Digital entrepreneurial ecosystems: an empirical contribution using SMAA

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Abstract

Framing of the research. *The concept of digital entrepreneurial ecosystems stands at the crossroads between the concepts of the digital ecosystem and the entrepreneurial ecosystem. We start with a summary of the data concerning the digital entrepreneurial pillars emerging in literature to provide robust and reliable measurement of digital entrepreneurial ecosystems.*

Purpose of the paper. *The aim of the paper is to measure and compare digital entrepreneurial ecosystems in European countries to ensure a productive context for new venture creation.*

Methodology. *We apply Stochastic Multicriteria Acceptability Analysis (SMAA) as a precise, robust, and reliable measurement approach to the Digital Economy and Society Index (DESI) data.*

Results. *The main contribution of this work is the provision of a probabilistic ranking that is more robust and reliable than the conventional single ranking derived from composite indices constructed with a single weight vector.*

Research limitations. *We applied SMAA allowing for a limited variation of the weights assigned in the computation of DESI. Allowing for a wider range of variation may provide further relevant insights. Furthermore, the database used for the operationalization of digital entrepreneurial ecosystem pillars may be enriched by adding further variables, thus enhancing the robustness of the analysis.*

Managerial implications. *Our work provides relevant managerial implications for policymakers and businesses. The analysis identifies strengths and weaknesses of the different countries thus offering useful guidelines for policy makers aiming to support territorial development and for businesses to identify market opportunities.*

Originality of the paper. *The originality of the paper lies in the application of SMAA methodology to digital entrepreneurial ecosystem literature, thus providing an empirical contribution to such a novel topic. We start from data used to compute the DESI index which, like most of the existing indices, is computed relying on fixed weights, thus being affected by a degree of subjectivity. The application of SMAA methodology allows us to consider how a variation in the assigned weights can affect the final ranking.*

Key words: *digital entrepreneurial pillars; digital society; entrepreneurship measurement framework; productive entrepreneurship; digital index; SMAA*

1. Introduction

The topic of digitalisation is growing in popularity in both the political and academic domains and has relevant implications in the field of entrepreneurial ecosystems as well. Digital technologies are indeed transforming entrepreneurship influencing both generating new entrepreneurial opportunities (Nambisan, 2017) and by impacting the entrepreneurial process itself (Ferreira *et al.*, 2019).

In this perspective, the level of digital maturity of an area may also be decisive for the emergence of new firms.

An entrepreneurial ecosystem can be defined as the combination of territorial actors and factors whose coordination and interaction support entrepreneurship (Corrente *et al.*, 2019; Neck *et al.*, 2004). GEM (Global Entrepreneurship Monitor) has followed the progress of nascent entrepreneurship in various countries over the past decade, evidencing that the growth rate and quantity of aspiring entrepreneurs vary between countries which differ in the level of economic and technological development (Cunningham and O'Kane, 2017).

The topic of entrepreneurial ecosystems as environments able to support new firms, has been of great interest not only for academics but also for both governmental and non-governmental entities and institutions, in the attempt to construct reliable and comparable rankings. Some examples are the World Bank, the World Economic Forum (WEF), and the Organization for Economic Co-operation and Development (OECD). However, some institutional reports and academic studies have also started to focus on digital entrepreneurship systems and technology-based entrepreneurship. A digital entrepreneurship system describes the environmental factors able to support digital entrepreneurship (Autio *et al.*, 2018b). Technology-based entrepreneurship describes the creation of new technology-based firms. These firms main features are: a growth potential, a need for external financing, the focus on niche markets with a high need of internationalization, the concentration in specific regions, the tendency to arise as spin-offs from existing organisations, the collaboration within an incubator or science park, the support to regional technology transfer and lastly the founders who are generally highly educated, and team based (Lindholm, 2017). Entrepreneurship has undergone a shift triggered by digitalisation and the application of digital technologies and infrastructures. Not only does digitalisation lead to radically reconsidering the way value is co-created and distributed at all levels in society, but it also affects all members of society, including present and aspiring entrepreneurs and their initiatives (Autio *et al.*, 2018a).

The academic literature in the field lacks empirical studies able to provide insights into digital entrepreneurial ecosystems to guide both entrepreneurs' and policymakers' investment decisions.

The present work consists in the application of Stochastic Multicriteria Acceptability Analysis (SMAA; Lahdelma *et al.*, 1998) as a precise, robust, and reliable measurement approach, to address the gap in the literature concerning a robust measurement of digital entrepreneurial ecosystems at the country level. By employing SMAA methodology, we provide a considerable contribution to the evaluation, rating, and comparison of digital entrepreneurial ecosystems. When comparing and evaluating nations, a composite index based on the arithmetic mean of key factors of importance is typically used.

SMAA avoids the arbitrary choice of weights by considering all feasible vectors of weights and their corresponding rankings. From an operational point of view, the consideration of all feasible weight vectors is approximated by the random sampling of a large number of weight vectors. Consideration of all the weight vectors permits SMAA to supply a more realistic ranking of countries. It is rather misleading to assign a well-defined and stable ranking position to each country when this essentially depends on the importance assigned to each factor through the corresponding weight. In this regard, it is much more reliable to consider a probabilistic ranking that assigns a probability of each ranking position being attained. Moreover, SMAA reveals the strengths and weaknesses of each country in terms of factors with a larger weight determining a better or worse ranking position. This gives relevant indications to academics, policymakers, and practitioners, especially in terms of policy implications.

The Digital Economy and Society Index (DESI) is taken as a reference index for the measurement of digital entrepreneurial ecosystems. It consists of micro-level measurements of digitalisation for each European country, which are taken as the unit of analysis in this study.

The remaining part of the paper is organised as follows: section 2 presents the main contributions in the literature concerning entrepreneurial ecosystems and digital entrepreneurial ecosystems, section 3 describes the research design and presents the data used, section 4 illustrates the methodology adopted for the analysis, namely Multiple Criteria Decision Analysis and Stochastic Multicriteria Acceptability Analysis. The last 2 sections present the empirical results, the conclusions, and implications of the work.

2. Literature review

2.1 From ecosystems to entrepreneurial ecosystems

Roy Clapham first used the term "ecosystem" in 1930 to describe the physical and biological elements of an environment interacting with each other to shape a unit. The concept of ecosystem has subsequently been used as an analogy to describe different complex phenomena. An industrial ecosystem is defined as a system where the used materials are recycled infinitely and efficiently, thanks to the cooperation between the different parties (Frosch and Gallopoulos, 1989; Korhonen *et al.*, 2001). In the business environment, the concept of ecosystem has been used to identify a network of interacting firms.

Moore (1993) resumed the idea of an ecosystem by adopting the lens of business organisation studies. Moore (1996) defined a business ecosystem as "an economic community supported by a foundation of interacting organizations and individuals - the organisms of the business world" (Moore, 1996, p.9). By applying the concept of ecosystem to denote business networks, he argues that the key to compete successfully for businesses is their belonging to an inter-sectoral ecosystem where they may cooperatively co-evolve, as well as gain skills and develop innovation.

The literature has therefore identified the analogy existing between business and biological ecosystems, defining the former as a business network characterised by interconnected actors which largely depend on each other for their survival (Peltoniemi and Vuori, 2004).

This analogy highlights similarities between business ecosystems and biological ecosystems existing in nature. Indeed, although businesses do not exactly imitate the way biological ecosystems work, the two types of ecosystems are thought to share some characteristics and follow the same rules (Lewin, 1999; Peltoniemi, 2006).

Another analogy that emerged is with the concept of service. A service ecosystem is defined as a "relatively self-contained, self-adjusting system of resource-integrating actors connected by shared institutional arrangements and mutual value creation through service exchange" (Vargo and Lusch, 2016, p. 11).

The ecosystem concept has also been applied to the realm of entrepreneurship, referring to the capacity of a certain area to establish a network of actors and infrastructures that foster the creation and development of innovative business projects. Thus, the entrepreneurial ecosystem is a broad notion that encompasses a variety of different components, thus enlarging the focus traditionally placed by scholars on entrepreneurs as the only object of analysis, to investigate the role played by a variety of actors and elements in the entrepreneurial process (Van de Ven, 1993).

As a result, a comprehensive definition of the entrepreneurial ecosystem is that of "a set of interdependent actors and factors coordinated in a way that enables productive entrepreneurship". An entrepreneurial ecosystem is therefore finalised to the creation of new value for society at large. On the one hand, entrepreneurial ecosystems increase wealth and generate value for firms (economic impact). They contribute to regional innovation performance using the knowledge flows and value creation processes realized by the firms and institutions participating in the ecosystem itself (technological impact). On the other hand, both the monetary and non-monetary value generated is distributed among the members of the ecosystem itself, and this is referred to as societal impact (Audretsch *et al.*, 2019). In this perspective, entrepreneurial activity will serve more as an intermediary product of the system. This entrepreneurial activity can take different forms, including innovative start-ups, high-growth start-ups, and entrepreneurial employees.

The presence of some favorable factors such as investors, human resources, culture, infrastructure, institutions, regulatory and fiscal conditions, social and environmental quality, the capacity to generate innovation as well as the availability of real and potential know-how can contribute to making an ecosystem a suitable habitat for the development of new businesses. A recent but well-established body of literature has theoretically investigated which factors should be considered essential to foster entrepreneurship.

Van De Ven (1993) provided a detailed description of the industrial infrastructure that enables the establishment of new businesses. This type of infrastructure consists of institutional arrangements to regulate and standardise a newly developed technology, public resource endowments of fundamental scientific knowledge, financing mechanisms, a pool of competent labor, as well as proprietary research and development, manufacturing, marketing, and distribution functions. Cohen (2006) explored the nine primary aspects to be considered essential for an entrepreneurial ecosystem: they are referred to as the Informal Network, the Formal Network, the University, the Government, the Professional Service, the Support Services, the Capital Services, and the Talent Pool.

Another framework for the entrepreneurial ecosystem is the one outlined by Isenberg (2011), whose model includes six main relevant factors: a supportive culture, enabling policies and leadership, the availability of dedicated funding, relevant people, venture-friendly markets, and a wide range of institutional and infrastructural supports. Feld (2012) placed strong emphasis on the interaction among ecosystem actors (strong group of entrepreneurs, mentors, and advisors, and a robust network) as well as the accessibility to all types of necessary resources (talent, services, finance), while recognising an important supporting background role to government. According to Spigel (2017), an entrepreneurial ecosystem is the result of 11 cultural, social, and material elements that offer resources to make entrepreneurship thrive. These include a supportive culture, a history of entrepreneurship, worker talent, investment capital, networks, mentors and role models, policy and governance, universities, support services, physical infrastructure, and an open market. The above-described body of literature has therefore elaborated various lists of crucial or essential factors characterising an entrepreneurial ecosystem, from a theoretical perspective.

Ács *et al.* (2014) filled a gap in entrepreneurship research by focusing on country-level aspects of the entrepreneurial process and introducing the notion of National Systems of Entrepreneurship as systems of resource allocation where the driving force is represented by individuals pursuing new business opportunities. The results of this entrepreneurial activity are then regulated based on the institutional characteristics of the country. According to Stam (2015), within an entrepreneurial ecosystem, two main types of conditions can be identified: framework conditions and systemic conditions. Framework conditions include elements like demand, informal and formal institutions, culture, and physical conditions that can either enable or constrain human interaction. Instead, systemic conditions include aspects like networks of entrepreneurs, leadership, finance, talent, and knowledge as well as support services.

Shifting the focus from academic definitions toward the conceptualisations made by governmental and non/governmental agencies, according to the OECD, the existence of a legal framework, market conditions, availability and accessibility of financing, the generation and dissemination of knowledge, as well as entrepreneurial competencies and culture all contribute to the development of an entrepreneurial ecosystem. Based on official government statistics sources, the OECD report "Entrepreneurship at glance" published in 2016 provides data at a global level on these entrepreneurial ecosystem factors for 50 countries. Rather than considering a single composite index, the OECD gives a series of indicators, as stated in the report itself:

"A defining characteristic of the program is that it does not provide a single composite measure of overall entrepreneurship within an economy. Rather, recognizing its multi-faceted nature, the program revolves around a suite of indicators of entrepreneurial performance that each provides insights into one or more of these facets" (OECD 2016, p. 9).

The Global Entrepreneurship Monitor (GEM) collects data on environmental factors that contribute to the formation of new firms. This data is gathered at a global level with the support of the National Experts Survey (NES) and allows different countries to be compared globally. The individual choice to launch a new business is indeed the result of many varying factors and it may have different consequences. Among these factors, the context is clearly decisive. The entrepreneurial environment or ecosystem plays a crucial role in influencing both the outcome of the decision (whether to start a new business or not) and the subsequent path of the potentially nascent entrepreneur in their attempt to progress from being an aspiring entrepreneur towards being the owner of a well-established firm. Apart from the support of family and friends, this shift is heavily dependent on some elements characterising the context. While it is nevertheless true that some entrepreneurial activities may prosper even under the toughest or most improbable conditions, it is undeniable that a supportive environment can inspire ambition and growth, thus facilitating the arduous shift from new to established firms. GEM proposes a wide categorisation of environmental factors, based on academic literature and on the results of its cross-country study: Entrepreneurial Finance & Ease of Access to Entrepreneurial Finance; Government Policy: Support and Relevance & Taxes and Bureaucracy; Government Entrepreneurial Programs; Entrepreneurial Education at School; Entrepreneurial Education Post-School; Research and Development Transfers; Commercial and Professional Infrastructure; Ease of Entry: Market Dynamics & Burdens and Regulation; Physical Infrastructure; Social and Cultural Norms.

In order to bypass the weighting issue, GEM suggests a variety of indicators rather than a single metric, similar to the OECD's approach. This decision entails giving up a single, comprehensive viewpoint in favor of a variety of signs that are more challenging to explain.

The World Economic Forum (WEF) evaluates the ecosystem competitiveness of 144 economies in its "Global Competitiveness Report", which provides useful insights into the main determinants of competitiveness. WEF suggests using 12 ecosystem competitiveness factors, including institutions, infrastructure, the macroeconomic environment, health and primary education, higher education and training, and market efficiency for goods, labour, and finances. Other factors include technological readiness, market size, business sophistication, and innovation. The 12 elements are measured individually and reported as well as consolidated into a single index.

A great effort has also been made by the World Bank with the "Ease of Doing Business" project. The findings provide results on two measures: the ease of doing business score and the ease of doing business ranking. The ease of doing business score evaluates an economy based on its performance in relation to the 41 measures of regulatory best practice for 10 Doing Business topics (Starting a business, Dealing with construction permits, Getting electricity, Registering property, Getting credit, Protecting minority investors, Paying taxes, Trading across borders, Enforcing contracts, Resolving insolvency). These scores benchmark economies according to their adherence to regulatory best practices and indicate how close they are to achieving the highest possible levels of regulatory performance (0 represents the lowest performance, 100 represents the highest). The ease of doing business ranking can take on values from 1 to 190, sorting countries based on how easy it is to do business in their territory (World Bank, 2020).

It is, however, necessary to note that most of the mentioned indices do not include weights, thus providing a simplified perspective of reality, or using weighting methods that are generally criticised because of their arbitrariness.

2.2 From entrepreneurial ecosystems to digital entrepreneurial ecosystems

Digitalisation and digital transformation are disrupting business processes and models as well as reshaping entrepreneurship. However, the intersection between the two concepts of digitalisation and the entrepreneurial ecosystem still seems to be understudied in academic literature, except for some contributions. In the digital economy, a large part of the emerging and successful new ventures leverages digital technologies to perform their activities.

Before dealing with the conceptualisation of the digital entrepreneurship ecosystem, it is necessary to clarify the idea of the digital ecosystem, which arose in the 2000s. A digital ecosystem can be defined as "a self-organizing, scalable and sustainable system composed of heterogeneous digital entities and their interrelations focusing on interactions among entities to increase system utility, gain benefits, and promote information sharing, inner and inter cooperation and system innovation" (Li *et al.*, 2012, p.119).

A relevant conceptualization in entrepreneurial literature was proposed by Autio *et al.* (2018b). The authors suggested that the evaluation of a digital entrepreneurial system should consider 4 general framework conditions as well as 4 systemic framework conditions. The general framework conditions are: (1) Culture and Informal Institutions, (2) Formal Institutions, Regulation, and Taxation, (3) Market Conditions, and (4) Physical Infrastructure. The degree of digitalisation of these conditions can be measured by associating each of them with a measure of the digital context. The systemic resource-related conditions are (1) Human Capital, (2) Knowledge Creation and Dissemination, (3) Finance, and (4) Networking and Support. They are supposed to vary depending on the stage of development of an entrepreneurial activity and, for this reason, they are differentiated into Stand-up, Start-up, and Scale-up stages.

According to Sussan and Acs (2017), from a theoretical point of view, the concept of a digital entrepreneurial ecosystem derives from the intersection between the concepts of the digital ecosystem (Dini *et al.*, 2011; Weil and Woerner, 2015) and entrepreneurial ecosystem, as above conceptualised. The authors suggested that in understanding a digital ecosystem, digital technologies should be thought of as the non-living element, while people who make use of them as the living element. The two elements interact with each other, generating dynamics and changes that characterise the ecosystem itself. Consequently, the two fundamental components of a digital ecosystem are the digital infrastructure and the users. The entrepreneurial ecosystem is instead seen as made up of agents and institutions.

Digital infrastructure is defined as a socially integrated mechanical system comprising technology and human components, networks, systems, and processes that produce self-reinforcing feedback loops. By users, we mean anyone who has access to digital technologies. Consistently, according to Autio *et al.*, (2018a), entrepreneurship is impacted by digitalisation by means of what is referred to as digital affordance, the possibility to conduct wholly new activities or already existing ones in novel ways. The concept of affordance has its roots in the work by Gibson (1979) who raised the issue of affordance of natural objects. In Gibson's view, human beings and animals perceive natural objects differently depending on the possibilities these objects offer for action (e.g. a river may represent a place to drink for a buffalo while a rock may provide a shelter for a reptile) (Gibson, 1979). The term user refers to the entire population having access to digital technologies. In this context, characterised by an intense net of interactions within the digital community, some users may accidentally become entrepreneurs by creating novel goods or services that enrich and improve the ecosystem itself (Shah and Tripsas, 2007).

Sussan and Acs' model (2017) was subsequently resumed and refined by Song (2019), who conceptualises four main dimensions: (1) digital user citizenship, (2) digital technology entrepreneurship, (3) digital infrastructure governance, and (4) digital multisided platform.

Another attempt to define the novel concept of digital entrepreneurial ecosystems was made by Elia *et al.* (2020), who refer to it as the coalition of components, operating within a specific region, supporting the advancement of innovative businesses that want to capitalise on emerging opportunities stemming from digital technologies.

Furthermore, more recent contributions have investigated how digital technologies facilitate interconnections inside entrepreneurial ecosystems (Bouncken and Kraus, 2022) as well as the process of converting a conventional market into an entrepreneurial ecosystem through the use of digitalization and an e-commerce strategy (Song *et al.*, 2022). Lastly, Bejjani *et al.* (2023) proposed a broad conceptual framework exploring seven digital entrepreneurial ecosystem attributes: governance, actors, resources, architecture, complementarity, reach, and identification process.

The literature on digital entrepreneurial ecosystems is still on the rise. However, what emerges from the above presented overview is that most of the contributions are conceptual and there is a lack of empirical investigation in the field.

Torres and Godinho (2022) identified a gap in the need to evaluate how necessary each element of a digital entrepreneurial ecosystem is. However, to date, academic research has failed to produce methodologies for evaluating and comparing digital entrepreneurial ecosystems from different perspectives that can highlight the underlying factors.

Having identified this gap, the paper proposes the application of an accurate, robust, and reliable measurement technique, namely stochastic multicriteria acceptability analysis (SMAA). It considers the variability of weights that can be assigned to the different factors, producing a probabilistic ranking to obtain a comparison between the entrepreneurial ecosystems. This ranking is more reliable than a single ranking proposed by the usual composite indices that consider a single vector of weights.

3. Research design

The present contribution considers 33 indicators, grouped into 10 subdimensions and 4 dimensions summarising the most common digital entrepreneurial pillars emerging in literature. Data are gathered from the Digital Economy and Society Index (DESI) which provides information on the digital progress made by European countries.

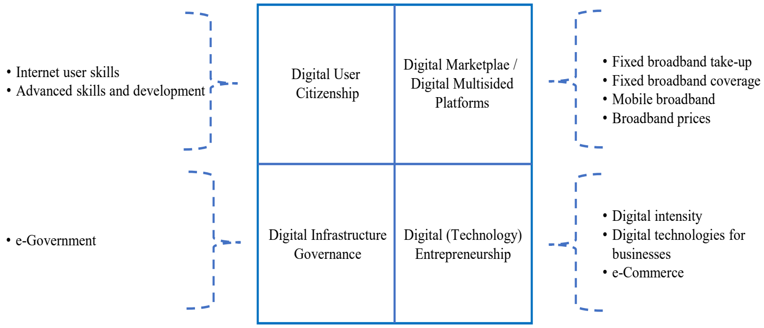
We use DESI because it was developed in line with the objectives of the 2030 Digital Compass: the European Way for the Digital Decade Communication which defines the EU's vision for digital transformation to realise by 2030 and outlines specific digital goals.

The raw data used to calculate the DESI, which also represents the input of our analysis, have been collected by the European Commission, by means of the competent authorities of each member state (the Directorate-General for Communications Networks, Content and Technology and Eurostat). Additionally, the Commission conducted ad hoc studies to supplement the data. Data collection and validation are described in detail in the methodological note (European Commission, 2021A).

The four cardinal points of this digital agenda are: a digitally skilled population and highly skilled digital professions; secure and sustainable digital infrastructures; digital transformation of businesses, and the digitalisation of public services (European Commission, 2021a). The DESI is built around them and is made up of four main dimensions: Human Capital, Connectivity, Integration of digital technology, and Digital public services. The index has a three-level structure, which means that for each dimension, a number of sub-dimensions and micro-level indicators are identified. Starting from the DESI index, the aim of the present paper is to provide an application of Stochastic Multicriteria Acceptability Analysis (SMAA; Lahdelma *et al.*, 1998) as a precise, robust, and reliable measurement methodology for the measurement of digital entrepreneurial ecosystems at the national level. We aim to compare different countries by evaluating, ranking, and comparing them as digital entrepreneurial ecosystems, by applying SMAA methodology.

Figure 1 represents the way in which already existing frameworks (Sussan and Acs, 2017; Song, 2019) can be integrated with the data collected by the European Commission, with the aim to operationalise the four pillars of a digital entrepreneurial ecosystem and provide an evaluation of digital entrepreneurial ecosystems at a country level.

Fig. 1: Integrating Digital Entrepreneurial Ecosystem Framework (Sussan and Acs, 2017; Song, 2019) with DESI structure



Source: authors' own elaboration based on Sussan and Acs (2017), Song (2019) and European Commission (2021a)

The DESI index is a composite index (Greco *et al.*, 2019) assigning a value to each European Country based on thirty-three elementary criteria structured hierarchically and weighted as follows:

1. Human capital (g_1): 25%
    1.1 Internet users' skills ($g_{(1,1)}$): 50%
        1.1.1 At least basic digital skills ($g_{(1,1,1)}$): 50%
        1.1.2 Above basic digital skills ($g_{(1,1,2)}$): 25%
        1.1.3 At least basic software skills ($g(_{1,1,3)}$): 25%
    1.2 Advanced skills and development ($g_{(1,2)}$): 50%
        1.2.1 ICT specialists ($g_{(1,2,1)}$): 33.33%
        1.2.2 Female ICT specialists ($g_{(1,2,2)}$): 33.33%
        1.2.3 Enterprises providing ICT training ($g_{(1,2,3)}$): 16.67%
        1.2.4 ICT graduates ($g_{(1,2,4)}$): 16.67%
2. Connectivity ($g2$): 25%
    2.1 Fixed broadband take-up ($g_{(2,1)}$): 25%
        2.1.1 Overall fixed broadband take-up ($g_{(2,1,1)}$): 33.33%
        2.1.2 At least 100 Mbps fixed broadband take-up ($g_{(2,1,2)}$): 33.33%
        2.1.3 At least 1 Gbps take-up ($g_{(2,1,3)}$): 33.33%
    2.2 Fixed broadband coverage ($g_{(2,2)}$): 25%
        2.2.1 Fast broadband (NGA) coverage ($g_{(2,2,1)}$): 25%
        2.2.2 Fixed Very High-Capacity Network (VHCN) coverage ($g_{(2,2,2)}$): 50%
        2.2.3 Fibre to the precises (FTTP) coverage ($g_{(2,2,3)}$): 25%
    2.3 Mobile broadband ($g_{(2,3)}$): 40%
        2.3.1 5G Spectrum ($g_{(2,3,1)}$): 25%
        2.3.2 5G coverage ($g_{(2,3,2)}$): 50%
        2.3.3 Mobile broadband take-up ($g_{(2,3,4)}$): 25%
    2.4 Broadband prices ($g_{(2,4)}$): 10%
        2.4.1 Broadband price index ($g_{(2,4,1)}$): 100%
3. Integration of digital technology (g_3): 25%

3.1 Digital intensity ($g_{(3,1)}$):15%
   3.1.1 SMEs with at least a basic level of digital intensity ($g_{(3,1,1)}$): 100%
3.2 Digital technologies for businesses ($g_{(3,2)}$): 70%
   3.2.1 Electronic information sharing($g_{(3,2,1}$)): 10%
   3.2.2 Social media ($g_{(3,2,2)}$): 10%
   3.2.3 Big data ($g_{(3,2,3)}$): 20%
   3.2.4 Cloud ($g_{(3,2,4)}$): 20%
   3.2.5 AI ($g_{(3,2,5)}$): 20%
   3.2.6 ICT for environmental sustainability ($g_{(3,2,6)}$): 10%
   3.2.7 E-Invoices ($g_{(3,2,7)}$): 10%
   3.3 E-Commerce ($g_{(3,3)}$) 15%
   3.3.1 SMEs selling online ($g_{(3,3,1)}$): 33.33%
   3.3.2 E-Commerce turnover ($g_{(3,3,2)}$): 33.33%
   3.3.3 Selling online cross-border ($g_{(3,3,3)}$): 33.33%
4. Digital public services (g_4): 25%
4.1 e-Government ($g_{(4,1)}$): 100%
   4.1.1 e-Government users ($g_{(4,1,1)}$): 14.29%
   4.1.2 Pre-filled forms ($g_{(4,1,2)}$): 14.29%
   4.1.3 Digital public services for citizens ($g_{(4,1,3)}$): 28.57%
   4.1.4 Digital public services for businesses ($g_{(4,1,4)}$): 28.57%
   4.1.5 Open data ($g_{(4,1,5)}$): 14.29%.

This means that Human capital, Connectivity, Integration of digital technology, and Digital public services are equally weighted. Under the Human capital macro-criterion, internet users' skills and Advanced skills and development have the same weight. The elementary criteria descending from a last, but one level criterion all have the same weights or double. For example, considering Internet users' skills, Above basic digital skills and At least basic digital content creation skills have the same weight (25%), while At least Basic Digital Skills has double the weight of the other two (50%).

Evaluations of the countries on the thirty-three elementary criteria are normalized to put them on the same [0,1] scale considering a minimum and a maximum value for each of them. Therefore, these evaluations are aggregated to obtain a comprehensive score on each macro-criterion and, at the global level.

Looking at the computation of the index, the following main issues can be underlined.

- *Normalization*: Many normalization techniques can be used to put all the evaluations on the same scale. However, different normalizations assign different values and, therefore, different aggregated values to the considered countries. Moreover, each normalization implies a loss of information concerning the original data.
- *Weighting*: As explained above, the DESI index is computed considering certain fixed weights for all criteria in the hierarchy. However, the choice of the weights is arbitrary, and different weight vectors would provide different scores to the considered countries and, therefore, different recommendations could be obtained.
- *Hierarchical structure*: The DESI index aggregates as a whole the evaluations on the thirty-three elementary criteria computing,

therefore, a global score taking all of them together. From a policy-making point of view, it would be useful to get a global level ranking as well as a ranking for each of the macro-criteria to obtain further insight into the weak and strong points of each country.

In this paper, we shall tackle the second and third issues. On the one hand, regarding the weighting issue, we shall consider a whole set of weight vectors and not only the one used to compute the DESI index. In this way, we shall show how a small variability in the weights attached to the criteria will imply a degree of variability in the ranking of the Countries. To this aim, we shall apply the Stochastic Multicriteria Acceptability Analysis (SMAA; Lahdelma *et al.*, 1998; Pelissari *et al.*, 2020). On the other hand, we shall apply the Multiple Criteria Hierarchy Process recently introduced in the literature to obtain a ranking on the comprehensive level as well as considering the 4 macro-criteria in the hierarchy.

4. Methodology. Multiple Criteria Decision Analysis and Stochastic Multicriteria Acceptability Analysis

In Multiple Criteria Decision Analysis (Greco *et al.*, 2016) a set of alternatives $A=\{a,b,c,\ldots\}$ is evaluated on a set of criteria $G=\{g_1,\ldots,g_m\}$ to deal with a ranking, choice, or sorting problem (Roy, 1996). Several different MCDA methods have been presented in the literature and all of them aim to aggregate the evaluations of the alternatives to give a recommendation on the problem at hand. In particular, Multiple Attribute Value Theory (MAVT), through a value function, assigns a real number to each alternative being representative of its goodness concerning the considered problem. Among the possible value functions, the simplest and most used in practice is the weighted sum.

$$WS(a,\boldsymbol{w}) = WS(g_1(a),\ldots,g_m(a),w_1,\ldots,w_m) = \sum_{j=1}^{m} w_j \cdot g_j(a).$$

Of course, the value assigned from the weighted sum to each alternative depends on the weights assigned to the criteria. SMAA was presented for the first time by Lahdelma, Hokkanen, and Salminen (1998). It produces information on the problem at hand considering a certain variability in the alternatives' evaluations as well as on the weights of the considered criteria (the parameters of the model, in general). In our case, we shall consider the same evaluations used in the DESI index and, therefore, we shall take into account a variability related only to the weights of criteria. Denoting by

$$\mathbf{W} = \left\{(w_1,\ldots,w_m) \in R^m : w_j \geq 0 \text{ and } \sum_{j=1}^{m} w_j = 1\right\}$$

the whole space of weights vectors that could be used, SMAA produces information in statistical terms considering a sampling of weights vectors in W. Fixed a certain alternative a and a weight vector $\mathbf{w}$, SMAA defines the following rank function

$$rank(a,\mathbf{w}) = 1 + \sum_{b \neq a} \rho\big(WS(b,\mathbf{w}) > WS(a,\mathbf{w})\big)$$

where *ρ(true)*=1 and *ρ(false)*=0. Denoting by W_{Sample} the set of weight vectors sampled from W, for each $\alpha,b\in$ A and each rank position s=1,…,|A| SMAA computes the following sets

$$\mathbf{W}^s(a) = \{\mathbf{w} \in \mathbf{W}_{Sample}: rank(a,\mathbf{w}) = s\}$$
$$\mathbf{W}(a,b) = \{\mathbf{w} \in \boldsymbol{W}_{Sample}: WS(a,\mathbf{w}) > WS(b,\mathbf{w})\}$$

and, therefore, the following indices:

- *The rank acceptability index, $b^s(\alpha)$*: it is the frequency with which a fills the position s and it is computed as

$$b^s(a) = \frac{|\mathbf{W}^s(a)|}{|\mathbf{W}_{Sample}|}.$$

It is a value in [0,1] and the best alternatives are those presenting a high-rank acceptability index for the first-rank positions,

- The central weight vector of a for position s is the barycenter of $\mathbf{W}^s(\alpha)$ and it is computed as the average, component by component, of the weight vectors in $\mathbf{W}^s(\alpha)$. It represents the average preferences giving to α position *s*,
- *The pairwise winning index, p(α,b)*: it is the frequency with which a is preferred to b and it is computed as

$$p(a,b) = \frac{|\mathbf{W}(a,b)|}{|\boldsymbol{W}_{Sample}|}.$$

It is a value in [0,1] and the greater *p(α,b)*, the more a is preferred to *b*.

Based on the rank acceptability indices, following Corrente *et al.*, 2019, the following additional information can be computed for each *α*:

- The lowest and the greatest rank positions that can be obtained by *α*,
- The three most frequent positions that can be obtained by *α*.

In our context, we shall assume that the weight assigned to the elementary criteria as well as to the second and third-level criteria are the same used in the computation of the DESI index and illustrated in the previous section, while we considered different weights for the four macro-criteria. In addition to the case in which the four criteria are equally weighted, we assumed that the weight of each macro-criterion can vary in the interval [20%,30%].

In the case of practical problems, criteria are not sited at the same level, but they are organized hierarchically. It is therefore possible to underline a root criterion, being the main objective of the problem; some first-level criteria having sub-criteria descending from them; finally, the elementary criteria on which the evaluation of the alternatives is provided are placed at the bottom of the hierarchy.

The MCHP was presented by Corrente, Greco and Słowiński (2012) to deal with problems in which criteria are structured hierarchically. The main objective of MCHP is therefore providing recommendations both at the global level, that is, considering all criteria simultaneously, and considering each node of the hierarchy.

From a computational point of view, denoted by g_r a certain criterion in the hierarchy, MCHP computes the weighted sum of an alternative *α* on g_r considering only the elementary criteria descending from it, that is, EL(g_r)⊆{g_1,…,g_m}. The weighted sum of *α* on criterion g is then computed as follows:

$$WS_{g_r}(a,\mathbf{w}) = \sum_{g_t \in EL(g_r)} g_t(a) \cdot w_t \,.$$

All indices of SMAA can easily be computed defining for each a,b∈A, for each rank position s and each macro-criterion g_r the following sets:

- $\boldsymbol{W}^s_{g_r}(a) = \{\mathbf{w} \in \mathbf{W}_{Sample} : rank(a,\mathbf{w},g_r) = s\}$ where

$$rank(a,\mathbf{w},g_r) = 1 + \sum_{b \neq a} \rho\big(WS_{g_r}(b,\mathbf{w}) > WS_{g_r}(a,\mathbf{w})\big)$$

- $\mathbf{W}_{g_r}(a,b) = \{\mathbf{w} \in \boldsymbol{W}_{Sample} : WS_{g_r}(a,\mathbf{w}) > WS_{g_r}(b,\mathbf{w})\}$.

Therefore, the typical indices of SMAA are extended to the MCHP context as follows:

- The partial rank acceptability index of a for criterion g_r and position *s*∈{1,…,m}:

$$b^s_{g_r}(a) = \frac{|\boldsymbol{W}^s_{g_r}(a)|}{|\boldsymbol{W}_{Sample}|}$$

- The partial central weight vector of *α* for criterion g_r and for position s∈{1,…,m}: It is computed as the average, component by component, of the weight vectors in $W^s g_r$ (*α*),
- The partial pairwise winning index for criterion g_r, p_{gr} *(α,b)*:

$$p_{g_r}(a,b) = \frac{|\mathbf{W}_{g_r}(a,b)|}{|\mathbf{W}_{Sample}|}.$$

5. Empirical analysis and results

By applying SMAA to the DESI input data, the rank acceptability indices, the pairwise winning indices, and the central weight vectors are obtained.

Table 1 reports the frequency with which a given country achieves each of the possible positions in the overall ranking, from the 1st to the 27th (which is the total number of countries considered). The results show that Denmark and Finland attain the 1st position with a frequency of 38,82 and 61,18 respectively. In contrast, Bulgaria and Greece are the 26th position with a frequency of 90,86 and 9,15 while the last position is occupied by Romania with a frequency of 100. The results are enriched by the figures given in Tables 2 and 3. Table three shows the best and the worst positions attainable for each country, based on the results of the rank acceptability indices.

Tab. 1: Rank acceptability index

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13	#14
Austria	0	0	0	0	0	0	0	0	2,987	96,931	0,082	0	0	0
Belgium	0	0	0	0	0	0	0	0	0	0	0	0	0,022	0,285
Bulgaria	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Croatia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cyprus	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Czechia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Denmark	38,824	61,176	0	0	0	0	0	0	0	0	0	0	0	0
Estonia	0	0	0	0	0	0	0	0	97,013	2,939	0,047	0,001	0	0
Finland	61,176	38,824	0	0	0	0	0	0	0	0	0	0	0	0
France	0	0	0	0	0	0	0	0	0	0,032	41,164	24,55	31,821	2,433
Germany	0	0	0	0	0	0	0	0	0	0,036	4,955	18,605	33,514	42,705
Greece	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hungary	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ireland	0	0	0	0	100	0	0	0	0	0	0	0	0	0
Italy	0	0	0	0	0	0	0	0	0	0	0	0	0	0,011
Latvia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0	0	0	0	0,018	15,501	13,377	16,405	54,513
Luxembourg	0	0	0	0	0	0	0	100	0	0	0	0	0	0
Malta	0	0	0	0	0	54,581	45,419	0	0	0	0	0	0	0
Netherlands	0	0	100	0	0	0	0	0	0	0	0	0	0	0
Poland	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Portugal	0	0	0	0	0	0	0	0	0	0	0	0	0	0,053
Romania	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slovakia	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slovenia	0	0	0	0	0	0	0	0	0	0,044	38,251	43,467	18,238	0
Spain	0	0	0	0	0	45,419	54,581	0	0	0	0	0	0	0
Sweden	0	0	0	100	0	0	0	0	0	0	0	0	0	0

	#15	#16	#17	#18	#19	#20	#21	#22	#23	#24	#25	#26	#27
Austria	0	0	0	0	0	0	0	0	0	0	0	0	0
Belgium	25,621	34,063	28,195	5,586	4,815	1,413	0	0	0	0	0	0	0
Bulgaria	0	0	0	0	0	0	0	0	0	0	9,145	90,855	0
Croatia	0	0	0	0,086	1,269	10,923	87,722	0	0	0	0	0	0
Cyprus	0	0	0,495	3,784	8,642	75,839	11,24	0	0	0	0	0	0
Czechia	0	0,192	7,257	56,113	35,231	1,207	0	0	0	0	0	0	0
Denmark	0	0	0	0	0	0	0	0	0	0	0	0	0
Estonia	0	0	0	0	0	0	0	0	0	0	0	0	0
Finland	0	0	0	0	0	0	0	0	0	0	0	0	0
France	0	0	0	0	0	0	0	0	0	0	0	0	0
Germany	0,181	0,004	0	0	0	0	0	0	0	0	0	0	0
Greece	0	0	0	0	0	0	0	0	0	2,503	88,352	9,145	0
Hungary	0	0	0	0	0	0	0	70,981	29,019	0	0	0	0
Ireland	0	0	0	0	0	0	0	0	0	0	0	0	0
Italy	4,143	8,636	25,969	21,108	39,434	0,698	0,001	0	0	0	0	0	0
Latvia	4,999	22,626	37,486	13,323	10,609	9,92	1,037	0	0	0	0	0	0
Lithuania	0,186	0	0	0	0	0	0	0	0	0	0	0	0
Luxembourg	0	0	0	0	0	0	0	0	0	0	0	0	0
Malta	0	0	0	0	0	0	0	0	0	0	0	0	0
Netherlands	0	0	0	0	0	0	0	0	0	0	0	0	0
Poland	0	0	0	0	0	0	0	0	0	97,497	2,503	0	0
Portugal	64,87	34,479	0,598	0	0	0	0	0	0	0	0	0	0
Romania	0	0	0	0	0	0	0	0	0	0	0	0	100
Slovakia	0	0	0	0	0	0	0	29,019	70,981	0	0	0	0
Slovenia	0	0	0	0	0	0	0	0	0	0	0	0	0
Spain	0	0	0	0	0	0	0	0	0	0	0	0	0
Sweden	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: our elaboration

Tab. 2: Best-worst position

	Best Position	%	Worst Position	%
Austria	9	2,987	11	0,082
Belgium	13	0,022	20	1,413
Bulgaria	25	9,145	26	90,86
Croatia	18	0,086	21	87,72
Cyprus	17	0,495	21	11,24
Czechia	16	0,192	20	1,207
Denmark	1	38,82	2	61,18
Estonia	9	97,01	12	0,001
Finland	1	61,18	2	38,82
France	10	0,032	14	2,433
Germany	10	0,036	16	0,004
Greece	24	2,503	26	9,145
Hungary	22	70,98	23	29,02
Ireland	5	100		
Italy	14	0,011	21	0,001
Latvia	15	4,999	21	1,037
Lithuania	10	0,018	15	0,186
Luxembourg	8	100		
Malta	6	54,58	7	45,42
Netherlands	3	100		
Poland	24	97,5	25	2,503
Portugal	14	0,053	17	0,598
Romania	27	100		
Slovakia	22	29,02	23	70,98
Slovenia	10	0,044	13	18,24
Spain	6	45,42	7	54,58
Sweden	4	100		

Source: our elaboration

Tab. 3: Most frequent position

	Most frequent 1	%	Most frequent 2	%	Most frequent 3	%
Austria	10	96,931	9	2,987	11	0,082
Belgium	16	34,063	17	28,195	15	25,621
Bulgaria	26	90,855	25	9,145		
Croatia	21	87,722	20	10,923	19	1,269
Cyprus	20	75,839	21	11,24	19	8,642
Czechia	18	56,113	19	35,231	17	7,257
Denmark	2	61,176	1	38,824		
Estonia	9	97,013	10	2,939	11	0,047
Finland	1	61,176	2	38,824		
France	11	41,164	13	31,821	12	24,55
Germany	14	42,705	13	33,514	12	18,605
Greece	25	88,352	26	9,145	24	2,503
Hungary	22	70,981	23	29,019		
Ireland	5	100				
Italy	19	39,434	17	25,969	18	21,108
Latvia	17	37,486	16	22,626	18	13,323
Lithuania	14	54,513	13	16,405	11	15,501
Luxembourg	8	100				
Malta	6	54,581	7	45,419		
Netherlands	3	100				
Poland	24	97,497	25	2,503		
Portugal	15	64,87	16	34,479	17	0,598
Romania	27	100				
Slovakia	23	70,981	22	29,019		
Slovenia	12	43,467	11	38,251	13	18,238
Spain	7	54,581	6	45,419		
Sweden	4	100				

Source: our elaboration

As already evidenced, Denmark attains the 1st position with a frequency of 38,82 and Finland with a frequency of 61,18. These are the only two countries which attain the optimal position. This means that there is at least one weight vector for which they turn out to occupy the best position in the ranking and, thanks to the adoption of SMAA methodology, we are also able to calculate the probability of occupying a given position. Therefore, even though both countries can range from the first (best) to the second (worst) position, the above-mentioned probabilities lead us to deduce that, given the higher probability for Finland to attain the first position compared to the probability for Denmark, there is a larger share of weight vectors for which Finland can occupy the first position.

As far as the last positions are concerned, the 23rd is the worst position potentially attainable by Hungary and Slovakia with a frequency of 29,02 and 70,98 respectively while the last position is occupied by Romania with a frequency of 100. Table 3 presents the most frequent position, i.e., the mode, for each country. The most frequent position for Finland is 1st, for Denmark is 2nd, for Netherlands is 3rd (100%), for Sweden is 4th (100%), for Ireland is 5th (100%), for Malta is 6th (54,58%), and so on. The table also contains the second and third most frequent positions for each country.

Table 4 presents the pairwise winning index for all the possible pairs of countries. This index represents the frequency with which a country is preferred to another. For example, Finland is preferred to all the other countries with a frequency of 100% apart from Denmark, in comparison to which Finland is preferred with a frequency of 61,18%. This is an important insight, considering that Finland and Denmark are the two overall best-performing countries.

Another example is that Italy is preferred to Croatia, and Cyprus with a frequency of 99,3% and 99,94% respectively; Portugal is preferred to Italy (95,6%). Moreover, a significant insight is linked to the strength of the preferences. While, on the one hand, some preferences are strong enough to denote an almost undeniable direction of the preference itself, on the other hand, there are cases in which the advantage of one country over another is quite small. For example, comparing Slovenia to France, it turns out that Slovenia is preferred to France for 54,05% of the weight vectors but, for the remaining 45,95%, the preference is inverted.

However, apart from the global indices, more detailed additional information can be extracted by applying SMAA. In Tables 5, 6, 7, and 8, we present the cases of Italy, Ireland, Romania and Finland. We selected 4 countries for the limits of this study, but the same tables are available for all 27 countries. These tables are important for policymakers since they show the barycenters (central weight vectors) for the various positions, thus revealing which aspects are mainly responsible for a country's ranking. The central weight vector is the representation of how important the factors are in influencing the possibility of the country to attain the various positions in the ranking. In other words, the results are able to throw light on the strengths and weaknesses of each individual country.

Tab. 4: Pairwise winning index

	Austria	Belgium	Bulgaria	Croatia	Cyprus	Czechia	Denmark	Estonia	Finland	France	Germany	Greece	Hungary	Ireland	Italy	Latvia	Lithuania	Luxembourg	Malta	Netherlands	Poland	Portugal	Romania	Slovakia	Slovenia	Spain	Sweden
Austria	0	100	100	100	100	100	0	2,987	0	99,98	100	100	100	0	100	100	99,982	0	0	0	100	100	100	100	99,956	0	0
Belgium	0	0	100	100	97,946	92,673	0	0	0	0	0,186	100	100	0	80,849	68,799	0,145	0	0	0	100	26,195	100	100	0	0	0
Bulgaria	0	0	0	0	0	0	0	0	0	0	0	9,145	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0
Croatia	0	0	100	0	11,454	0	0	0	0	0	0	100	100	0	0,703	1,562	0	0	0	0	100	0	100	100	0	0	0
Cyprus	0	2,054	100	88,546	0	4,802	0	0	0	0	0	100	100	0	0,059	10,994	0	0	0	0	100	0	100	100	0	0	0
Czechia	0	7,327	100	100	95,198	0	0	0	0	0	0	100	100	0	43,376	24,095	0	0	0	0	100	0	100	100	0	0	0
Denmark	100	100	100	100	100	100	0	100	38,824	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Estonia	97,013	100	100	100	100	100	0	0	0	99,988	99,964	100	100	0	100	100	100	0	0	0	100	100	100	100	99,999	0	0
Finland	100	100	100	100	100	100	61,176	100	0	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
France	0,02	100	100	100	100	100	0	0,012	0	0	85,614	100	100	0	100	100	72,943	0	0	0	100	100	100	100	45,952	0	0
Germany	0	99,814	100	100	100	100	0	0,036	0	14,386	0	100	100	0	100	100	55,234	0	0	0	100	99,986	100	100	16,088	0	0
Greece	0	0	90,855	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2,503	0	100	0	0	0	0
Hungary	0	0	100	0	0	0	0	0	0	0	0	100	0	0	0	0	0	0	0	0	100	0	100	70,981	0	0	0
Ireland	100	100	100	100	100	100	0	100	0	100	100	100	100	0	100	100	100	100	100	0	100	100	100	100	100	100	0
Italy	0	19,151	100	99,297	99,941	56,624	0	0	0	0	0	100	100	0	0	35,453	0,011	0	0	0	100	4,404	100	100	0	0	0
Latvia	0	31,201	100	98,438	89,006	75,905	0	0	0	0	0	100	100	0	64,547	0	0	0	0	0	100	5,078	100	100	0	0	0
Lithuania	0,018	99,855	100	100	100	100	0	0	0	27,057	44,766	100	100	0	99,989	100	0	0	0	0	100	99,959	100	100	17,904	0	0
Luxembourg	100	100	100	100	100	100	0	100	0	100	100	100	100	0	100	100	100	0	0	0	100	100	100	100	100	0	0
Malta	100	100	100	100	100	100	0	100	0	100	100	100	100	0	100	100	100	100	0	0	100	100	100	100	100	54,581	0
Netherlands	100	100	100	100	100	100	0	100	0	100	100	100	100	100	100	100	100	100	100	0	100	100	100	100	100	100	100
Poland	0	0	100	0	0	0	0	0	0	0	0	97,497	0	0	0	0	0	0	0	0	0	0	100	0	0	0	0
Portugal	0	73,805	100	100	100	100	0	0	0	0	0,014	100	100	0	95,596	94,922	0,041	0	0	0	100	0	100	100	0	0	0
Romania	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Slovakia	0	0	100	0	0	0	0	0	0	0	0	100	29,019	0	0	0	0	0	0	0	100	0	100	0	0	0	0
Slovenia	0,044	100	100	100	100	100	0	0,001	0	54,048	83,912	100	100	0	100	100	82,096	0	0	0	100	100	100	100	0	0	0
Spain	100	100	100	100	100	100	0	100	0	100	100	100	100	0	100	100	100	100	45,419	0	100	100	100	100	100	0	0
Sweden	100	100	100	100	100	100	0	100	0	100	100	100	100	100	100	100	100	100	100	0	100	100	100	100	100	100	0

Source: our elaboration

Looking at table 5, it starts with the 14th position which is the best position possibly attainable for Italy. Although the differences are not so sharp, we can make some relevant considerations. First of all, focusing on "Digital technologies for businesses", we can note how, going from the worst to the best position, the importance of these factors increases. Similarly, an enhancement in the positions is also gained with the growing importance of "Internet users' skills". This means that these factors can be considered as a strength and investing in these areas would avoid losing ground. The policymaker should implement actions to improve these aspects in order not to lose ground. Looking at the differences between the best and the worst position (first and last row), it is also worth noting that an increase in the weight of "Advanced skills and development", "Fixed broadband coverage", "Human capital" and "Digital public services" leads the country to move down in the ranking, which suggests that these factors are weaknesses when investing in getting a better positioning. As for Ireland and Romania (Tables 6 and 7), they always maintain the same position (5th and 27th respectively). Looking at Table 8 for Finland, the Dimension "Human capital" can be considered as a strength while "Connectivity" is a weakness. Although keeping in mind that this country is the best performer, it could be valuable to know that there is room for improvement in connectivity.

Digital skills can therefore be considered a key factor for the improvement of a digital entrepreneurial ecosystem. Although the role of digital skills as a driver of innovative performance has been widely investigated (Scuotto *et al.*, 2021), they may turn out to be relevant for new firms' development as well.

Tab. 5: Barycenters for all positions (Italy)

Position	Internet users skills	Advanced skills and development	Fixed broadband take-up	Fixed broadband coverage	Mobile broadband	Broadband prices
14	0,52	0,48	0,28	0,21	0,44	0,06
15	0,50	0,50	0,23	0,22	0,43	0,12
16	0,50	0,50	0,24	0,24	0,42	0,10
17	0,50	0,50	0,25	0,25	0,41	0,10
18	0,50	0,50	0,25	0,26	0,39	0,10
19	0,50	0,50	0,25	0,26	0,39	0,10
20	0,52	0,48	0,27	0,27	0,38	0,08
21	0,45	0,55	0,28	0,30	0,37	0,05

Position	Digital intensity	Digital technologies for businesses	e-Commerce	Human capital	Connectivity	Integration of digital technology	Digital public services
14	0,17	0,72	0,11	0,21	0,30	0,29	0,20
15	0,16	0,70	0,14	0,22	0,29	0,27	0,22
16	0,15	0,70	0,14	0,24	0,29	0,25	0,23
17	0,15	0,70	0,14	0,24	0,26	0,26	0,23
18	0,15	0,70	0,14	0,24	0,25	0,26	0,26
19	0,15	0,70	0,16	0,27	0,23	0,24	0,26
20	0,13	0,69	0,18	0,30	0,21	0,25	0,24
21	0,16	0,66	0,18	0,30	0,20	0,21	0,29

Source: our elaboration

Tab. 6: Barycenters for all positions (Ireland)

Position	Internet users skills	Advanced skills and development	Fixed broadband take-up	Fixed broadband coverage	Mobile broadband	Broadband prices
5	0,50	0,50	0,25	0,25	0,40	0,10

Position	Digital intensity	Digital technologies for businesses	e-Commerce	Human capital	Connectivity	Integration of digital technology	Digital public services
5	0,15	0,70	0,15	0,25	0,25	0,25	0,25

Source: our elaboration

Tab. 7: Barycenters for all positions (Romania)

Position	Internet users skills	Advanced skills and development	Fixed broadband take-up	Fixed broadband coverage	Mobile broadband	Broadband prices
27	0,50	0,50	0,25	0,25	0,40	0,10

Position	Digital intensity	Digital technologies for businesses	e-Commerce	Human capital	Connectivity	Integration of digital technology	Digital public services
27	0,15	0,70	0,15	0,25	0,25	0,25	0,25

Source: our elaboration

Tab. 8: Barycenters for all positions (Finland)

Position	Internet users skills	Advanced skills and development	Fixed broadband take-up	Fixed broadband coverage	Mobile broadband	Broadband prices
1	0,50	0,50	0,25	0,25	0,40	0,11
2	0,50	0,50	0,25	0,26	0,40	0,09

Position	Digital intensity	Digital technologies for businesses	e-Commerce	Human capital	Connectivity	Integration of digital technology	Digital public services
1	0,15	0,70	0,15	0,26	0,23	0,25	0,25
2	0,15	0,70	0,15	0,23	0,28	0,25	0,24

Source: our elaboration

6. Implications and concluding remarks

Entrepreneurship is a complex phenomenon, and many different factors may exert influence on it in a given entrepreneurship ecosystem. Evaluating the ability of a territory to encourage and support entrepreneurial initiatives becomes even more challenging in the digital era, where many entrepreneurial activities are digital-oriented.

The implications of the present work are both theoretical and practical. From a theoretical perspective, the most relevant contribution deriving from the application of SMAA to DESI data consists in the creation of a probabilistic ranking that is more robust and reliable than the conventional single ranking derived from composite indices constructed with a single weight vector. Most of these indices, including DESI, are indeed computed relying on fixed weights identified by a panel of experts and are, for this reason, affected by a degree of subjectivity. SMAA allows us to consider how a variation in the assigned weights can affect the final ranking.

These results have relevant practical implications for both policymakers and businesses. On the one hand, the identification of strengths and weaknesses of the different countries provides useful guidelines for policymakers' decisions aiming to support territorial development.

From the present analysis, policymakers can obtain information both in relation to the entrepreneurial ecosystem of their own country and, in general, in relation to the most important environmental factors affecting entrepreneurship.

Measuring, understanding, and comparing the entrepreneurial ecosystem of their own country is critical to the momentum and maturity of policymakers. We have offered information on each specific country that could help policymakers define appropriate strategies to enhance and sustain strengths and protect from the negative effects of weaknesses. This puts the country in a position that enables it to attain better performance compared to other countries. In addition, the paper provides policymakers with robust general indications on the most relevant digital factors affecting entrepreneurship.

On the other hand, the present study can support businesses in identifying market opportunities to develop enabling technologies for the improvement of digital entrepreneurial ecosystems. Therefore, it may be relevant from an entrepreneurial decision-making and entrepreneurial behaviour perspective. Entrepreneurs or aspiring entrepreneurs could leverage this kind of information to make more informed investment decisions, based on clearer identification of market opportunities, given the current situation of the different countries, their strengths, and their weaknesses.

The paper has some limitations. Specifically, it is based on a single dataset. Despite DESI being considered a valid and reliable source of data, future developments of the study may rely on different sources.

Furthermore, some future research directions can be identified. We applied SMAA allowing for a limited variation of the weights assigned in the computation of DESI. This, however, produced some considerable fluctuations in the position of various countries (i.e. Italy, originally assigned to the 18th position, turns out to attain positions from the 14th to the 21st). Future applications may consider a broader range of weights, thus providing even more relevant changes in the ranking. Other datasets could also be used to enhance robustness. In addition, from a methodological point of view, we intervened on weights assignment and on the hierarchical structure of the index, but it is also possible to intervene on normalisation (both adopting a different normalisation method or applying a model that does not take normalisation into account) and on the interaction between criteria as an improvement opportunity, reconsidering the DESI methodological note.

Future research could validate such results by applying SMAA to various other entrepreneurial ecosystem factors, not yet analysed by DESI. It should also be noted that the analysis is based on the evaluations of the countries for a single year, namely 2021. Thus, future research could develop a dynamic analysis studying how the computed data evolve over time. Another issue that could be considered is the consideration of more advanced models that permit the analysis of the possible interaction between factors (Angilella *et al.*, 2015). Finally, we hope that in taking inspiration from this contribution, future studies might apply SMAA to the managerial field, making a substantial contribution to the evolution of the discipline.

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