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Research Article

Evaluation of Open Science for co-creation of Social Innovations: A conceptual framework

Evaluación de la Ciencia Abierta para la co-creación de Innovaciones Sociales: Un marco conceptual

Monika Maciuliene

Kaunas University of Technology, Kaunas 44249, Lituania.
Correspondence: monika.maciuliene@ktu.lt

Abstract: Open Science is a rapidly expanding and diversifying field of social innovation with significant implications for and potential benefits to society, policy and various academic research areas. However, much is still unknown about the co-creation processes in Open Science and an overall conceptual framework which aids such understanding is missing. The article aims to address these limitations and identify the key dimensions of an ecosystem allowing co-creation in Open Science to unfold its social and economic impact. The research presented integrates the literature analysis on co-creation in multi-stakeholder ecosystems and suggest that three important dimensions have to be considered in evaluation of Open Science ecosystems: *framework conditions, system conditions and outcomes*. The proposed model was applied in qualitative analysis of thirty-three Open Science case studies. Based on the results of evaluation, it can be concluded that Open Science landscape is highly heterogenous, fragmented and not fully coordinated. The fragmentation appeared in all dimensions of evaluation. The outcomes of the research provide a first exploratory step in proposing innovative measures to determine the elements of co-creation practices within Open Science context.

Keywords: open science; social innovation; stakeholder engagement; co-creation.

Resumen: La Ciencia Abierta es un campo de innovación social en rápida expansión y diversificación, con importantes implicaciones y beneficios potenciales para la sociedad, la política y diversas áreas de investigación académica. Sin embargo, todavía se desconoce mucho sobre los procesos de co-creación en la Ciencia Abierta y se carece de un marco conceptual general que ayude a su comprensión. Este artículo pretende abordar estas limitaciones e identificar las dimensiones clave de un ecosistema que permita la co-creación en la Ciencia Abierta para desplegar su impacto social y económico. La investigación presentada integra el análisis de la literatura sobre la co-creación en ecosistemas de múltiples partes interesadas y sugiere tres dimensiones importantes a ser consideradas en la evaluación de los ecosistemas de Ciencia Abierta: *las condiciones marco, las condiciones del sistema y los resultados*. El modelo propuesto ha sido aplicado en el análisis cualitativo de treinta y tres estudios de caso de Ciencia Abierta. A partir de los resultados de la evaluación, se puede concluir que el panorama de la Ciencia Abierta es muy heterogéneo, fragmentado y no está totalmente coordinado. La fragmentación aparece en todas las dimensiones de la evaluación. Los resultados de la investigación proporcionan un primer paso exploratorio para proponer medidas innovadoras que permitan determinar elementos clave en las prácticas de co-creación en el contexto de la Ciencia Abierta.

Palabras clave: ciencia abierta; innovación social; participación de las partes interesadas; co-creación.

1. Introduction

Open Science is one of the approaches put forward by the European Commission and international institutions such as UNESCO and OECD addressing the inefficiencies of R&I (European Commission, 2021; UNESCO, 2021; OECD, 2021). The trend towards openness, transparency and inclusion is mirrored in a paradigm shift from deficit to the participative mode in science communication where knowledge is created with those who are likely to use it and within the context of its use (Greenhalg et al., 2016; Gagliardi, 2016). Such an outlook has the potential to transform the society through the validated scientific knowledge and allow different Quadruple Helix stakeholder groups to make the science useful for themselves, their working environments and the society overall.

There is a large literature about Open Science initiatives covering different areas such as transdisciplinary research (OECD, 2021), university-driven interactions (D'Este & Perkmann, 2011), citizen science (MacSweeney et al., 2019) and Triple Helix relations between universities, industry and government (Etzkowitz & Leydesdorff, 2000). New forms of engagement are mostly based on principle of co-creation where value is created as the nexus of interaction (Osborne et al., 2018). The strength of co-creation is that it both captures the plurality of actors and the innovative potential that emerges when the actors aim to solve shared social problems (Mezirow, 2000). Given the centrality of the co-creation concept in Open Science discourse, it is vital for contemporary research to deepen and extend the understanding of the phenomenon in R&I systems since it seldom occurs naturally. Much is still unknown about the co-creation processes in Open Science and an overall conceptual framework which aids such understanding is lacking.

Hence, the scientific question emerges: what are the key dimensions of an ecosystem allowing the co-creation in Open Science to unfold its social and economic impact? It is this question that provides the focus of the article. To address it, first an integrative review of the academic literature regarding co-creation in complex systems was conducted to go beyond the scope of a single theory. Hence, the underlying premise of the proposed conceptual model is the interdisciplinarity integrating multiple reference disciplines dealing with co-creation in complex multi-agent systems. The literature review showed that although the researchers agree on the importance of co-creation as a new type of organizing, how to actually design Open Science initiatives for co-creation is researched to a much lesser extent. This is in part because the concept of value co-creation itself is elusive (Grönroos & Voima, 2013). The second part of the study applied the proposed conceptual framework through a meta-analysis of 33 Open Science case studies. The last part of the paper is dedicated to conclusions and implications for further research and innovative practices of Open Science.

2. Conceptualizing the Co-Creation in Open Science

Traditional innovation theories focus on the linear and one-directed flows of information from science to industry (Arnkil et al., 2010). Recent academic thought, however, increasingly acknowledges that multifaceted knowledge is needed in addressing the global social and environmental problems (Kazadi et al., 2016). Such knowledge cannot be generated within the boundaries of a single organization. Hence, we argue that knowledge creation processes in Open Science should be approached through the view of the ecosystem since it embraces a much wider socio-cultural system than the pure dyadic relationships of research/industry or research/civic society. In contrasts to the linear process approach, the ecosystem view emphasizes complex interdependencies between a variety of stakeholders and their different expectations and capacities (Clarysse et al., 2014). The notion of ecosystems has been widely used in collaborative innovation research with different qualifiers such as innovation ecosystem (e.g. Adner, 2006; de Vasconcelos Gomes et al., 2018), social innovation ecosystems (e.g. Domanski et al., 2020; Terstriep et al., 2020), knowledge ecosystem (Järvi et al., 2018), open innovation ecosystem (Chesbrough, 2003) and ecosystems of shared value (Kramer & Pfitzer, 2016). The functional purposes of the ecosystems vary but they share certain inherent features especially when it relates to the facilitation of co-creation between different Quadruple Helix actors.

Table 1. Dimensions and criteria of conceptual evaluation framework.

Dimensions	Framework conditions	System conditions	Outcomes
Criteria for evaluation	Policies and funding Commitment of formal institutions and decision-makers Infrastructure for openness Socio-economic and cultural aspects	Diversity of actors involved Consistent and dynamic communication Shared vision and trust Feedback mechanisms Intermediaries	Outcomes of co-creation activities / benefits for stakeholders
Definition	*Favorable for Open Science implementation.*	*Favorable for co-creation and stakeholder engagement processes.*	*Beneficial for all stakeholders involved.*

Source: Developed by author.

Theoretical insights from these fields were harmonized into more general evaluation dimensions defined in Table 1. The framework suggests that in the evaluation of Open Science ecosystems three important dimensions have to be considered: framework conditions, system conditions and outcomes. Further sections will detail the three dimensions and related research.

2.1. Framework conditions

Scientists, research teams and research performing institutions do not operate in a vacuum. They work in environments which can be seen as a reservoir of possible (dis)incentives for Open Science. The contextual characteristics can influence the content, course and consequences of co-creation processes (Kumari et al., 2019). Implicitly, this means that the capacity to adopt Open Science practices and co-create depends on the wider economic and institutional environment. The framework conditions focus on the contextual factors such as policies, governance, financial and social structures amendable through policy interventions. Even though the framework conditions cannot be distinguished incisively as they are overlapping, the literature focuses on the following aspects:

- **Policies and funding favoring Open Science approaches.** Researchers strongly depend on external funding to carry out their work. Therefore, policies and funding criteria which seek to bring science closer to society can influence research practices (European Commission, 2021) and make open collaborations more attractive for professional scientists (Silvertown, 2009). Regeer and Bunders (2009) suggest that adequate funding criteria serve as stimuli for enhanced cooperation. Both OECD (2021) and UNESCO (2020) guidelines on Open Science mainstreaming in R&I systems recognize the importance of developing effective institutional and national policies and legal frameworks in line with the values and principles of Open Science.
- **Commitment of formal institutions and decision-makers.** Co-creation processes involving broad spectrum of stakeholders are big challenges for public leaders since the leadership in networks cannot rely on traditional forms of authority. Co-creative approaches require creation of mutual trust, dialogue with the stakeholders and removal of power balances in collaborations (Torfing et al., 2019; Maiello et al., 2013).
- **Infrastructure for openness (tools, spaces and training).** Open Science requires systematic and long-term strategic investments in technical and digital infrastructures and related services, including their long-term maintenance (UNESCO, 2020). Both

financial and human resources are needed for the upkeep of sustainable infrastructures which serve the needs of different communities (OECD, 2021). The resources, however, do not have intrinsic value on their own. Rather, they become valuable for a specific actor when applied in co-creative process (Mele et al., 2010). Hence, strategies are also needed to develop necessary skills to manage and use the infrastructures, while taking measures to facilitate its openness, reliability and integrity.
- **Socio-economic and cultural aspects.** Political statements and infrastructure are not enough for co-creative approaches to occur. Scientific knowledge production is a societally embedded process (Smart et al., 2019). Hence, scientific community needs at large to accept the changes on how research is conducted, measured and valued. Eckhardt et al. (2021) define the context of norms as societal framework conditions.

2.2. System conditions

While the traditional approaches to Open Science evaluation focus on the policies, infrastructures and funding that support openness paradigm by broadening attention to the ecosystem more intangible and qualitative aspects affecting knowledge co-creation can be isolated. The ecosystem concept provides a framework for co-creation, in which actors with diverse backgrounds and perspectives collectively work to improve their environment to make it favorable to innovation (Valkokari et al., 2017; Mercan et al. 2011). The co-creative ecosystem can be characterized through the following system conditions:

- **Diversity of actors involved.** When discussing the stakeholders of Open Science, the Quadruple Helix model defining industry, government, academia and civil society as the main actors in any innovation system dominates (Smart et al., 2019). Heterogeneity of actors involved is increasingly recognized as an important feature of co-creative processes. However, few studies identify the exact number and range of stakeholders needed for co-creation to happen (Reypens et al., 2016). Corsaro et al. (2012) based on previous literature identified six attributes of actors' heterogeneity which seem to influence the development of collaborative knowledge: goals, knowledge bases, capabilities and competences, perceptions, power and position, culture. This shows the importance of capacity evaluation of different stakeholder groups (i.e. can and how they participate in co-creation processes).
- **Consistent and dynamic communication.** Luoma-aho & Halonen (2010) argue that communication is a key process supporting knowledge creation by network of actors. The dynamic dialogue stipulates sharing of experiences which in turn leads to greater co-creative potential (Tchorek et al., 2020). Open communication increases awareness and diminishes resistance of the stakeholders (Tabarés-Gutiérrez et al., 2020). Dobers and Stier (2018) suggest a focal enabler here are the communication skills in how to adjust information and vocabulary depending on the target group, context and purpose of co-creative activities. Consistent communication provides a common language between interacting actors and strengthens their relationships (Frow et al., 2016). The development of common language, however, requires time and an open climate between the potential co-creators (Dobers & Stier, 2018).
- **Shared vision and trust.** Innovation ecosystems are defined by the complex interactions between various stakeholders. For co-creative outcomes to emerge the stakeholder relations require trust and understanding rather than status and position (Haxeltine et al., 2016). Here the notion of social capital reveals its importance. Social capital refers to the social networks of individuals and the norms and trustworthiness that arise from them (Putnam, 2000). According to the social capital theory, a high level of trust reduces transaction costs between stakeholders and thus increases the efficiency of ecosystems (Tchorek et al., 2020). Coordinated actions reduces conflicts and creates synergies (Torfing et al., 2019).

- **Feedback mechanisms.** For systems to learn and adapt, crucial process is one of the feedback (Chandler et al., 2019). The feedback loops in innovation ecosystems arise from the interactions between different actors and resources (Ngongoni et al., 2021). The adjustment of certain key factors may have a lasting and effective impact on the system and its stakeholders. According to Roundy et al. (2018) the quantity and quality of feedback determines the overall effectiveness of ecosystem due to the mutual interdependence of actors. Tabarés-Gutiérrez et al. (2020) suggest that the integrated feedback mechanisms also create incentives for the uptake of Open Science practices.
- **Intermediaries.** There is also extensive literature on innovation intermediaries providing support for collaboration between two or more actors and bridging gaps of knowledge, competency and capability (Edler & Yeow, 2016). Intermediaries possess experiences and insight into the logics, language and obstacles of co-creation (Dobers & Stier, 2018). Such facilitators support the ecosystem actors in making new connections and sharing their knowledge and resources in concrete ways (Ketonen-Oksi & Valkokari, 2019). Universities seem to play an essential role in innovation ecosystems as knowledge integrators (Tolstykh et al., 2021; Cai et al., 2020).

2.3. Outcomes of co-creative activities

Researchers agree on the significant benefits of co-creation including but not limited to active enhanced innovation processes and democratized participation (Torfing et al., 2019; Rock et al., 2018). As co-creation involves new social practices and modes of interaction, Eckhardt et al. (2021) consider it as an emerging and currently diffusing social innovation itself. Opening up the scientific process is not simply about sharing, but increasingly about participation, ensuring new knowledge is better used for societal improvement (MacIntosh et al., 2017). There is already qualitative (D'Este et al., 2018) and quantitative evidence (Mascarenhas et al., 2018; Sjöö & Hellström, 2019) that open collaboration in science generates benefits for the society and the economy. The notion of ecosystem emphasizes the systemic nature of relation of actors linked together in mutually beneficial collaborations (Mele et al., 2014). Hence, when evaluating the outcomes deriving from co-creative ecosystems both benefits for the whole ecosystems and individual actors have to be considered.

3. Practical Understanding of Open Science: Applying the Conceptual Evaluation Framework

Meta-analysis aims to apply the proposed conceptual evaluation framework and gain a more practical perspective of co-creation in Open Science. The meta-analytical methods offer powerful means to summarize and synthesize existing knowledge. Meta-analyses are becoming an increasingly popular way of combining findings across research studies in social science (e.g. Jensen & Rodgers, 2001; Newig & Rose, 2020; van der Jagt, 2020). In general, meta-analysis presumes that the originating question in primary studies is not dramatically different. Hence, case studies focusing on Open Science implementation were selected.

Two primary sources were used for meta-analysis: Open Science Monitor (2019) and European Research Council (2019) case studies. Open Science Monitor (OSM) study covers cases on applications of open access to publications, open research data and open collaboration. The OSM data collection approach included semi-structured interviews, direct observations and secondary data analysis. European Research Council (ERC) case studies focused on specific ERC projects that showcase particularly interesting Open Science related activities. The aim of the case studies was to identify common challenges encountered by researchers, incentives and support available to them. These two before mentioned sources provided access to 33 case studies representing a broad spectrum of Open Science initiatives concerning the entire cycle of scientific process and different fields of science (see Table 2 for summary).

Table 2. Sample of case studies.

Code	Project title and/or acronym	Code	Project title and/or acronym	Code	Project title and/or acronym
OSC1	AsPredicted	OSC12	Mendeley	OSC23	Neuronal Dynamics
OSC2	Zenodo	OSC13	Research Data Alliance	OSC24	BrainInBrain
OSC3	The Netherlands' Plan on Open Science	OSC14	Electronic Laboratory Notebooks (ELNs) as Key Enablers of Open Science	OSC25	OurMythicalChildhood
OSC4	Yoda	OSC15	Citizen Science in the Surveillance and Monitoring of Mosquito-Borne Diseases	OSC26	INDIRECT
OSC5	Open Targets	OSC16	ORCID	OSC27	CompMusic
OSC6	REANA	OSC17	Open Metadata of Scholarly Publications	OSC28	Twelwe Labours
OSC7	Pistoia Alliance	OSC18	Open Hardware Licences: parallels and contrasts	OSC29	PROduCTS
OSC8	Faculty of 1000	OSC19	DATA SCIENCE	OSC30	RATE
OSC9	White Rabbit	OSC20	WORDS FOR ART	OSC31	TransMID
OSC10	Utrecht University Open Science Programme	OSC21	PHASENANOCRACKER	OSC32	VIRALPHYLOGEOGRAPHY
OSC11	Finnish Open Science and Research Initiative	OSC22	CompEnzymeEvolution	OSC33	BEGMAT

Source: Developed by author.

The research objectives can be described as exploratory. Although each case had unique challenges and characteristics which can influence the knowledge co-creation and behavior of involved stakeholders, it was possible to gain transferable insight. The case-based evidence was collected using the qualitative content analysis. The content was coded using content analysis software Nvivo. The bottom-up approach was applied by creating simple codes and eventually grouping them together. Each case study was analyzed to find instances where the case study discussed (1) framework conditions; (2) system conditions and (3) outcomes of Open Science initiatives. After descriptive coding, output lists per code and per code set were analyzed and recurrent themes were identified for each code set (thematic analysis). By treating these cases as a series of experiments, the focus was on finding patterns across different contexts. One of the main limitations of this meta-analysis is that it analyzed a limited number of case studies to explain a complex and evolving phenomenon. Also, some aspects that are relevant to the evaluation framework were not discussed in full depth in primary case studies. It certainly does not provide a complete overview of all types of factors influencing co-creation processes nor can it be a generalization of all Open Science initiatives.

4. Results of the meta-analysis

4.1. Framework conditions

4.1.1. Policies and funding favoring Open Science approaches

The meta-analysis of cases studies confirmed that the "current system of rewards <…> is geared towards the impact factor of journals and the importance of the journal of publication"

(OSC8). In addition, the analysis revealed that there is no clear structure and responsibilities (OSC11) and well-aligned vision for science between EU (and national) and research institutions (OSC13). OS contributions of researchers are not visible (OSC13) and predominant model at the moment is decentralized (OSC2). The discussions also focused on the financial barriers such as additional costs of databases (OSC20, OSC24, OSC29), software development (OSC24, OSC31), assistance of IT professionals (OSC14) and high open access publishing fees (OSC22, OSC29). Meta-analysis revealed difficulties in ensuring the longevity of projects in terms of associated costs and resources needed for platform maintenance after the end of grant (OSC29). It has been noted, that "OSC2: "Policies usually emphasize the problem of adoption of open science practices <…> but they also need to address the challenge of sustaining and scaling up the services"). In addition, most of the projects are still new and developing, hence there are limited examples of successful "sustainability models for the maintenance, development, and exploitation of science gateways" (OSC13). In addition, Open Science practices require a serious commitment and time resources from researchers (OSC7, OSC22, OSC23, OSC28, OSC29, OSC31).

The case studies revealed an absence of legal mechanisms ensuring a fair economic return for contributors (OSC9). The current regulatory framework is insufficient and/or outdated (OSC21: "Scientific publishing is run under a legislation that is not designed for it: the copyright law is not appropriate for academia but rather is designed to protect the authors of novels"). Hence, there is a need to establish a clear legal framework at least within projects e.g., OSC9: "A legal framework was also provided by CERN to foster the knowledge sharing among the diverse organizations." Management of data, information and knowledge flows pose several complex challenges which inhibit implementation of Open Science. Such uncertainties include concerns about applicable copyright of data shared (OSC25, OSC30), liability issues (OSC4, OSC18), data integration between tools (OSC2, OSC31), data fragmentation (OSC19), research ethics (OSC30, OSC31) and data security (OSC3, OSC14, OSC30, OSC31).

However, the situation is not so dim and one can already notice positive developments in Open Science application. For example, the requirements of funding agencies for Open Access (OSC19, OSC21) influenced the way research results are published. Hence, similar top-down approaches were suggested in the case studies including coordination and commitment of key actors with a central role dedicated to European Commission (OSC2, OSC3, OSC8, OSC11, OSC13, OSC14, OSC16), stable funding (OSC17), monitoring (OSC5, OSC9, OSC11) and development of basic infrastructure (tech solutions, data infrastructure) (OSC3, OSC11, OSC13, OSC16).

4.1.2. Commitment of institutions and decision-makers

The commitment of institutions and decision-makers was discussed to a limited extent. The case studies underlined the importance of clear European policies and guidelines in furthering national developments and raising awareness about benefits of Open Science (OSC11). However, the case studies did not further extent on the obligations of other institutions and decision-makers.

4.1.3. Infrastructure for openness

Although current research infrastructures have grown both in quality and quantity, there is still a wide range of aspects to improve in order to support research and collaboration workflows to transit to a culture of openness. Technologies pose both the complication of OS processes and acceleration of their solutions. The case studies underlined the difficulties in finding a cost-efficient and reliable solutions for data management (OSC22), platforms offering a one-size-fits-all approach despite the fact that researchers are solving unique problems with different methods (OSC14, OSC20), the complexity of data preparation (OSC29), use (OSC14), licensing (OSC18) and integration (OSC16) within technological solutions; challenges in mimicking industrial-scale data management software (OSC33), limited accessibility (OSC14, OSC26) and interoperability (OSC5, OSC8, OSC12, OSC14) of open science tools. A number of case studies underlined the lack of training on what Open Science is, how to do it and why it is beneficial (OSC8, OSC13, OSC22).

4.1.4. Socio-economic and cultural aspects

Socio-cultural barriers come mainly from researchers and are related to the lack of motivation (OSC13), benefits for a career (OSC4, OSC8, OSC9, OSC10, OSC11) and awareness of what Open Science entails (OSC6, OSC8, OSC11). The ecosystem faces resistance to change (OSC11) since the researchers are attached to the more traditional ways of conducting research (OSC6) and feel a strong sense of ownership towards research data (OSC3). In most cases, open science approaches are understood as an additional burden (OSC22: "The extra effort involved in curating and managing data is a challenge for many people. They feel they could be working on another paper instead of curating the data"). In the research and innovation systems, a culture of secrecy often prevails (OSC4: "the prevailing culture of secrecy has been one of the most significant barriers in creating and making grow YODA"). Hence, cultural change is inevitable on the part of other stakeholder groups including research institutions, funders and government bodies on their vision, policies, practices (OSC19: "The simple reason is that the changes around data sharing are cultural, involving tensions and conflicts between parts of academia and beyond academia"). The case studies highlighted some signs of changes. Most notably the positive perceptions of Open Science by young researchers (OSC22) and collaborative culture in some research fields such as insect neurophysiology (OSC23, OSC24, OSC25, OSC27, OSC32).

4.2. System conditions

4.2.1. Diversity of actors involved

The concept of Open Sciences calls for more transparent, collaborative and participative science. The way to achieve this is through cooperation with different stakeholders during the research process. The meta-analysis aimed to identify the variety of stakeholder groups involved in Open Science initiatives. The main actors identified fall into the four categories defined in the Quadruple Helix model. However, the qualitative content analysis provided a more granular view of the stakeholders involved in the system (See Table 3 below).

The case studies underlined the need for stakeholder diversity in (1) levering the capabilities of many organizations by giving access to different stakeholders leading to combination of expertise, capabilities and capacities (OSC5); (2) harnessing the strengths of all stakeholders (OSC5); (3) facilitating data exchange and information flows between stakeholders (OSC7) and (4) use of information in combination with stakeholders' own knowledge and experiences (OSC3). The case studies indicated that there is no one-size-fits-all approach when it comes to defining stakeholders of Open Science initiatives. Stakeholders are often drawn to the reputation and/or unique resources (knowledge, technologies, infrastructure) the initiative possesses.

Table 3. Stakeholders of Open Science ecosystems.

Academia	Industry	Government	Civil Society
Researchers	Startups, SMEs	Governmental institutions	General public
Administrators and research managers	Large industrial organizations	Public health organizations	Individual citizens
Research performing organizations	Private funding bodies	Environmental organizations	Citizen scientists
Universities and other higher education establishments	Individual entrepreneurs	Public funding agencies	Non-Governmental Organizations (e.g. UN, OECD)
Libraries	Experts from private sector	European level institutions	
Open science platforms, tools (developed by universities)	Commercial publishers	Museums	
	Private research institutions		
	Open science platforms, tools (commercial)		

Source: Developed by author.

4.2.2. Consistent and dynamic communication

The case study content underlined the importance of knowledge sharing through dialogue (OSC10, OSC11), knowledge exchange between public and private sectors (OSC13), diverse collaborative practices, tools, and protocols (OSC9), new modes of collaboration (e.g. OSC31: workshops with collaboration researchers, OSC5: forming partnerships in earlier stages of R&D process; OSC7: collaborative development of common standards between industry and academia). Purposeful communication is needed when showcasing the benefits of Open Science (OSC8: “that open science is not seen as an alternative to good science - open science is good science and good science needs to be open science”). The role of success stories here is of crucial importance because they can illustrate a real-life impact on individual researchers, research groups and institutions (OSC25). Education and training were also highlighted as an essential element of communication through the fostering of the international exchange of practices and learning activities (OSC11), skills development at scientist, specialist and managerial levels (OSC3, OSC6, OSC11), training activities for citizens for better data collection outcomes (OSC15), promotion of open science platforms by funders (OSC8) and mentoring programmes (OSC13).

4.2.3. Shared vision, confidence and trust

The case studies highlighted a lack of coordination and common between stakeholders (OSC11, OSC13). Upfront credit of trust is necessary for broader stakeholder groups to align with visions of openness (OSC16: “This shows that in order for the ORCID registry to be implemented, a certain, upfront credit of trust is necessary - at least as long as network effects due to growing numbers of users are not visible yet, or as long as benefits are not immediately visible either.”). A number of strategies were suggested to alleviate this barrier including centralized support through consensus and regular discussion (OSC13), guidance (OSC14), concerted action (OSC16), economic support of funding organizations (OSC2), operationalization of policies (OSC3), targeted action plans (OSC3).

4.2.4. Feedback and monitoring

Feedback and monitoring mechanisms were discussed to a limited extent. Case studies mentioned the importance of transparent, periodical and systemic monitoring as a prerequisite for a merit system inclusive of Open Science (OSC3, OSC5, OSC9, OSC11). However, more concrete instances of how the initiatives and stakeholders collect evidence and use it to improve performance were missing in analyzed content. The lack of feedback loops can be attributed to a limited number of Open Science projects that are ongoing for a longer period of time.

4.2.5. Intermediaries

The roles and presence of intermediaries of the ecosystem were mentioned seldomly. While waiting for more complete public regulation, effective initiatives can be put in place by stakeholders. The case study content revealed that such initiatives are prominent drivers of Open Science. For example, PubMed by the United States National Library of Medicine at the National Institutes of Health (OSC17), Initiative for Open Citations (i4OC) (OSC17), CERN (OSC2, OSC6, OSC9) and Center for Digital Humanities at the University of Trier (OSC20). In most cases, such organizations are understood as more neutral providers in terms of content custody and are perceived more positively by various stakeholders (OSC2).

4.3. Outcomes

The content analysis revealed that the perceived outcomes of the Open Science initiatives are mostly academia-centric and do not consider potential added-value for all Quadruple Helix groups. Especially when it comes to the participation of civil society in the scientific processes. This might of course be the fault of limited diversity of case studies. However, the findings relate to other studies and broader trends in Open Science, which highlight that opening up the scientific processes, especially when it involves the general public, is a complicated endeavor requiring time, resources and dedicated strategies (Wehn et al., 2020). The outcomes discussed in the case studies can be grouped in three broad categories: (1) for science system and progress, (2) for researchers and (3) for non-academic actors.

4.3.1. Outcomes beneficial for the science system (quality of science) and progress

The first set of outcomes relates to the scientific advancements and improvements in how the science is conducted. In most cases, the focus was on more abstract outcomes of opening up the science e.g., advance knowledge, make research easier, increased research coverage. However, some more specific impact was mentioned too such as an emergence of new subfields of research (OSC30), novel scientific findings (e.g. detections further from known insect invasion areas in OSC15), application of innovative methodology based on a highly sophisticated network of interlinked information (OSC20). The case studies also showed that Open Science can lead to a greater impact of research (OSC31), visibility of science and scientific papers (OSC30) by reaching wider academic and non-academic public (OSC28).

One of the core values of Open Science is sharing, not only traditional research outputs such as publications, but also the scientific data and corresponding documentation. The case content analysis showed a clear move towards applications of FAIR (findable, accessible, inter-operable and reusable) data principles. The meta-analysis of selected case studies revealed that when properly used Open Science tools (e.g. ELNs) can help promote the implementation of FAIR principles (OSC10, OSC13, OSC14). When the scope of the initiative is broad (e.g. OSC10, OSC7 initiatives in national context or consortiums of partners), the FAIR principles are presented as general guidelines for collaboration. However, how the principles are applied depends on the specific disciplines, methods used and contexts. When discussing the outcomes, some projects focus some FAIR principles more than others e.g., defined standards, databases, repositories and policies (OSC13, OSC14, OSC33), efficient reuse of data (OSC15, OSC19, OSC20, OSC28, OSC31, OSC6), transparency (OSC16, OSC8), effort to improve practices around documenting and depositing data and software (OSC25, OSC27), access to data (OSC2, OSC4, OSC5, OSC24).

4.3.2. Outcomes beneficial for the researchers

If we are looking at the outcomes of Open Science directed towards researchers, the meta-analysis showed the impact in various steps in the academic work cycle: investigation of literature (OSC12), easier compliance with internal and external standards (e.g. rules, regulations) (OSC14, OSC33), enhanced academic productivity (OSC12, OSC14), more sophisticated tech tools supporting research (OSC7). For the teams of researchers, the application of Open Science can lead to spending less time on managerial issues (OSC16), enforcement of academic communities and/or research teams' goals (OSC18) and a more comprehensive overview of workflows between team members (OSC33). In general, Open Science is mentioned often in the context of enhanced collaboration opportunities. The participants of the case studies (OSC28, OSC29, OSC31) noted that the researchers applying the Open Science principles are often perceived as more accessible and OS tools allow them to connect with colleagues working outside their institutional boundaries. This might also lead to new career opportunities (OSC12), especially for scholars who are less advanced in their careers and do not have established positions or well-known names (OSC20). Open Science can also bring personal satisfaction to the project leaders when they see data used in different contexts (OSC29).

4.3.3. Outcomes beneficial for non-academic actors

The outcomes for other stakeholder groups were discussed to a much lesser extent. In relation to the civil society, Open Science initiatives can lead to an increased innovative capacity (OSC3), accountability of science to society (OSC16) and relevance to the wider communities (OSC10). It can also result in reduction of costs (e.g. OSC5: "lengthy, costly, low success rate, high attrition rates and complexity in drug discovery"). From the public interest perspective, open information makes it easier for governmental authorities to make decisions (i.e. implement evidence-based policies). In the case of OSC29, the novel information sources allowed the team to track the pesticide transformation products in the ground water. In the context of benefits for industry, it was mentioned that companies could gain some reputational benefits because of collaborations with established academic institutions (OSC9). Otherwise, the benefits discussed were academia focused.

5. Conclusions

The proposed conceptual model allowed to gain a deeper understanding of how Open Science initiatives work and provided a basic, open analytical grid for data synthesis through ecosystem heuristics. Based on the results of evaluation, it can be concluded that Open Science landscape is highly heterogenous, fragmented and not fully coordinated. The fragmentation appeared in all dimensions of evaluation. The analysis of the framework conditions indicated a clear need for political commitment and regulation. The analyzed ecosystem of 33 Open Science initiatives currently lacks an enabling environment for actors to engage in co-creation activities. The analysis of system conditions showcases limitations on part of common vision, clear communication and intermediaries. The outcomes of analyzed initiatives are mostly academia-centric and do not consider potential added-value for other Quadruple Helix groups. This is largely in line with findings from previous literature. For example, the 2020 UNESCO multi-stakeholder consultation on Open Science concluded that the Open Science policy system is fragmented and appears to be a collection established by individual universities and research funding agencies (UNESCO, 2020). However, the case-based findings allow to pin down the specific aspects of Open Science implementation which need to be refined.

This paper extends knowledge on co-creation in research and innovation systems by conceptualizing the phenomenon. First, the paper captures the conceptual essence of Open Science and co-creation. Second, the paper integrates the research to capture the multiple dimensions of the concepts and adapts it to conceptual framework. Third, the proposed conceptual framework is applied in analysis of Open Science case studies. Hence, from a scientific point of view, the research contributes to the literature by deconstructing the social rather than technological links in Open Science development. The proposed framework underlines the importance of evaluation of the collective actions by multiple stakeholders in creating innovations. The conceptual framework offers a first exploratory step in proposing measures to determine the elements of co-creation practices within Open Science context. The study provides insights for the exploration of the co-creation of social innovation and settles research agenda for further studies.

The practical implication of the analysis is the provision of evaluation tool leading to the insights for policy-makers on how to facilitate co-creation of social innovations through Open Science measures. Open Science is a rapidly expanding and diversifying field of social innovation with significant implications for and potential benefits to society, policy and various academic research areas. In facing global challenges, the scientific knowledge development needs to leverage strength of different stakeholder groups and to find new ways to control the influx of information. Society is currently facing grand challenges which are complex, interconnected and multidisciplinary. The solutions to such problems are almost impossible without the active and direct participation of actors of society. Effective measurement and management of the co-creation processes in Open Science would strengthen the confidence of the public in the science system and enable collective problem-solving in multiple contexts.

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