geographical areas have correlated to a specific argument considered and is defined for each region as:

$$DP_{2i} = \sum_{j=1}^n \frac{d_{ij}}{\sigma_j} * \left(1 - R_{jj-1, \dots, 1}^2\right) \quad \forall i \in [1, m] \quad (1)$$

where $j = 1, 2, \dots, n$ are the input variables, $d_{ij} = |x_{ij} - x_{jmin}|$ is the difference between the value of j -th variable in the i -th region and the minimum of j -th variable in all the regions and σ_j is the standard deviation of the j -th variable and is used as scaling factor allowing to solve problems of heterogeneity of unit measures. As defined by Pena, $(1 - R_{jj-1, \dots, 1}^2)$ is a “correction factor” which measures the variation for each variable elucidated by the linear regression relative to preceding variables and allows to delete redundant information from the variables already in the synthetic index. $R_{jj-1, \dots, 1}^2$, for $j > 1$, is the coefficient of determination in the regression of x_j over $x_{j-1}, \dots, x_1$. Moreover $R_1^2 = 0$ (Somarriba et al., 2009).

4. Results

The first step of our analysis was the reduction of the dimensionality of our data set. The authors performed a hierarchical agglomerative cluster analysis to identify homogeneous groups of variables. The statistical analysis was conducted in R using the free, open-source packages “FactorMiner” and “Fcp”. Fig. 1 shows the dendrogram or classification tree obtained using the automatic arrangement of the cluster and recommends considering four clusters to characterize the structure of our dataset.

Considering each group, we first highlighted that each cluster tends to contain variables that belong to the same topic and then applied a low-variance filter algorithm to reduce the parameters, ensuring that only the variables that include sufficient and not redundant information remain. The statistical analysis was conducted in R using the free, open-source package “Creditmodel” with the automatic arrangement

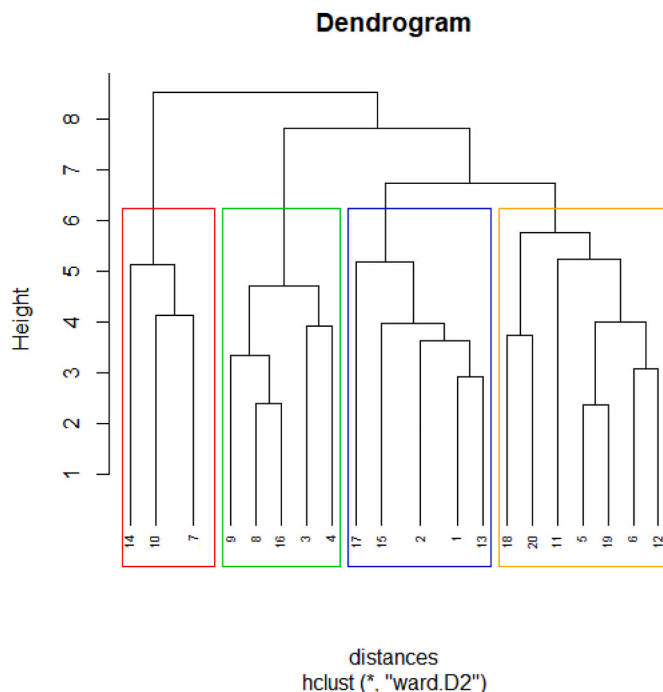


Fig. 1. Classification tree.

suggested to select 14 variables (Table 2).

Hence, to quantify the degree of innovation, research and creativity of each Italian region, we constructed an index applying the P2 distance algorithm to the variables selected. In Table 3, the correlation coefficient and correction factors are reported for each variable. The data indicate that all variables have a significant correction factor, which implies that they all contribute significantly without adding duplicate information. The first variable has a correction factor of 100 %, meaning that 100 % of the information from this factor contributes to creating the DP2 index.

Variables “Impact of knowledge workers on employment”, “Availability of at least one computer and Internet connection in the household” and “Research and development expenditure as a proportion of GDP” have high values for the correlation coefficient. This suggests that investments in scientific research and technological innovation, the available and effectively employed human capital in knowledge-based economies, and dissemination of ICT technologies are fundamental drivers of social well-being and economic development. In Italy, the pandemic crisis caused by Covid-19 has highlighted the relevance of research, innovation, and the diffusion of digital technology (Alghamdi et al., 2022). The new reforms under the National Plan for Recovery and Resilience focus on promoting investment recovery, particularly in intangible assets (such as research and development, software, etc.). Furthermore, one of the three strategic axes of the plan is a digital

Table 2

Variables used for ranking (Source: Authors' own creation).

Variables	Dendrogram index	Source
Impact of knowledge workers on employment	10	Istat - Labour force survey
Innovation rate of the national productive system	8	Istat - Cis (Community Innovation Survey)
Brain circulation (italians, 25–39 years old)	14	Istat - Registrations and cancellations from the registry for residence transfer and Permanent census of population.
Regular internet users	2	Istat - Survey on the use of ICT in the Households and by individuals
Availability of at least one computer and Internet connection in the household	13	Istat - Survey on the use of ICT in the Households and by individuals
Municipalities with online services for families	15	Istat - Survey on information and communication technology in public administrations
Enterprises with at least 10 persons employed with web sales to end customers	9	Istat - Survey on information and communication technology in enterprises
Employed persons with basic or above basic overall digital skills (20–64 years)	17	Istat - Survey on the use of ICT in the Households and by individuals
Manufacturing value added as a proportion of GDP and per capita	3	Istat - National Accounts
Manufacturing employment as a proportion of total employment	4	Istat - National Accounts
Proportion of small-scale industries in total industry value added	5	Istat - Territorial FRAME Information system
Proportion of small-scale industries with a loan or line of credit	6	Istat - Permanent census of enterprises
Research and development expenditure as a proportion of GDP	11	Istat - R&D survey in companies; R&D survey in non-profit organizations; Survey on R&D in public bodies; National Accounts; Italian innovation survey
Proportion of medium and high-tech industry value added in total value added	18	Istat - Territorial FRAME Information system

Table 3

Dataset structure (Source: Authors' own creation).

Variables	Correlation coefficient (ρ)	Correction factors
Impact of knowledge workers on employment	0.9643	1.000
Availability of at least one computer and Internet connection in the household	0.8126	0.7498
Research and development expenditure as a proportion of GDP	0.7597	0.5681
Innovation rate of the national productive system	0.6934	0.4815
Municipalities with online services for families	0.6791	0.4609
Proportion of medium and high-tech industry value added in total value added	0.5574	0.4973
Enterprises with at least 10 persons employed with web sales to end customers	0.4391	0.2987
Regular internet users	0.3895	0.3287
Employed persons with basic or above basic overall digital skills (20–64 years)	0.3298	0.2965
Manufacturing employment as a proportion of total employment	0.3065	0.3190
Proportion of small-scale industries with a loan or line of credit	0.2786	0.4107
Proportion of small-scale industries in total industry value added	0.2354	0.1975
Manufacturing value added as a proportion of GDP and per capita	0.2286	0.2412
Brain circulation (italians, 25–39 years old)	−0.6965	0.5792

transition, with measures aimed at the digitalization of public administration, the justice system, and the healthcare system; the modernization of businesses; and the development of digital skills for citizens and workers (PNRR, 2023). This shows that to promote social well-being and economic development of a State, importance must be given to scientific research, a strategic tool for finding solutions to needs and problems that cannot be otherwise solved. It is important to note that improvement interventions in the manufacturing industry (“Manufacturing employment as a proportion of total employment” and “Manufacturing value added as a proportion of GDP and per capita”) are an added value to promote innovation and fair, responsible and sustainable industrialization. The variable “Innovation rate of the national productive system” also plays an essential role in determining a state’s innovation, research, and creativity level. It is therefore necessary to invest in both material and immaterial capital, research and development and the development and acquisition of licenses and patents. To enhance Italy’s innovative capacity, private investments in research and development must be accompanied by increased public spending on basic research and technology transfer. The government must therefore provide a timely and effective investment of funds from the European Instrument for Recovery and Resilience so that Italy and its regions make significant progress in innovation and competitiveness (Franzò, 2023 [64]).

The correlation coefficient related to the migration balance of young Italian citizens (aged 25–39) with a university degree is negative. A transfer abroad leads to cultural impoverishment in Italy. As demonstrated by various studies (Grüning et al., 2023 [65], [66]), this phenomenon has been affecting Italy for years. Young Italians, especially bright university graduates, increasingly consider leaving their home country to escape economic difficulties. Most of them describe a feeling of unhappiness and frustration and go because they believe that finding a good job is possible in other countries where all doors are open if you are young and dynamic. In contrast, in Italy the economic system is not very dynamic and is based mainly on family structures and the elderly who do not want to give up power.

Identified and described the variables that influence investments in scientific research and technological innovation, the human capital available and effectively employed in the processes of the knowledge

economy, and the diffusion of ICT technologies, we determined the situation of 20 Italian regions applying the DP2 index. The regions are sorted based on distance from a hypothetical region where all variables have the lowest value. The ranking is determined by the DP2 index, with the closest region having a zero index (Table 4).

In 2021, the region with the highest level was Lombardia, with 8.65 points from the imaginary baseline region. Calabria was the region that is least able to provide adequate education (1.66). The DP2 index ranges of 6.99 points between the highest and lowest region. The first five positions resulting from the composite indicator are occupied by Lombardia, Lazio, Trentino-Alto Adige, Emilia-Romagna and Friuli-Venezia Giulia, regions that mainly invest in qualified human capital and research and development, aspects that have a positive effect on the social and economic well-being of the community ([64]; Pellegrin et al., 2023 [67]). In terms of technological progress, some scholars ([68]; Guarascio, 2023 [69]; Franzò, 2023 [70]) suggest, in fact, that the use of ICT technologies in the economy needs to be strengthened. Accelerating adoption rates of technologies such as cloud computing, big data applications, enterprise resource planning solutions, customer relationship management, and e-commerce platforms is necessary. For many companies, significantly smaller and traditionally managed ones that require support and incentives to overcome the challenges posed by digital transition, the government has initiated ad hoc measures to support economic recovery after the Covid-19 pandemic as part of the National Recovery and Resilience Plan.

Important information is added from the spatial pattern of the ranking results. A visual analysis (Fig. 2) reveals substantially that similar ranking values are grouped. Furthermore, computing a spatial autocorrelation test through Global Moran, the authors show a positive spatial autocorrelation (0.45) among region ranks. The finding reveals that, with few exceptions, the performance of each region is not randomly spatially distributed but that each region influences its neighbours.

The figure underscores how the utilization of information and communication technologies (ICT) and the commitment to research in Italy exhibit subtle variations across different geographical regions: North, South, Central, and the Islands. The North of Italy has consistently stood out as the region with the highest adoption of ICT and a notable concentration of high-tech enterprises. Cities such as Milan, Turin, and Bologna have long been renowned as epicenters of technological and digital innovation, where numerous companies pioneer cutting-edge solutions, including automation, advanced engineering, and digital services. In Central Italy, the utilization of ICT remains significant, particularly in cities like Rome and Florence, which play

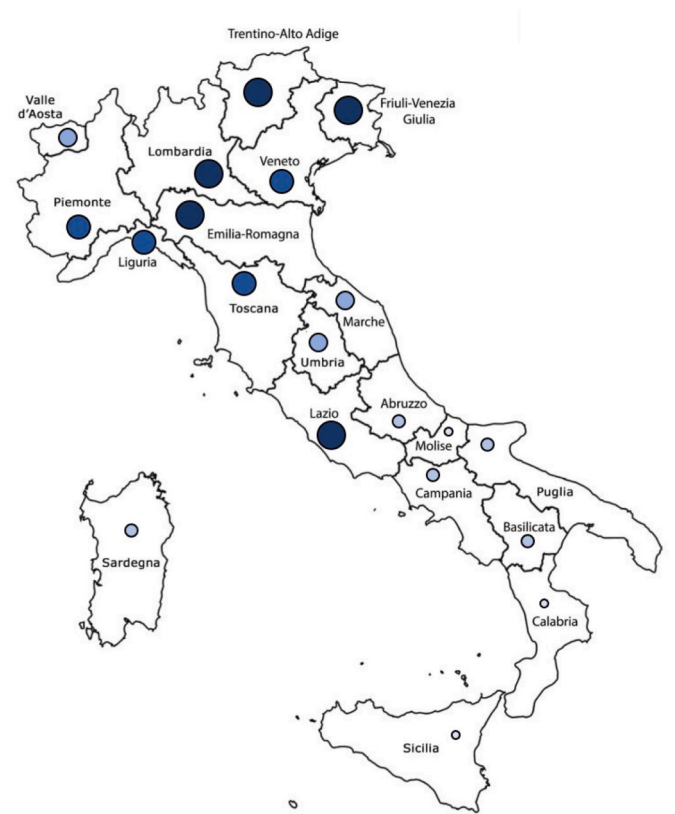


Fig. 2. Ranking of Italian regions.

pivotal roles both culturally and administratively. These cities host governmental and cultural institutions that leverage ICT to enhance administrative efficiency, manage cultural heritage, and foster innovation in cultural and artistic sectors. As evidenced by the data provided in the BES report [36], the South of Italy has made strides in embracing ICT, although it still lags behind the North. Recent years have witnessed the launch of various initiatives aimed at promoting technological and digital innovation, including funding programs and support for ICT startups. The South of Italy is actively harnessing digital technologies to develop sectors such as tourism, precision agriculture, and renewable energy. Even in the Italian islands, such as Sicily and Sardinia, there is a drive to promote the utilization of ICT and technological innovation. Digital solutions have been implemented to enhance the efficiency of public services, encourage sustainable tourism practices, and stimulate economic growth on the islands. Furthermore, access to ICT can facilitate interconnectivity with other regions and foster networking opportunities among businesses and research institutions.

4.1. Validation

To validate the study, we determined the Spearman correlation coefficient [71] between the ranking obtained using the DP2 index and the ranking obtained by applying the Adjusted Mazziotta-Pareto index (AMPI) (Mazziotta et al., 2016 [72]; Mazziotta et al., 2018 [73]). The AMPI is a non-compensatory composite index used to summarize a set of variables presumed to be non-substitutable. The Italian National Institute of Statistics (ISTAT) has identified this indicator as an efficient method for aggregating this type of data.¹ The ranking obtained is presented in Table 5.

The analysis found a robust positive correlation (correlation coefficient of 0.95) between the rankings obtained using the DP2 index and

Table 4
Rank scores of italian regions (Source: Authors' own creation).

Rank	Regions	DP ₂ index
1	Lombardia	8.65
2	Lazio	8.35
3	Trentino-Alto Adige	7.89
4	Emilia-Romagna	7.46
5	Friuli-Venezia Giulia	7.13
6	Toscana	6.43
7	Veneto	6.04
8	Liguria	5.84
9	Piemonte	4.97
10	Umbria	4.37
11	Valle d'Aosta	4.23
12	Marche	3.79
13	Abruzzo	3.28
14	Sardegna	3.02
15	Campania	2.89
16	Puglia	2.78
17	Basilicata	2.69
18	Sicilia	2.03
19	Molise	1.78
20	Calabria	1.66

¹ https://www.istat.it/it/files/2015/12/Rapporto_BES_2015.pdf.

Table 5

Rank scores of Italian regions (Source: Authors' own creation).

Rank	Regions	AMPI index
2	Lombardia	118.2
1	Lazio	117.9
3	Trentino-Alto Adige	115.4
5	Emilia-Romagna	114.7
7	Friuli-Venezia Giulia	112.7
6	Toscana	113.1
8	Veneto	112.4
9	Liguria	110.3
4	Piemonte	114.9
10	Umbria	108.7
11	Valle d'Aosta	107.9
13	Marche	105.6
12	Abruzzo	106.7
14	Sardegna	104.7
15	Campania	103.2
20	Puglia	96.3
17	Basilicata	99.1
18	Sicilia	98.8
16	Molise	99.8
19	Calabria	97.6

the AMPI index. According to Evans and Over (2013), the two methods provide similar results, supporting the reliability of the proposed synthetic indicator. The correlation's statistical significance further reinforces the findings' validity, confirming that the results obtained with a compensatory method (DP2) and a non-compensatory (AMPI) method yield comparable outcomes. This is an essential result for the study, as it demonstrates the consistency of the analysis using a different methodology. The finding is significant because it proves the compensatory method's validity. This allows researchers to utilize a comprehensive and flexible index that considers multiple factors and permits trade-offs. This becomes particularly valuable in a context similar ours where certain variables are more crucial and have higher priority over others [74–77]. As a result, the compensatory method provides a powerful tool for analyzing complex data and making informed decisions based on the relative importance of different variables.

5. Discussion

Despite the widespread availability of digital technologies in the market, their adoption among EU-27 companies needs to be improved. Consequently, efforts have been underway for many years to promote and stimulate broader usage (Brodny et al., 2022 [78]).

Individual countries increasingly recognize that investing in cultivating an innovative digital economy is highly desirable and profitable. The magnitude of such investments serves as a measure of societal advancement for individual nations.

The significance of digitalization for businesses and the overall economy is widely acknowledged within the EU-27. Clearly, countries or regional blocs where digital transformation is advanced stand to gain a competitive edge. Businesses operating in such environments, leveraging modern and innovative solutions, demonstrate greater resilience to crises and market fluctuations. Their adaptability and responsiveness to customer needs are key strengths, enhancing customer perception and effectiveness, particularly amid the pandemic induced by the SARS-CoV-2 coronavirus (Brodny et al., 2024 [79]).

The literature strongly confirms the relationship between research and development (R&D) spending, innovation, and a nation's productivity (Baumann and Kritikos, 2016 [80]; [81]; Mohnen, 2019 [82]). The European Commission emphasizes the crucial role of R&D and innovation in any effective growth strategy [83]. However, studies [11,84] in the European Union reveal that the impact of R&D investments varies among Member States, with higher GDP per capita countries hosting more innovative firms, particularly in Nordic and Western Europe. These considerations emphasize the need to monitor knowledge

creation, application, and diffusion and highlight that research, creativity, and innovation are crucial in driving intelligent and technologically advanced solutions contributing to overall well-being (Martinez et al., 2022 [85]). Regarding economic impact, innovation leads to developing new technologies, products, and services, promoting economic growth, productivity, and competitiveness [86]. Research and development investments drive efficiency and adaptability to market needs [87]. Innovation and research have significant social benefits, improving sectors such as healthcare and education and enhancing people's quality of life [88]. They also contribute to sustainable development by promoting eco-friendly technologies and practices. Research and creativity are essential for knowledge creation and dissemination [24]. Universities and research centres are vital in generating new ideas, discoveries, and advanced skills, fostering societal progress and innovation. Furthermore, innovation, research, and creativity promote cultural preservation, diversity, and social cohesion [89]. They contribute to developing national identity through art, literature, and creative industries [90].

Everything highlights how an index measuring innovation, research, and creativity is crucial in guiding strategic decisions, promoting growth, and fostering a culture of continuous improvement in a rapidly evolving global landscape. This paper focused on the Italian situation, a nation characterized by a tradition of excellence in design and manufacturing, cultivating a creative environment for years. However, as the Global Innovation Index 2023 indicates, its global innovation ranking has sometimes lagged due to slower economic growth. Efforts to boost innovation are evident: a growing focus on startups and increased investment in research and development. The country hosts prestigious research institutions and universities, yet national spending on research has occasionally fallen behind its European counterparts. Italy's innate creativity, evident in its rich artistic and culinary history, thrives in sectors like design and the arts.

For constructing a complex index, we used indicators such as R&D investments, patents, scientific publications, technology transfer, and economic impact, proposed by the BES project and the 2030 Agenda, to describe the dimensions of "Research, innovation, and creativity". Data were analyzed using mixed methods research. In the first instance, we selected a feature through the cluster analysis and the low-variance filter algorithm. We eliminated redundant information from the initial dataset and reduced the complexity of the subsequent investigation. Subsequently, we applied the P2 distance algorithm, defined by Pena, on selected variables to define the complex index. The method allowed us to determine the extent to which the variables influence the considered dimension and show the Italian regions' situation.

The proposed index brings forth several benefits. Firstly, it streamlines the comprehension and dissemination of outcomes, leading to a clearer and more readily accessible overview. This enhanced clarity aids in capturing the attention of the general public and fostering a greater understanding of matters related to innovation and creativity. By having a single indicator, the focus can be placed on final results and specific objectives to be accomplished while also identifying areas that necessitate prioritized interventions. Consequently, this approach offers valuable guidance for shaping public policies concerning innovation, research, and creativity. Moreover, it furnishes a concise performance assessment and facilitates identifying sectors or domains that warrant increased investment or corrective measures. Overall, this operation serves as a valuable tool for aligning efforts, promoting awareness, and effectively directing resources to support innovation and creativity.

The attributes "Impact of knowledge workers on employment", "Availability of at least one computer and Internet connection in the household" and "Research and development expenditure as a proportion of GDP" exhibit high correlation values. This highlights how investments in scientific research and technological innovation, the available and effectively employed human capital in knowledge-based economies and the dissemination of information and communication technologies (ICT) are fundamental factors for social well-being and

economic development. The pandemic crisis caused by Covid-19 has clearly emphasized the importance of research, innovation, and the dissemination of digital technologies (Alghamdi et al., 2022).

"Innovation rate of the national productive system" plays a significant role in determining a country's innovation, research, and creativity level. Investing in both tangible and intangible capital, including research and development and the acquisition of licenses and patents, is necessary. To enhance Italy's innovative capacity, private investments in research and development must be accompanied by increased public spending on basic research and technology transfer. The government should ensure the timely and effective allocation of funds from the European Instrument for Recovery and Resilience, enabling Italy and its regions to make substantial progress in innovation and competitiveness. (Franzò, 2023 [64]).

The variable "Brain circulation" negatively impacts research and innovation, as transfers abroad lead to cultural impoverishment in Italy. This phenomenon can harm the economy and overall development of the country of origin, as it results in the loss of valuable talent and expertise. Brain drain undermines innovation, research, and development efforts, limiting economic growth opportunities. Several factors contribute to the brain drain in Italy, including the lack of satisfactory career prospects, insufficient investments in research and development, inadequate recognition and appreciation of talent, and bureaucratic constraints and limitations within the labour system (Siar et al., 2023 [91]). Effectively addressing the brain drain requires concerted efforts to improve working conditions, create enticing career opportunities, and foster a culture of research and innovation. This entails implementing policies that promote investments in research and development, establish international collaboration networks, and cultivate an engaging work environment to retain and attract talented individuals.

We identified the variables using the DP2 algorithm and analyzed the situation of the 20 Italian regions. The index enables the establishment of a ranking. The first five positions are occupied by Lombardia, Lazio, Trentino-Alto Adige, Emilia-Romagna and Friuli-Venezia Giulia, regions that mainly invest in qualified human capital and research and development, aspects that have a positive effect on the social and economic well-being of the community ([64]; Pellegrin et al., 2023 [67]).

A ranking of regions that invest most in ICT and research is important for several reasons. Firstly, it allows for identifying regions that excel in these sectors, serving as role models for others. Additionally, the ranking enables the assessment of regional competitiveness and fosters healthy competition among regions to attract investments and talent. The information provided by the ranking is crucial for informing public policies and directing targeted interventions in regions that require increased investments in ICT and research. Moreover, the ranking facilitates partnerships between leading regions in these fields and regions seeking to enhance their capabilities, promoting knowledge sharing and collaboration for joint projects. In conclusion, the ranking of regions that invest most in ICT and research provides a clear overview that guides public policies, promotes regional competitiveness, and stimulates collaboration among regions to advance innovation and research.

Further insights can be gleaned through spatial pattern analysis of the obtained ranking. This adds value to the analysis by providing information on territorial dynamics, aiding in identifying trends, hotspots, or spatial relationships among different regions. The findings indicate that, with few exceptions, the performance of each region is not randomly distributed in space. Each region influences its neighboring regions.

The actual relevance of this study lies in the fact that the methodology used is compensatory. Previous studies used non-compensatory methods to construct a synthetic index (Bacchini et al., 2022 [92]). The validation process, carried out by comparing it with the already validated non-compensatory method (AMPI) typically used by ISTAT, opens up numerous advantages. This approach enables researchers to adopt a comprehensive and flexible index that considers various factors

and allows for trade-offs. This becomes particularly valuable in contexts similar to ours, where certain variables are more crucial and have a higher priority than others [74–77]. Consequently, the compensatory method provides a powerful tool for analyzing complex data and making informed decisions based on the relative importance of different variables.

6. Conclusion

The study proposes a synthetic index that provides a detailed measure of the situation of Italy's research and innovation sector. These sectors are indirect determinants of well-being but fundamental for social and economic progress. Research, creativity and innovation are essential to promote intelligent and technologically advanced solutions contributing to general well-being. The proposed index is based on a comprehensive set of indicators from the BES Report and the Agenda 2030. To define the index, the authors employed hierarchical clustering analysis in conjunction with the P2 distance method developed by Pena [14]. The real innovation proposed by this article lies in demonstrating the possibility of using a compensatory method instead of the classic non-compensatory approach. The resulting advantages in dimensions such as "Research, innovation and creativity" differ. This methodology allows you to give the right weight and priority to each variable, unlike the non-compensatory method, which does not allow you to balance or compensate for differences. This is of fundamental importance when analyzing the dimension of "Research, innovation and creativity", where, as widely discussed, some factors have more or less relevance or positively or negatively influence the performance of a region. The compensatory method allows you to balance the characteristics of the variables, allowing decisions based on the balance between the different factors of the investigation. The index developed is a powerful tool to identify and prioritize specific objectives, pinpoint areas requiring immediate attention, and guide resource allocation. It is a valuable resource for policymakers, enhancing their understanding of innovation and creativity issues and informing strategic investment decisions. The results highlight how innovation has a robust economic impact, promoting the development of new technologies, products and services and promoting economic growth and competitiveness. Investments in research and development improve market efficiency and adaptability, while innovation and research bring significant social benefits by improving sectors such as healthcare and education, improving people's quality of life and contributing to sustainable development through green technologies. Research and creativity are fundamental to creating and disseminating knowledge, and universities and research centres play a crucial role in generating new ideas and discoveries and promoting social progress. Furthermore, innovation, research and creativity promote cultural conservation, diversity and social cohesion, contributing to the development of national identity through art and literature. The proposed complex index offers several advantages, simplifying the understanding and dissemination of results. A ranking provides a clear and accessible overview of the situation and can serve as a valuable guide for public policies on innovation, research and creativity. Furthermore, the index provides an in-depth analysis of the variables considered, helping to identify the sectors that require more significant investments or corrective measures, representing a valuable tool for allocating resources to support innovation and creativity effectively. The study results allow the performance of regions to be compared, allowing policymakers to identify critical areas for improvement. The study has some limitations. The authors used only two datasets, and future studies could expand the research with other datasets; the analysis is focused on Italy, and future research must be conducted in different countries and make comparisons. Furthermore, only one dimension of BES was analyzed; future studies could investigate others. In addition, the results obtained could be compared with those of other indices to verify robustness. In future studies, following the same road map, we will verify the possibility of using this complex index for all the other 11

dimensions of the BES report. Subsequently, through a compensatory method, we will attempt to build a complex index that synthesizes all the individual indices and indicates equitable and sustainable well-being in Italian regions.

CRedit authorship contribution statement

Luca Rossi: Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation, Conceptualization. **Maria Giovina Pasca:** Writing – review & editing, Writing – original draft, Validation, Resources, Investigation, Formal analysis. **Gabriella Arcese:** Writing – original draft, Validation, Supervision, Project administration. **Stefano Poponi:** Writing – original draft, Validation, Supervision, Project administration.

Data availability

Data will be made available on request.

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