Sustainability of Research-based Ecosystem

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Abstract. The aim of the paper is to study sustainability of the research-based entrepreneurial ecosystem BioMed-Varna. The BioMed-Varna is focused on interdisciplinary research in Biomedical Image Analysis, Computational Life Sciences, and Neuroscience. Its main activities include multidisciplinary scientific research, educational projects, development of STEM practices and events/cases for educational institutions, promotion of innovation and entrepreneurial culture, and support for its members' scientific advancement. This paper investigates the development and performs a sustainability appraisal of the research-based entrepreneurial ecosystem using real-world data. The analysis applied by Social network analysis (SNA), reveals the participants' roles, activities and relationships. Using Key Point Indicators (KPIs) and network-based models, this research can support decisions about necessary changes in the ecosystem. Results can be implemented for running evaluation as well as for predictive sustainability assessment. The methodology can be transferred for further research on other regional ecosystems.

INTRODUCTION

Development of a research-based ecosystem is crucial for the stimulation of the technological development and innovations that are considered to be an engine for the digital economy and is of high priority in the European Research Area. The efforts of BioMed-Varna to a great extent correspond with the aims and objectives outlined in the National Strategy for Development of Scientific Research 2017-2030. The Innovation Strategy of Smart Specialization of the Republic of Bulgaria 2021-2027 also reflects and aims to develop the national innovation potential and competitive advantages of the regional business communities based on the entrepreneurship development as an instrument for fostering the entrepreneurial and innovation culture and active citizens participation. On European level the BioMed - Varna activities target the priorities of the Cohesion Policy Objective 1 fo: 2021-27 A smarter Europe by promoting innovative and smart economic transformation through the development of the capacity and productivity of the research, scientific and innovation regional ecosystem.

Ecosystems' Understanding Review

Biologically, an ecosystem is a community or a group of living organisms that live and interact with each other in a specific environment. An ecosystem is a basic unit of the field of the scientific study of nature. According to this, an ecosystem is a physically defined environment, made up of two inseparable components:

- The biotope (abiotic): a particular physical environment with specific physical characteristics such as the climate, temperature, humidity, concentration of nutrients or pH.
- The biocenosis (biotic): a set of living organisms such as animals, plants or microorganisms, that are in constant interaction and are, therefore, in a situation of interdependence.

At the heart of biological ecosystems are food webs as key relationships based on both antagonism / competition and cooperation. This understanding can be transferred to other ecosystems interpretations [1].

Entrepreneurial Ecosystem. The notion of an entrepreneurial ecosystem emerged in the 2000s and there are various definitions. The reason is that this unit is defined in very diverse ways, using different scales, models and data. [2] As a consequence, many different definitions have been offered. Some of them stress on the key components while others stress on the interaction among its elements. One of the most frequently used was developed by Isenberg. According to him, the entrepreneurial ecosystem consists of six domains: policy, finance, markets, human capital, support and culture [3]. Entrepreneurship ecosystem is further defined as a set of interconnected entrepreneurial actors, entrepreneurial organizations, institutions, and entrepreneurial processes that formally and informally coalesce to connect, mediate and govern the performance within the local entrepreneurial environment. [4]. Theodoraki and Messeghem propose another definition: "The entrepreneurial ecosystem includes three dimensions: actors who form it and their interactions (formal and informal network), physical infrastructure, and culture" [5].

Innovation Ecosystem. A research-based ecosystem is indirectly linked to innovation. That is why we have also studied definitions of innovation ecosystems. Granstrand and Holgersson [6] as well Feng, Jiarui and Wang [7] review the accepted definitions of the innovation ecosystem. In summary, innovation ecosystem definitions often place emphasis on collaboration/complements and actors, while less commonly so on competition/substitutes and artifacts. From the existing definitions review, we consider that the following definition is appropriate for our case: An innovation ecosystem is the evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors. This definition is compatible with related conceptualizations of innovation systems and natural ecosystems [6].

Research Ecosystem. A Research Ecosystem is a community of researchers who interact with one another, with their environment and with other stakeholders interested in their respective areas of research. In this way knowledge is transferred between them and system-level processes emerge. A sustainable research ecosystem is a system that survives, functions, and updates itself over time; a system in which the research community can continue to interact, share, and transfer the knowledge. The properties of a research ecosystem are governed by four dynamic elements or interactive controls: regional research culture, research resource management, research stakeholders, and disturbance regime. These interactive controls are constrained by following external factors: global research culture, global research community, and time [8].

Quantitative indicators for research organizations and researchers can be tracked in scientific databases such as Scopus or social network platforms for scientists such as ResearchGate. Scopus offers metrics on journal-level, article-level and author-level. Journal-level metrics are CiteScore™ metrics, SCImago Journal Rank (SJR), Source-Normalized Impact per Paper (SNIP). Article-level metrics are total number of citations, citations per year, citation benchmarking (percentile) and field-weighted citation impact, PlumX metrics. To the author metrics count h-index and h-graph, citation overview tracker. The main ResearchGate metrics are RG score, total research interest, number of publications, citations. Usually, the indicators are used for evaluation of scientists and their scientific results [9], [10] not for their support. Some support within ResearchGate is the notification of similar research or new publications by authors that are followed.

These ecosystems' understandings can be continued in further research in the context of the new reality where ecosystems in virtual environment and digital communities will become increasingly important.

BioMed-Varna Ecosystem

BioMed-Varna started as an informal interdisciplinary initiative of two researchers from Varna Free University and Medical University Varna. It evolved as a research-based entrepreneurial and innovation ecosystem. It is focused on Biomedical Image Analysis, Bioinformatics and Neuroscience. Its main activities include multidisciplinary research, educational projects, development of STEM practices, promotion of innovation and entrepreneurial culture, dissemination of scientific achievements. BioMed-Varna is awarded with Varna City Award 2020 and Innovation Award 2020 from Bulgarian Chamber of Commerce and Industry. BioMed-Varna ecosystem can be defined as a community of researchers who interact with each other, in the surrounding environment (infrastructure) and cooperate with other stakeholders according to the established community culture.

The BioMed-Varna ecosystem is regional-based in its establishment but hybrid in the nature of residence. Combining the benefits of in-person communication and virtual collaboration it exceeds the regional framework. Additional worth includes attracting Bulgarian diaspora and researchers worldwide which is recommended also in Bulgarian national strategy for higher education and research.

Varna as a startup city and as a city of knowledge can provide an advantageous environment for this type of research and entrepreneurial ecosystem.

RELATED WORK

Research on ecosystem sustainability is based first on the study of ecological ecosystems. Gunderson [1] determines ecosystem resilience as the amount of disturbance that a system can absorb without changing stability domains. In ecological systems, resilience lies in the variety of functional groups and the accumulated capital that provide sources for recovery.

The research literature on entrepreneurial ecosystems [11] includes topics such as the relevance of contextual factors to the entrepreneurship process [12, 13], local embeddedness [12, 14], relational approaches attending to interactions between key aspects of the systems [15], resilience [16, 17], network interactions [18], entrepreneurial diversity [19], significance to governments and policy [12, 20, 3], and dynamic perspectives on institutions and networks [20, 21, 22, 23] amongst others. The lack of understanding of how ecosystem elements interact makes it difficult to comprehend ecosystem dynamics [15]. Furthermore, research is needed on how the various elements of the ecosystem enhance entrepreneurship [24]. Adopting a dynamic network approach to ecosystems could help understand elements that enhance entrepreneurship, for instance, investigating the nature of network ties between actors, role of networks and type of linkages that matter [25].

Based on the holistic approach, a conceptual framework for an ecosystem is created [11]. The approach is an integration derived from the fusion of aspects of entrepreneurial activity, value creation and interactions [26]. The framework is a relational organization of ecosystem attributes [23], in addition to aspects of social networks and institutional perspectives [24]. Entrepreneurial action implies conducive behaviors for entrepreneurial activity derived from the critical element of entrepreneurial thinking [27]. Through the creation of value, entrepreneurship is an engine to create economic, social and personal merit [28]. These aspects, together with the interdependent actors within the ecosystem, describe the variety of interactions and relationships that occur in these systems [26].

Key point indicators and metrics of ecosystem performance

Due to the complex nature of the entrepreneurial ecosystem and the many different stakeholders and factors that have impact on it there is no unified detailed framework of measures offered. One of the most widely acknowledged model to measure the vitality and sustainability of an entrepreneurial ecosystem is proposed by Stangler and Bell-Masterson [29] and is based on four major indicators and specific measures to refer:

1) Density: New and young firms per 1,000 people; share of employment in new and young firms and sector density, especially high tech.

2) Fluidity: population flux, labor market reallocation and high-growth firms

3) Connectivity: program connectivity, spinoff rate and dealmaker networks

4) Diversity: multiple economic specializations, mobility and immigrant populations [29]

Metrics can help to determine the strengths and weaknesses of ecosystems, which in turn can help to interpret its special qualities or deficiencies and the strength of the ecosystem over time. Vogel [30] suggests an entrepreneurial ecosystem index based on three levels: individual, organization, community (Table 1).

Albourini et al [31] investigate the behaviors that boost the chances of entrepreneurs and their startups achieving success. The authors propose and study six networking behaviors as independent variables, namely cultivating internal contacts, cultivating external contacts, socialization, getting involved in professional activities, taking part in community activities, and raising one’s profile within the company. The dependent variable is the success of entrepreneurial startups. The results confirm that the better entrepreneurs are at practicing these networking behaviors, the more influence they have on the success of their startups. The most influential behaviors are maintaining internal contacts, maintaining external contacts, and participating in professional activities.

TABLE 1. Ecosystem index

Scale	Measures
Individual	Culture index Personal wealth index Work and life satisfaction index
Organization	Organisational performance
Community	Policy index Market index Location index Job creation index Infrastructure index Visibility index Support index Network index Talent index Funding index Education index Innovation index New venture index

The challenges and threats for the sustainability of the ecosystem arise from the actors, activities and artifacts. Actors are the weakly connected stakeholders in each phase of the ecosystem lifecycle. Activities refer to those in which the actors drop out and resources are used up. Artifacts describe the infrastructure and tools that actors use for joint innovations. The sustainability and success of the remediation depends on the coevolution of the actors within the ecosystem and on the coevolution between the actors and the environment. [32]

METHODOLOGY OF RESEARCH

The methodology of research includes a study of the literature and network-based methods. After the analysis of the sources, the key point (preliminary list) of indicators and metrics of the ecosystems are identified. We determine the factors relevant to BioMed-Varna. Some of these metrics are then explored through social network analysis and calculations with the Python NetX library. Based on the results, conclusions are drawn about key actors, interactions and sustainability.

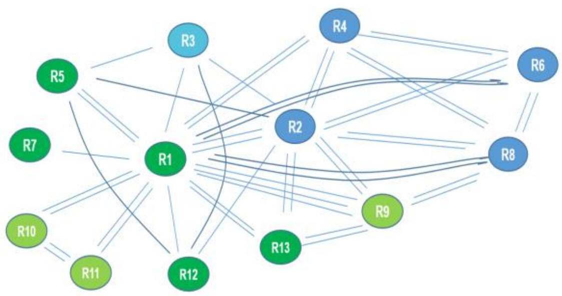
Social network analysis (SNA) is a process of quantitative and qualitative analysis of a social network. SNA measures and maps the flow of relationships and relationship changes between knowledge-possessing entities. Simple and complex entities could include humans, groups, organizations etc. [33]. In our example entities are persons participating in the ecosystem. The result of the analysis of social networks can be used to:

- Identify individuals or teams that play central roles
- Support and accelerate the transmission of information within the ecosystem
- Detection of information interruptions, as well as the presence of isolated individuals or teams
- Increasing the efficiency of existing communication channels
- Improving innovation and learning
- Refining strategies

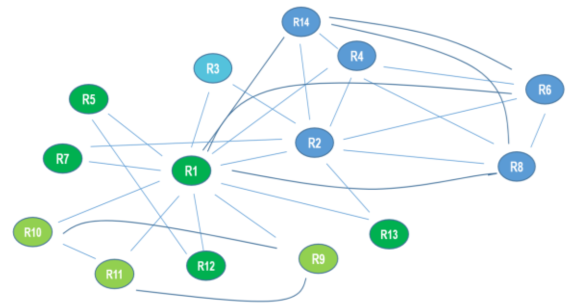
The SNA metrics which are used for evaluation of connectivity and influence are applied for researching the ecosystem. The computations are implemented with NetworkX. NetworkX is a Python package for the creation, manipulation, and study of the structure, dynamics, and functions of complex networks. Applying network structure analysis and metrics calculation with NetworkX, we’ll compare results.

RESULTS

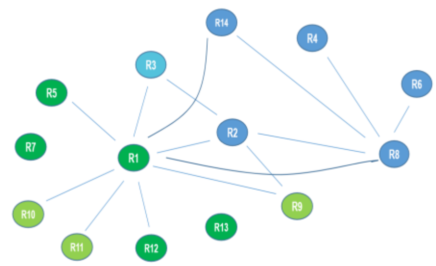
The Biomed-Varna Ecosystem is analyzed in three categories of activities: scientific research activities, education activities and entrepreneurial activities. The scientific research network represents the articles written by the participants and the collaboration in publications. The education activities network consists of relations between actors participating in seminars or courses, developing STEM practices. The entrepreneurial practices network represents the business initiatives where participants are collaborating. The initial relationship between members of the BioMed-Varna is taken November 2020.



(a) Scientific research activities



(b) Education activities



(c) Entrepreneurial activities

FIGURE 1. Bio-Med Varna networks

For each of the activities a separated graph is modelled (Fig. 1). The metrics we study concern both the networks as a whole and the participants in them. Graph vertices are participants in the ecosystem.

Social network analysis metrics are calculated for all the networks/graphs. Some of the important for the ecosystem node related metrics like degree centrality, betweenness centrality, closeness centrality and eigen centrality are considered. These metrics are calculated in two ways - with a SNA tool (NodeXL) and with NetworkX Python Library (Table 3). The computational pipeline or what is prepared with NodeXl also in order to give freedom for non CS/IT researchers to continue the research and to involve in open science initiatives in this area.

Network related metrics like graph density, maximum geodesic distance (diameter), average geodesic distance are presented in Table 2.

TABLE 2. Networks metrics calculated with NodeXL

Graph Metric	**Scientific research network**	**Education activities network**	**Entrepreneurial activities network**
Graph Type	Undirected	Undirected	Undirected
Vertices	13	14	14
Unique Edges	8	27	14
Edges With Duplicates	37	0	2
Total Edges	45	27	16
Maximum Vertices in a Connected Component	13	14	12
Maximum Edges in a Connected Component	45	27	16
Maximum Geodesic Distance (Diameter)	2	3	3
Average Geodesic Distance	1,538462	1,632653	1,791667
Graph Density	0,333333	0,296703297	0,2272727273

The graph density is important to understand how connected the network is compared to how connected it might be. In the BioMed-Varna networks density has values between 0,227 and 0,33 which means that potential connections could be established. The low values of maximum geodesic distance (diameter) and average geodesic distance in all graphs of the BioMed-Varna ecosystem are indicative that most network actors know one another directly.

TABLE 3. Top 3 metrics values computed with NetworkX Python Library

	Researcher	**Betweenness**	**Degree centrality**	**Closeness centrality**
Scientific Research	R1	0.583	1.000	1.000
	R2	0.144	0.750	0.800
	R8	0.010	0.417	0.632
Education Practices	R1	0.631	0.923	0.929
	R2	0.147	0.615	0.722
	R6	0.029	0.385	0.619
	R14	0.029	0.385	0.619
Entrepreneurial practices	R1	0.692	0.558	0.716
	R2	0.308	0.045	0.517
	R8	0.308	0.244	0.517

Next two metrics are related to influence. Degree centrality refers to the number of ties (relationships) a node has to other nodes. High values determine higher influence of that node. The metric assigns an importance score based simply on the number of links held by each node. In our example results R1 has the highest degree centrality in the three networks. Betweenness Centrality is a way of detecting the amount of influence a node has over the flow of information in a graph. In both research and education networks the highest values are identified for R1 and R2 but in the entrepreneurial network R1 and R8 are the leaders.

Closeness Centrality is a way of detecting nodes that are able to spread information very efficiently through the graph [34]. It measures the degree to which a node is close to all other network nodes. The metric indicates how quickly exchanges occur between entities. The closeness centrality of a node measures its average farness (inverse distance) to all other nodes. In the ecosystem networks R1 and R2 indicate highest values and display the shortest distances to all other nodes.

After analysing the ecosystem with the two network approaches, we found that the results were similar and thus confirmed the claims about the key figures and characteristics of the networks.

Applying SNA evaluates connectivity and influence in principle (as is mentioned as is visible in the results). The key characteristic of an ecosystem is its dynamics.

FUTURE WORK AND CONCLUSIONS

Research of sustainability will continue with enhancing the ecosystem participants and relations. Future research can continue with testing of the approach to other existing research-based ecosystems. Combination between different approaches - SNA, multilayer graphs, ontologies is planned to be studied. The next phase of the evaluation is taking consideration of the enhancement of the network focused on the dynamic nature of the community and defining a model that combines approaches SNA, Multilayer graphs, process mining, dynamic systems and ontologies focusing on both dynamics, connectivity and semantic connections/influences.

Another aspect of our focused research is also the process of keeping sustainability after merging existing research networks and entrepreneurial and start up ecosystems between regions (e.g. Varna (BG) and Cluj-Napoca (RO)).

Sustainability indicators can be successfully examined through social network analysis. This method allows us to determine key roles, successful interactions, expansion opportunities, and critical places in the network (ecosystem) through the calculations of metrics and through visualizations. Research of BioMed-Varna R&D Ecosystem based on SNA can be implemented for running evaluation as well as for predictive sustainability assessment.

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