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Developing a knowledge ecosystem for large-scale research infrastructure

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Abstract
Large-scale research infrastructures (RIs), such as MAX IV and European Spallation Source in Lund, Sweden, are considered critical for advancing science and addressing social challenges. These research facilities are central to research, innovation, and education; in playing a key role in developing and disseminating knowledge and technology. In this study, we develop a conceptual framework of a knowledge ecosystem for large-scale RIs. The study is explorative, with primary data from 13 interviews with key informants from different stakeholders in academia, industry, and policy. Secondary data were obtained from reports from national agencies that develop and operate research facilities and from industrial and regional governmental reports, internal reports, newsletters, and information from the facilities' websites. We find that academia, industry, and policy, together with four themes, have an effect on the value proposition of these facilities, on geographical distances (nodes), catalysts, platforms, and hubs. Therefore, they will affect the structure and design of a knowledge ecosystem. Our framework explains knowledge ecosystem structure and design.

Keywords Research infrastructures · Knowledge ecosystems · Technological change · Policy · Innovation systems · Entrepreneurial environments

JEL Classification O25 · O32 · O38

1 Introduction

Large-scale research infrastructure (RI) is considered critical for advancing scientific research and addressing challenges (ESFRI, 2010). However, the social and economic benefits of scientific research are little known (Gutleber, 2021), take longer to materialise, and are more difficult to substantiate (Martin & Tang, 2007). Nevertheless, the large-scale RIs have enormous potential, and considerable attention in the literature has been paid to the impact of research

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on innovation and economic consequences. Scientifically advanced and accessible RIs are central in research, education and innovation and RIs play a key role in advancing, exploiting, and disseminating knowledge and technology (Beck & Charitos, 2021; Marcon & Ribeiro, 2021). Furthermore, large research facilities can only be realised through multinational collaboration and public support. Mobilising such large resources involves negotiation between various actors (Autio et al., 1996, 2004) in also creating common interests and collaborations. A research facility is valued and defined in interaction with its environment (Horlings et al., 2012). Utilisation and the development of research facilities depend on other compatible resources (Carayol & Matt, 2004). Advanced technologies embedded in a research facility can only be used effectively if there are sufficient researchers with the right skills (Horlings et al., 2012). Therefore, a new facility sets pressure on its institutional environment and encourages researchers to consider partners with complementary skills and talent.

The literature is scarce regarding the economic and social impacts of large-scale RIs (Horlings et al., 2012). Impacts of large-scale RIs has mainly concentrated on innovation and social network formation around CERN (the European Organisation for Nuclear Research) regarding advanced technology and the dynamic nature of CERN. To analyse CERN, Autio et al. (1996) propose a framework in which the motivations of the three main groups of actors that collaborate in a large research facility—academia, government, and industry—are compared. It is argued that measurable incentives constitute only a fraction of the overall benefits stemming from the industrial-scientific collaboration. In our study, there are three perspectives and four themes where these themes are more focused on research and infrastructure, university and industry collaboration and on the policy perspective. There has been little research regarding the non-scientific impacts of large-scale RIs. However, there have been a few studies regarding policy and more studies about collaborative projects within large-scale RIs (MacEachren et al., 2006; Schissel, 2006; Zuijdam et al., 2011). The recommendations made by the European Strategy Forum on Research Infrastructures, ESFRI (2018), have drawn the attention of various stakeholders interested in strengthening relations between research facilities and industry.

Regional innovation ecosystems are built using several intermediary mechanisms or space-based organisations, such as science parks and incubators, creating a vital nurturing environment to support new firms (Stam, 2015). Several studies have analysed knowledge ecosystems and how to organise and coordinate these systems (Clarysse et al., 2014; Järvi et al., 2018; Leten et al., 2013; Ritala et al., 2013; Rohrbeck et al., 2009; Still et al., 2014). Others have focused on the role of firms (Leten et al., 2013; Lingens et al., 2021; Ritala et al., 2013; Rohrbeck et al., 2009). In knowledge ecosystems, stakeholders such as universities, public and private research institutions, and industrial firms must collaborate (Clarysse et al., 2014; Valkokari, 2015; van der Borgh et al., 2012). These systems can be formed around technological and societal challenges in a certain geographical area where different stakeholders are co-located (Dougherty & Dunne, 2011; van der Borgh et al., 2012). Clarysse et al. (2014) finds that knowledge ecosystems can be important to solve basic and applied research problems and can result in a more efficient search for new knowledge (Clarysse et al., 2014; Franzoni & Sauermann, 2014; Perkmann & Schildt, 2015). The organisation of knowledge production is becoming more heterogeneous in terms of the nature and expertise of the parties involved (Hessels & van Lente, 2008).

However, Lingens et al. (2021) posit that many studies on ecosystem design are conceptual, suggesting a high level of abstraction and lack of knowledge of how ecosystems are designed (Adner, 2017; Kapoor & Lee, 2013). Several scholars have focused on university entrepreneurship, large industrial firms, and the development of small high-tech firms. Therefore, research has extensively highlighted the role of focal firms, while giving less attention to other stakeholders such as governments, research institutes, and policy-makers, which means that several central actors are analysed as complements. Research is lacking on comprehensive stakeholders' perspective of handling the innovation and entrepreneurial challenges to analyse the complexity of knowledge ecosystems, including large-scale RI. Thus, this study will focus on different stakeholders at the system level to advance innovation and entrepreneurship and complex challenges regarding RIs. The understanding of knowledge ecosystems can thus be further developed. Our analysis will include three different perspectives: academia, industry, and policy-making. A deeper understanding of the driving forces of academia and industry is crucial when considering RIs, such as MAX IV and European Spallation Source (ESS) outside Lund in Sweden, and building a knowledge ecosystem enhancing socio-economic value creation. In this paper we propose, based on the study, initial essential assets to be developed in establishing knowledge ecosystems, including stakeholders' perspectives on the four themes: research and infrastructure, industry utilisation and involvement, university-industry collaboration, and education. Therefore, we will consider three different perspectives: academia, industry, and policy.

Aiming to determine the factors needed in creating a knowledge ecosystem in the emerging unique RIs: MAX IV and ESS, this paper seeks to enhance the understanding how innovation and entrepreneurship, which may capture the value of the research in those facilities. We will focus on aspects of importance from different stakeholders in establishing a fruitful environment around large-scale RIs to provide support in driving a socio-economic impact of the research infrastructures and exemplifying it with a case based on MAX IV and ESS. These infrastructures are investments in large state-of-the-art research facilities. MAX IV is the next-generation synchrotron radiation facility, and ESS includes the most powerful linear proton accelerator and is expected to be the world's most powerful neutron source. Thus, our study explores the conditions for creating an innovative and entrepreneurial environment around MAX IV and ESS. The research question can be formulated as:

RQ How to develop the research infrastructures MAX IV and ESS in a knowledge ecosystem that drives innovation and entrepreneurship?

Our findings contribute to the ecosystem and RI literature in several ways. (i) It will provide three different perspectives (academia, industry, and policy) on what is important in building a knowledge ecosystem around large-scale RI. (ii) It will provide four themes and perspectives considered highly relevant in establishing MAX IV and ESS. (iii) Finally, we show how stakeholders participate in building a forthcoming knowledge ecosystem and the coordination of activities supporting knowledge creation. The rest of this paper is organised as follows. Section 2 reviews the literature, while Sect. 3 describes the data collection methods. Section 4 presents the empirical results, and Sect. 5 discusses the results and finally, Sect. 6 presents the conclusions and limitations.

2 Literature review

2.1 Large-scale RIs

Large-scale RIs are crucial to advancing science across several scientific domains and can perform pioneering experiments. Coughlan et al. (2016) categorised RIs as follows: (i) university RI, which is linked to a country and utilised for both research and education;

(ii) campuses, which are hubs for special research and collaboration with industry; (iii) corporate large-scale RIs, which are large strategic partnerships; (iv) specialised RIs at research institutes, which are independent institutes undertaking multi-disciplinary research; (v) national facilities, called 'equipment of excellence'; and (vi) international facilities, founded by several countries or organisations. A classification of the economic impacts of research facilities involves: (1) procurement (2) technology/knowledge transfer including spin-offs, and (3) industrial use (Hallonsten, 2016). Hallonsten and Christensson (2017) underpinned the importance of maintaining a holistic view of impact and study Secondary effects are likely to appear, because suppliers of products and services in the high-tech sector seem to undergo significant learning as part of the procurement processes, which enhance their learning (Autio et al., 2004; Schmied, 1982). One primary issue faced in scientific research is the generation of social and economic impacts. There has been a debate regarding the difference between the social and economic impacts of public and private scientific research and fundamental and applied scientific research (Dasgupta & David, 1994). The organisation of knowledge production is becoming more heterogeneous in terms of the nature and expertise of the parties involved (Hessels & van Lente, 2008).

The recommendations made by the European Strategy Forum on Research Infrastructures (ESFRI, 2018) have attracted drawn the attention of various stakeholders interested in strengthening relations between research facilities and industry. These stakeholders must pay attention to 'the operational performance, the scientific excellence and the quality of the services delivered as a prerequisite for attracting users, and ultimately [ensure] the structural and legal sustainability of the facilities' (ESFRI, 2018, p. 124). In the past 10 years, academics, managers, and policy-makers have been increasingly acknowledging the entrepreneurial character of regional innovation ecosystems (Stam, 2015). Such ecosystems are built using several intermediary mechanisms or space-based organisations, such as science parks and incubators, creating a vital nurturing environment to support new firms. One of the ecosystems' assumptions is that those will act as an intermediate infrastructure to bridge gaps between universities and industry and an entrepreneurial environment.

2.2 Innovation, entrepreneurial, and knowledge ecosystems

The ecosystem concept as a beneficial environment has been developed from earlier work on industrial districts (Becattini, 1979) over the years. The concepts have dispersed, resulting in several concepts such as innovation ecosystems, platform or technology ecosystems, service ecosystems and entrepreneurial ecosystems (Akaka et al., 2013; Almpanopoulou, et al., 2019; Autio et al., 2018; Ceccagnoli et al., 2012; Wareham et al., 2014). The concepts 'entrepreneurial ecosystems' and 'innovation ecosystems' are studied across different research areas in business and policy (Aarikka-Stenroos & Ritala, 2017; Ansari et al., 2016; Autio et al., 2018; Clarysse et al., 2014; Granstrand & Holgersson, 2020; Helfat & Raubitscheck, 2018; Kshetri, 2014; Zahra & Nambisan, 2011, 2012).

The concepts 'entrepreneurial ecosystems' and 'innovation ecosystems' are increasingly and widely studied in research areas such as management, policy, economic geography, and marketing and from a conceptual view (Adner, 2017; Autio et al., 2018; Clarysse et al., 2014; Ganco et al, 2020; Gu et al., 2021; Jacobides et al., 2018; Stam, 2015; Tsujimoto et al., 2017). Valkokari (2015) distinguishes three different ecosystems: business, innovation, and knowledge ecosystems, to describe the meta-organisations between actors. Valkokari (2015) describes these ecosystems as: (i) the literature of business ecosystems as well as service or industrial ecosystems, in which the economic outcomes and business relationships between different actors are in focus; (ii) innovation ecosystems and regional clusters that give special attention to policies fostering the creation of innovative new high-tech firms around regional hubs or clusters, and (iii) knowledge ecosystems that focus on the creation of new knowledge through joint research work, and collaboration.

An entrepreneurial ecosystem aims to nurture economic development by promoting entrepreneurship through innovative startups (Feld, 2012; Malecki, 2011; Mazzarol, 2014; Spigel, 2017; Zacharakis et al., 2003). Several scholars use the network approach, which includes collaboration with the environment, while some underline leadership or policy orientation (Habbershon, 2006; Teece, 2007; Shepherd & Patzelt, 2011; van der Borgh et al., 2012; Zahra & Nambisan, 2012; Ben Letaifa & Rabeau, 2013; Maia & Claro, 2013; Overholm, 2015; Zander et al., 2015). Etzkowitz and Klofsten (2005) state that ecosystems can develop gradually, evolve from an existing knowledge base, or emerge as a new system that comprise an interplay between academic, public, and private actors. The increasing diversity of conceptual and empirical applications creates not only a challenge but also an opportunity for ecosystem scholars.

Altman and Bourg (2018) identified six challenges for creating a scholarly ecosystem that must build on integrity and trust in an increasingly politicised climate. Hardwicke et al. (2020) and Maron et al. (2019) refer to ecosystems on the global impacts and interconnected networks of scholarships or ecosystems. Lingens et al. (2021) are among the first scholars to apply the attention-based view to business ecosystems and explain which ecosystems are suitable under certain conditions. Lingens et al. (2021) claim that most of the publications regarding ecosystem design are conceptual and hence have few empirical contributions (Brusoni & Prencipe, 2013; Teece, 2007; Williamson & de Meyer, 2012).

Quinn et al. (1998) claim that the main outcome of a knowledge ecosystem is new knowledge, and it could be shaped by setting the network nodes. In this area, open-source communities are examples of this type of ecosystem based on knowledge exchange, and research highlights how co-location can mean virtual proximity between the actors (Coughlan, 2014; Koenig, 2012). An innovation ecosystem includes fostering growth, interaction, and startups around knowledge hubs where the financial network has been found to be important (Clarysse et al., 2014; Engel & Del-Palacio, 2011). Chang and Tan (2013) describe the ecosystem as individualised information enriched through learning and then applied to practical situations. They propose knowledge management strategies to strengthen the relationships among the components interacting within each organisational ecosystem. Jones-Evans (1996) and Klofsten and Jones-Evans (1996) argue that firms with a competence structure primarily based on technology tend to underperform compared to firms that have a more mixed knowledge of operating business and technology. One main issue in science is to generate social and economic impacts. There has been a debate regarding the social and economic impacts of science between public and private research and between fundamental and applied research (Dasgupta & David, 1994).

Almpanopoulou et al. (2019) states that the knowledge ecosystem literature is based on the broader ecosystem literature. Clarysse et al. (2014) define knowledge ecosystems as 'where local universities and public research organizations play a central role in advancing technological innovation within the system' (p. 3). Almpanopoulou et al. (2019) states that it is important to distinguish between knowledge and innovation ecosystems. Innovation ecosystems have a broader task of exploration and exploitation (Autio & Thomas, 2014). Almpanopoulou et al. (2019) claims that the concept of a knowledge ecosystem narrowly focuses on early knowledge creation and search. Several actors create new knowledge in a pre-competitive setting (Clarysse et al., 2014; Valkokari, 2015). Knowledge ecosystems aim to create knowledge collaboratively. The broader ecosystem literature has mainly focused on collaboration and can be developed with the help of focal actors (Autio & Thomas, 2018; Dattée et al., 2018; Poblete et al., 2022). Bagchi (2021) claims that knowledge organisation ecosystems are becoming functionally ineffective components for knowledge-based artificial intelligence systems because of their inability to capture the continuous factorisation.

Moore (1993, 1996) has introduced the concept of business ecosystems involving the firm and its stakeholders, thus indicating the importance of stakeholders for the science park facility (Rowley, 1997), and leading to a model of resource relationships. In addition to the resource-sharing perspective, Hoffmann and Giones (2019) discuss the distinctive aspect of innovation and entrepreneurial ecosystems. They imply that ecosystems are not limited to a region and that the market demand is likely to drive technological evolution and structural changes. These contrasting elements differentiate ecosystems from clusters or regional innovation systems (Ritala & Almpanopoulou, 2017). This underlines an important advantage of science parks: offering services that firms internally find difficult to provide. The ecosystems in which science parks operate normally support organisations active in private, academic, public, and civil society sectors (Albahari et al., 2019).

2.3 Regional innovation systems and science parks

Regional innovation systems, science parks and clusters are also discussed within the concepts of innovation, entrepreneurial or knowledge ecosystems. Industrial clusters focuses on the competitive advantage at the regional level. Theeranattapong et al. (2021) claim that regional innovation systems show an interconnected context and structure ‘defined in terms of both actors and dynamics within the local innovation ecosystem’ (p. 3). Asheim and Isaksen (2002), Gerstlberger (2004), Takeda et al. (2008), and Zhang (2015) underline the importance of innovative local agencies, science parks, and other infrastructure providers. Theeranattapong et al. (2021) claim that in the literature in both research innovation systems and science parks, universities play a crucial role because they form a key component in research innovation systems.

The fundamental idea behind the concept of a cluster is locality or regionalism and how different actors can benefit from these clusters (Almeida & Kogut, 1999; Peltonimei & Vuori, 2004; Clarysse et al., 2014; Coughlan, 2014). The literature on science parks has focused on increased innovation and entrepreneurship for the localised high-tech firms and the environment. These studies have a different focus, such as the growth of localised firms in high-tech sectors, technology transfer, and collaboration with universities or research institutes. There are some expectations that localised firms will collaborate with public research organisations. There is a substantial literature on R&D performance and collaboration, technology transfer and knowledge spillovers (e.g. Adams, 2004; Archibugi & Coco, 2004; Arranz & de Arroyabe, 2008; Audretsch et al., 2005; Bozeman, 2000; Djokovic & Souitaris, 2008; Henderson, 2007) and the effects of science parks (Cadorin et al., 2021; Lindelöf & Löfsten, 2004, 2006; Link & Scott, 2003; Löfsten & Lindelöf, 2001, 2002, 2003, 2005; Löfsten et al., 2020; Phan et al., 2005; Siegel et al., 2003). Link and Scott (2020) found that 79% of the increase in scientific publications per unit of scientific personnel is explained by an increase in federal R&D capital per unit of scientific personnel. The researchers claim that the unexplained 21% measures creativity-enhancing technology change.

One important benefit for localised science park firms is an enhanced reputation rather than increased levels of innovation. When a science park is attracting new firms in an area, secondary business opportunities will also increase, in the form of technical expertise, suppliers, and new business partners. In some circumstances, a cluster of firms or industrial districts will attract more firms. A public research institute does not necessarily play an important role. Squicciarini (2009) analyses the role of science parks as seedbeds of innovation. The study aims to verify the extent to which firms' innovative performance is affected by relocating inside a science park. Examples of governments and regions using science parks to help restructure and stimulate an innovative economy abound, as is evident in Taiwan (Tsai et al., 2007). In Sweden, Hommen et al. (2006) identified the important role of university education and its innovation infrastructure, such as science parks, in developing regional entrepreneurship ecosystems. Considerable resources are provided to science parks as policy instruments for promoting research-based innovative and industrial activities (Löfsten & Lindelöf, 2002).

The literature in this study is mainly related to innovation, social and economic impacts of large-scale RIs, innovation and entrepreneurial ecosystems, and knowledge ecosystems, where science parks may be a driving force. Ritala and Gustafsson (2018) emphasise that forthcoming research should integrate ecosystem research into existing research streams, which would help in empirical research design and shed light on the ecosystem concept. It is the same challenge and opportunity for ecosystem scholars, with many scholars committed (Autio & Thomas, 2014; Tsujimoto et al., 2017). Although recent interest in ecosystems amongst academic researchers is driven by its popularity with policy-makers and entrepreneurs, it is, however, part of a larger trend in innovation and entrepreneurship studies. Several different actor perspectives are involved in developing a knowledge ecosystem around these large-scale research facilities, such as the academic perspective, the industrial perspective, and the policy perspective. The perspectives are relevant to managers, researchers, entrepreneurs, and policy-makers.

3 Method and data

3.1 Qualitative investigations

We chose an exploratory qualitative research design to explore the drivers and needs to create a knowledge ecosystem around the emerging unique RIs of ESS and MAX IV that may effectively capture the value of the research (Eisenhardt, 1989; Silverman, 2013; Yin, 2018). A single case study (Dyer & Wilkins, 1991; Ridder, 2017) further seemed relevant to function as a critical case (Yin, 2018), which is considered a powerful example (Siggelkow, 2007). In addition, critical cases are useful for developing an existing theory; they identify gaps and provide recommendations for further research (Siggelkow, 2007; Yin, 2018).

The study has been carried out in real-time (Miles & Huberman, 1994) in the early phase of planning and building a knowledge ecosystem around the facilities. We wanted to grasp the ideas and understandings of important factors from different stakeholders in this early stage. Although a single case has potential limitations, such as the lack of external validity of the results, it is an accepted approach in social sciences. Flyvbjerg (2006, p. 242) notes a citation from Kuhn (1987): 'A discipline without a large number of thoroughly executed case studies is a discipline without systematic production of exemplars, and a discipline without exemplars is an ineffective one.'

3.2 MAX IV and ESS in Sweden

MAX IV and the ESS will be two of the most advanced research facilities in their fields globally. MAX IV, inaugurated in June 2016, is the world's most powerful synchrotron radiation facility and its accelerators produce high-quality x-rays, enabling its researchers to see what has previously been invisible. Once completed, the laboratory will accommodate more than 2000 researchers from material science, structural biology, chemistry, and nanotechnology. ESS is a research facility based on the world's most powerful neutron source. The facility, likened to a giant microscope, receives funding from 13 countries and is expected to host 2000–3000 researchers annually.[1] The ESS is one of the largest science and technology infrastructure projects being built today.

MAX IV and ESS complement each other because they can create important synergistic effects and can create an interesting research environment in Lund. They can also provide a hub in Europe's RIs. ESS is, to a large extent, built through in-kind contributions from the 13 founding member states in the form of technical equipment, personnel and support services provided by over 40 partners in Europe. This comes with an issue to evaluate the performance of these high-tech research facilities because the facilities will provide opportunities for researchers in universities, institutes, and industrial firms. Like the earlier MAX labs, MAX IV will remain a part of Lund University. RIs in research and innovation policy are increasingly becoming important in industrialised nations. The basic characteristics of the case are listed in Table 1.

Our main focus is on several impact areas found in roadmaps for large-scale RIs. These include promoting innovation and entrepreneurship in the public and private sectors, attracting researchers from Sweden and abroad, retaining domestic talent for science, forming a focal point for collaboration among a multitude of actors, and generating synergy among the producers of knowledge in research, business, and education.

3.3 Data collection

Both primary and secondary data have been included in this study. To achieve a deeper understanding of relevant issues and challenges related to the two research facilities and guide the interview study design, we collected and analysed available published reports from various stakeholders and agencies. These secondary data include reports from national agencies responsible for developing and operating the research facilities, industrial and regional governmental reports, and national government reports and analyses. Table 2 shows the type of reports included in data collection. The secondary data were analysed and then used to design the interview study, identifying relevant aspects, actors, and respondents. Further, it was also used as input to design the interview guide.

The primary data were collected through semi-structured in-depth interviews (Fontana & Frey, 2000; Kvale, 1996), with key informants having the understanding and knowledge about RIs of the kind that MAX IV and ESS are representing. The interviewees were selected from those involved in academia, industry, and policy, identified from documentation and reports, different associations and collaborative networks, universities, and agencies involved in MAX IV and ESS. They were selected from different settings from the regional level, the national level (research), firm level, engineering firm organisations,

[1] https://www.lund.se/en/brunnshog/about/project-phases/max-iv-and-ess/.

Table 1 Characteristics MAX IV and ESS

MAX IV	ESS
Description	*Description*
MAX IV is a Swedish national laboratory providing scientists and industry with the X-rays for research. MAX IV is home to research projects in biology, physics, chemistry and environmental science, as well as geology, engineering, pharmacology and cultural heritage.[a]	The facility's unique capabilities will both exceed and complement those of today's leading neutron sources, enabling new opportunities for researchers across the spectrum of scientific discovery, including materials and life sciences, energy, environmental technology, cultural heritage and fundamental physics.[b]
Governance and funding	*Governance and funding*
MAX IV Laboratory is a Swedish national laboratory, hosted by Lund University where Lund University is the legal entity of the laboratory. The formal goals and basic governance of MAX IV Laboratory were set out in an agreement between Lund University, the Swedish Research Council and the Swedish Governmental Agency for Innovation Systems in June 2010 as well as in a related agreement between Lund University and Region Skåne in July 2010. The Swedish Research Council, Swedish Governmental Agency for Innovation Systems, Lund University and Region Skåne are the initial funders of MAX IV.[a]	The ESS is a pan-European project with 13 European nations as members, including the host nations Sweden and Denmark. The ESS facility is under construction in Lund, while the ESS Data Management and Software Centre is located in Copenhagen, Denmark. Around 2000–3000 guest researchers will carry out experiments at ESS each year. Most of the users will be based at European universities and institutes, others within industry.[b]
Vision of the facilities	*Vision of the facilities*
”These X-rays will be used to understand, explain and improve the world around us. They will enable the study of materials that we use today and improve them beyond the performance that we know. In addition, MAX IV will allow scientists to develop new materials and products that we cannot even imagine today, such as medications with better and more precise functions and fewer side-effects, nanoparticles for diverse areas of application, including paints, catalysis or computing, or lighter and stronger packaging materials for the future”.[a]	”Our vision is to build and operate the world's most powerful neutron source, enabling scientific breakthroughs in research related to materials, energy, health and the environment, and addressing some of the most important societal challenges of our time”.[b]

[a] https://www.maxiv.lu.se

[b] https://europeanspallationsource.se

Table 2 Types of reports included in the data collection

Type of published reports	Nr of reports	Year	Focus
National and regional government	6	2010–2018	Regional development, competence
National research funding agencies	4	2018–2021	Research utilisation in academia and industry
Industry agencies	4	2020–2021	Research utilisation in industry and competitiveness
Universities and institutes	3	2017–2019	Research utilisation in academia and industry

Table 3 Interviewed respondents

Id nr	Category	Position	Major perspectives
9	Academia	Researcher & Director	Academic & Infrastructure
10	Academia	Director	Industry & University
13	Academia	Director	Industry & University
12	Academia	Researcher & Director	Academic & Infrastructure
7	Academia	Director	Industry & Infrastructure
8	Industry	CEO	Industry &Infrastructure
11	Industry	Senior manager	Industry & University
1	Industry	Senior manager	Industry & Utilisation
5	Industry	Ind. association	Industry & Utilisation
4	Industry	Ind. association	Industry & Utilisation
2	Policy	Manager Regional dev	University & Utilisation
3	Policy	Manager Regional dev	University & Utilisation
6	Policy	Research fund. agency	Academic & Infrastructure

people from Science Village and Science Centre in Lund, MAX IV and ESS. Table 3 shows the actors and perspectives included by the interviewees.

A case study protocol was developed, laying out the questions and describing the respondents' field procedures. The 13 in-depth semi-structured interviews were carried out in either face-to-face meetings or via conference calls, mainly restricted by the 2020–2021 pandemic situation. All interviews lasted between 60 and 75 min and followed the semi-structured interview guide (see Appendix, Table 8). The interviewees were guaranteed anonymity and all the interviews were recorded and transcribed. Notes were also taken during the interviews, and there were two persons attending the interviews: one person leading the interview and the other taking notes or capturing details. All data were stored according to the guidelines outlined by Yin (2018) in a case study database.

3.4 Definition of a knowledge ecosystem and the interview guide

In the ecosystem field it´s crucial to differentiate between innovation and knowledge ecosystems where innovation ecosystems have a more comprehensive task of exploration and exploitation (Autio & Thomas, 2014). In this context, the concept of knowledge ecosystem especially focus on early knowledge creation and search where different actors create new knowledge in a pre-competitive setting (Almpanopoulou et al., 2019; Clarysse, et al., 2014; Valkokari, 2015). The main purpose of knowledge ecosystems is therefore to create new knowledge collaboratively and this collaboration can be developed by different focal actors (Autio & Thomas, 2018; Dattée et al., 2018; Poblete et al., 2022; van der Borgh et al., 2012).

In innovation, entrepreneurship and business there are several partially overlapping ecosystem concepts to describe and analyse the meta-organizations between different stakeholders. However, in a knowledge ecosystem, the distance and suitability between problems and knowledge is important. The definition of a knowledge ecosystem in this study can be formulated as the interest in *creation of new knowledge through research collaboration and development of a knowledge platform where the network nodes are crucial for knowledge creation, exploration and dissemination.* It is in this context important with stakeholders grouped around knowledge exchange, knowledge nodes, research institutes and universities and the high-tech industry. Knowledge ecosystems therefore emphasise new knowledge where research institutes, universities and entrepreneurs in technology plays important roles in these ecosystems.

The interview guide (see "Appendix") is semi-structured and developed according to the knowledge ecosystem concept where the stakeholders in knowledge ecosystems, such as universities, private and public research institutions and industrial firms have to collaborate: (i) Knowledge dissemination and exploitation of the facilities in creating competitiveness and innovation (ii) Research facilities' relevance for the industry and business and (iii) About the environment. The interview guide is developed according to the different views from stakeholders such as academia, industry and policy. The knowledge ecosystem is formed around technological challenges in a special geographical area where these different stakeholders are located (Dougherty & Dunne, 2011) where one of the main objectives is to solve basic and also applied research problems and hopefully result in a more efficient search of knowledge and knowledge dissemination.

3.5 Data analysis

We approached the data analysis in multiple ways. Following an abductive qualitative research approach, moving back and forth between data and theory (Dubois & Gadde, 2014), the analysis built on the concepts of research and infrastructure, industry utilisation and involvement, university-industry collaboration, and education. The analysis was data-driven, and the empirical material was organised into meaningful groups, forming the basis of the coding scheme. The codes were collated into broader themes and then reviewed to consolidate and identify the most salient themes relevant to the research question (Silverman, 2013). Next, the themes were labelled and refined by returning to the literature.

To ensure the validity and quality of the analysis, we performed two types of triangulation (Denzin & Lincoln, 2008): (a) method triangulation, where field material compiled from different types of sources was compared to ensure the consistency of findings using different data collection methods, and (b) data triangulation, where the empirical material collected from different people from different sets of actors around the same phenomenon was compared. Here, we analysed different sets of empirical material separately. Through triangulation, conclusions are likely to be more reliable (Denzin & Lincoln, 2008).

3.6 Perspectives and themes

As depicted in the case description, the plans and decision for establishing the two RIs also included buildings for research support, offices for industrial actors, including intermediating companies, and a science park function. While a strong focus has been on each of the RIs in building, financing, and operating them, the area for collaborations, innovation, and support has not yet been given the same attention. However, the focus on the area between the facilities has increased, as MAX IV is already in operation and ESS is halfway through the building phase and plans to be fully operational by the end of 2027. From reports, documentations, and investigations, there are many views on different needs related to using the infrastructures for research and using the data and results from tests. Several actors interested in the facilities and their surrounding milieu are engaged in the discussions in reports and investigations. As seen in Fig. 1 and the literature in Sect. 2, the actors represent three groups: academia, industry, and policy. Figure 1 illustrates the chosen actor perspectives and the themes that emerged from data analysis performed in this study.

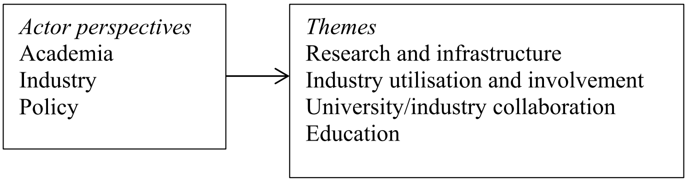

Fig. 1 Perspectives and themes

The interviewees in our study were selected from different settings from the regional level, national level (research), firm level, engineering firm organisations, and from Science Village and Science Centre in Lund. Therefore, we used this set of representatives when structuring the data from interviews. The four themes that emerged were the ones that all three sets of actors put forward as being of high relevance in establishing MAX IV and ESS: (i) research and infrastructure (ii) industry utilisation and involvement (iii) university-industry collaboration and (iv) education. In the section below, tables are presented for each theme where characteristic citations are brought in from the three perspectives, showing typical aspects brought forward by respondents for the different sets of actors.

4 Empirical findings

4.1 Background

Sweden has a strong research tradition and was even involved in founding the CERN after World War II. However, Sweden has no experience of, or background in, driving technological development by way of large facilities and thereby creating such ecosystems. Nonetheless, the Max-lab (MAX I) was founded in 1986 and the second and third facilities, MAX II and MAX III, founded in 1996 and 2007, respectively. Region Skåne met industrial firms and conducted study visits to MAX I, II, and III, which already existed in Lund, together with several firms. In 2009, Lund University, the Swedish Research Council, Region Skåne, and Sweden's Innovation Agency decided to finance the construction of MAX IV. Problems were faced due to multiplicity of vision, and because proceeding in practice was difficult. However, many actors, people and organisations were involved in the process and expressed several thoughts and ideas about what to do; however, there was no clear strategy from the owners. The Swedish Research Council will hold the entire initiative together in the two RIs MAX IV and ESS, with both academia and industry. Research Institutes of Sweden (RISE) works with Sweden's Innovation Agency to connect academics with the industry in consideration of methods to collaborate. They also try to establish collaboration between industrial and academic research; however, metal and engineering industries do not enjoy the same degree of maturity of research collaboration as do the life sciences.

The Ministry of Trade and Industry and the Ministry of Education were also involved in gaining a national understanding of the issues. They discussed not only the focus of research, but also the return on investment. Other role models were, for example, the CERN. When Sweden as a nation invests money in research facilities, an important question for the Ministry of Education is how Sweden will benefit from the facilities. It is critical to be able to look at the whole picture, that is, everything from innovation to the facilities, and innovations that are linked to firms that will deliver, develop, and maintain new technology. Further, it is critical to consider opportunities for increasing exports.

Swedish Governmental Agency for Innovation Systems received an assignment from the Swedish government to manage the Swedish industrial office function around MAX IV, ESS and CERN, which Big Science Sweden also works with. A feasibility study was initiated with Region Skåne in Sweden and several key universities, such as Chalmers University of Technology, Lund University, Uppsala University, Luleå University of Technology, were identified, as well as RISE and the Association of Swedish Engineering Industries. One possibility is of course to encourage cooperation across national borders, as experienced by such facilities in other countries, such as the UK.

Big Science Sweden has collected and documented the ideas of approximately 400 members of the Association of Swedish Engineering Industries. These could be incorporated into some form of a collaborative development with MAX IV and ESS, and also be developed into solutions that are then sold on the global market. Of the 4,200 members of the Association of Swedish Engineering Industries, who are active in the manufacturing industry, 400 of them were directly or indirectly affected by MAX IV and ESS. Therefore, the question is how the industry organisation of the Association of Swedish Engineering Industries should address such an issue. There are quite a few interfaces where the Association of Swedish Engineering Industries can help, in addition to sending out emails and newsletters and making information available on its website.

However, the fact that 400 industrial firms may have an interest in these large research facilities and in Big Science, has led the organisation to consider what role it might play in the same. However, there is a dearth of a secure structure with a long-term organisation, or financing with a strategic focus. Big Science Sweden was created to invest in the facilities, and it allows Sweden some return on investment, as the facilities are a fantastic opportunity. Big Science Sweden employs operational staff throughout Sweden and has undertaken a transnational assignment; it collaborates with universities and the Swedish industry and assumes a special role relating to knowledge transfer.

4.2 Research and infrastructure

The focus on research in the labs of MAX IV and ESS depends on whether the users are pure academic researchers working at a university or in an industrial setting. Academic respondents' views regarding MAX IV and ESS were mostly concerned that the research conducted in the labs be of the highest standard in the views of academia on an international level. The risk of diluting the focus of the facilities is higher than that of having the facilities not being used enough. In contrast, concerns from industry and policy are articulated regarding the need for a more holistic perspective in the building and establishing phases to attract multiple actors to the area and sector. There is lack of a common vision or understanding of what those infrastructures and surroundings can become to society. This needs focus, including how to bring out the industrial and innovation perspective early on to attract industrial users to engage in the environment. The different views on research from the pure academic perspective versus how industry relates to basic research were expressed in the interviews (see Table 4).

The main advantage of large-scale RIs is that researchers can conduct pioneering experiments and link the facilities to a large network, and can consequently increase their observations. Another advantage of large-scale RIs is a better opportunity to perform multidisciplinary research. The use of the large-scale infrastructure as a platform for scientific

Table 4 Citations on aspects of *research and infrastructure* based on the perspectives of different actors

Actors	Research and infrastructure—illustrative aspects
Academia	Basically, we need to make sure that what these facilities are used for, is really outstanding research, whether it be of an academic nature, or in collaboration with the business community. Otherwise, they will become obsolete pretty soon. (interviewee 9) EMBL—the European Molecular Biology Lab is large and prestigious. Their head office is located in Heidelberg but they have "out-stations", or sites, in Grenoble, Hamburg and other places. For me, it is a given that they will also establish a branch in Lund. It is an actor that will attract much varied interest. Good researchers attract good companies, and it becomes interesting to be there. A holistic approach is needed to create this, because there are many things, many components that are needed. (interviewee 12)
Industry	These environments are about innovation with a fairly distant horizon, as it is about building a basic understanding of things that in turn could lead to possibly very interesting innovations at some point in the future. An important aspect then becomes the sharing of information and how it can be made readily accessible (interviewee 8) However, there is a certain impatience from the university, as there are many thoughts and ideas about what should be done, and it is not known why industry has not embraced this yet. Building properties in connection with MAX IV and ESS is not enough either. Other dimensions are needed for the facilities to be successful. There is a risk of being "dazzled" by the fantastic technology that the facilities have. Both MAX IV and ESS are basically two microscopes, which are very large and expensive, but the extra value lies in what these large microscopes can be used for. (interviewee 5)
Policy	The problem is that there is more than one vision, and how to proceed in practice is difficult. However, many actors, people and organizations are involved and have many thoughts and ideas about what to do, but there is no clear strategy from the owners and, additionally, no-one has clear responsibility. (interviewee 2)

collaboration and with various collaboration channels between academia and industry can be useful in developing innovation.

4.3 Industry utilisation and involvement

Based on the interviews, there is a strong common ground in the close links between academia and industry utilising the RIs. Respondents from both academia and industry believe it is highly important that it becomes more widely known what those research facilities are about and how the research and tests may contribute to a stronger interest from industry. Utilisation here is not only in the narrow aspect of individual industrial users researching in the labs but also in the wider context of being involved in research projects using the results. Academic respondents emphasised the importance of industrial involvement in academic research projects and advisory groups. In contrast, industrial participants indicated the importance of having the facilities open to industrial use and not only academic research projects (see Table 5).

Furthermore, it is important to communicate with the industry about what those facilities are and what kind of research can be done there. For now, what comes forward is that the industrial actors already participate in research and projects relevant to the facilities involved in the discussions. Extensive work needs to be done to increase the awareness and attract relevant industrial actors, as well as develop what industrial utilisation and involvement to have at the facilities. Here, it is highly relevant that research intermediaries be included.

Table 5 Citations on aspects of *industry utilisation and involvement* based on the perspectives of different actors

Actors	Industry utilisation and involvement—illustrative aspects
Academia	Linked to ESS, we have an "executive advisory board" that looks at how and in what way the business community can be involved and how to raise interest in the facility and what is relevant. Those involved companies are starting to grasp quite well now how they can look at this strategically. The communication challenge is to reach out to other actors, such as CTOs, in the business community, about what and how to use this type of facility. Not many people understand what can be done at these facilities. This has also been the case before at other facilities abroad but however needs to be addressed here. (interviewee 7)
	In the council of ESS, only Swedish companies and people have been involved so far. Of course the idea is to have a strong international representation in the future. Clear interests are seen from the UK, Germany, and Denmark. (interviewee 12)
	Ease of use is lacking, and when companies come to MAX IV they have to bring their own "toolbox". In some cases, there is not even any software prepared to evaluate the advanced and rather expensive experiments, where there are also different programs depending on which synchrotron is used, which makes the processes quite immature. (interviewee 13)
Industry	There are a number of companies in Sweden, such as Alfa Laval, SSAB, Gränges, Uddeholm and Höganäs, where there is already competence and an understanding and knowledge of the instruments employed at MAX IV. (interviewee 1)
	It is important that there are enough companies that understand what this is. We can take the example of Alfa Laval, which is a large global company, located in Lund. They have been doing advanced materials research for a long time through "Sandvik Com", and therefore have the knowledge to understand what this is about. Companies that come here need sufficient perspective to understand how to develop the company here. (interviewee 11)
Policy	One critical issue is how companies can have increased access to the facilities. There should be a structure in place to stimulate the use of the research facilities. Important pillars include inclusion, openness, the offering of a neutral space and the bringing together of a local ecosystem in the form of companies, academic and research institutes, and the increasing of the value of using the facilities. (interviewee 6)
	It is important to include assessments made by business and industry as to how the facilities can maximize availability. Sometimes companies come to the research facilities via the university, where research is collaborative, but it is important not to forget that there is also very advanced research conducted internally in companies, which have both industrial relevance and academic standing. (interviewee 3)

4.4 University and industry collaboration

To further develop how to conduct different types of research and tests in research facilities such as MAX IV and ESS, collaborations between academia and industry are highly important. Respondents have pointed to the need for more and advanced collaboration between industry and academia, where different aspects of basic research are brought forward as well as connected to more applied research. Even though many actors are used to collaborating, they see a need to have this developed further and to constantly enhance innovations in the different areas in the future (see Table 6). The openness for multiple universities and an environment supporting new forms of collaboration is also mentioned. Structures and processes inviting collaborations and developing a dynamic environment relevant to the RIs become crucial. Such processes and structures need to be managed and demand resources.

The use of the large-scale infrastructure as a platform for scientific and technological collaboration and with various collaboration channels between academia and industry can be useful in developing innovation. However, it is difficult to industrialise results

Table 6 Citations on aspects of *university and industry collaboration* based on the perspectives of different actors

Actors	University and industry collaboration—illustrative aspects
Academia	There is both academic and industrial utilisation. We collaborate differently. I think that the image has perhaps become a bit static and it is not clear how things should go. It does not happen that much. There are mostly many hopes that are linked to collaborative work, which are not clarified. (interviewee 13)
	In Sweden, there is an openness that one can take advantage of to develop a more innovative and entrepreneurial climate, and to obtain further exchanges, because one should be able to see, for example, that an environment is emerging around these labs. There are big beautiful houses and there are big signs on each house, lots of different names, looking fantastic, but there is not much to cooperate on. (interviewee 9)
	We have a culture of collaboration, we have the ability to bring together different competencies and we are not as hierarchical as in many other places. It is an important aspect that drives the development not only of facilities but what is done generally. Then we have the advantage of being able to act fairly quickly as a relatively small country. We are fast-footed and innovative. We have an innovation system that is attractive. (interviewee 10)
Industry	For industrial actors it requires a great understanding of the need, because it is not something that one quickly grasps and quick results. In fact the universities must be in place and be connected and have good cooperation at the facilities—not just Lund University, but several universities that are doing that kind of research. The pharmaceutical industry is a little closer there, but most other companies are quite distanced. (interviewee 1)
	There are already well-functioning collaborations around MAX IV and its test environments, where many of the universities are already involved and it is just a matter of scaling it up. It is the same if you now look at this nano lab that Lund University is building. Since then, Science Village has launched a platform together with MAX IV and ESS, called MAXESS Industry Arena, which focuses on the provision of information and how to move processes forward. It is still a digital platform, but it will become a physical reality sometime in the future. It is also one of the pillars that would fit well into the technology park function. (interviewee 11)
	A catalyst is needed to bring about a collaboration, and this applies not only to the functions around the facilities, but more than that, the bringing together of national and international perspectives through the development of a node structure. (interviewee 5)
Policy	There is also a contradiction between academic and industrial research, where academics should have as many publications as possible, which is rewarded within the university, while companies are run according to other reward mechanisms, such as good business and profits. These two different worlds can have difficulty communicating, regardless of industry such as life science, food or advanced materials in the manufacturing industry, and there are few people who belong to both worlds. (interviewee 2)
	For a technology park function, it is important not only to have a connection to seven national nodes, but also international connections. In this context, Big Science Sweden has a very large network in terms of deliveries to the facilities and various types of collaborations that have taken place in connection with the two facilities. Funding is an issue that is also unclear, where we need a long-term solution as this is different compared to what we have done before in Sweden. Big Science Sweden could have an operational, coordinating, catalysing and visible role, together with the nodes. (interviewee 3)

from academic labs when an industry has not been involved in it early. Collaboration opportunities between academia and industry can be fostered, including research and development of key technology prototypes, professional training, patenting and certification, and training. Academia and industry can also be associated in the evaluation of large-scale RIs and such efforts may stimulate the innovation potential of the large-scale RIs and the collaboration with the industry.

Table 7 Citations on aspects of *education* based on the perspectives of different actors

Actors	Education—illustrative aspects
Academia	After contact with study directors and various research groups, it has been established that a MAX IV- and ESS-led research school is wanted. However, it is not known whether their own universities or other universities provide relevant courses relative to the two large research facilities, and in fact it has also been agreed that not everyone should give the same courses, and that there should be different specialisations to provide wider learning opportunities. (interviewee 13)
Industry	The industrial companies collaborate not only with Swedish higher education institutions, but also with international higher education institutions, and the goal is to attract international higher education institutions to MAX IV and ESS. There is a great need to increase knowledge, which is usually done through education. (interviewee 11)
	In terms of education, we also need education related to the use of all data and results that is coming out of the research and tests in those facilities. Here I see the need for broader educational initiatives. All in all there are several needs related to education on different levels if we want to have increased participation from industry related to those facilities. (interviewee 4)
Policy	Education must be packaged in a customised format. It may be appropriate to use good examples in courses where good progress has been made, where research infrastructures have been important for development. (interviewee 6)
	With regards to higher education institutions, they need a clearer message about expectations regarding utilisation and also a clearer general strategic objective for what is expected of higher education institutions. Perhaps an unconditional dialogue should be established with the higher education institutions, rather than giving directives about what is expected. (interviewee 2)

4.5 Education

A large role for universities apart from research is education. With the establishment of MAX IV and ESS, specific knowledge areas will be advanced and require new educational offers. Doctoral schools and courses developed in collaboration with international and national research settings come naturally because they are strongly connected to the research conducted (see Table 7). However, coordination and collaborations also need to be developed. The lack of experience in hosting international RIs becomes evident. Furthermore, educational aspects related to courses on other levels and programmes than the ones with direct connection is crucial to increase the knowledge and awareness of the research facilities.

Large-scale RIs are important for communication and can also be used to introduce the public to science. This circumstance leads to a commitment and requires large-scale RIs to provide information to the public and stakeholders. This means that large-scale RIs also have a social assignment because they will generate data and hopefully later on solutions to societal problems. Training PhD students at large-scale RIs may be one way form of employment in industry and interacting with industry and technology transfer.

4.6 Concluding remarks

A knowledge ecosystem in large-scale RIs will require expanding participation. As depicted in this empirical section, establishing the two large-scale RIs will need to include not only buildings for research support, offices for industrial stakeholders, but also actively support and manage activities and collaboration in a central science park function. Our definition of a knowledge ecosystem is related to research collaboration and development of a knowledge platform where the network nodes are crucial for knowledge creation, exploration and dissemination. In our study academic respondents´ view on MAX and ESS were concerned that research conducted in the labs must be of the highest international standards and focus should be how to bring out the industrial and innovation perspective in an early stage to also attract the industry. Utilisation is not only in the narrow aspect of separate industrial users researching in the labs but also in the wider context of being involved in research projects using the results because the industrial actors already participate in projects relevant to the RIs.

However, the empirical results show a need for more and also advanced collaboration between industry and academia, where different aspects of basic research are brought forward. Even though many actors are used to collaborating, the actors see a need to have this developed further. A large role for universities apart from research is education. With the establishment of MAX IV and ESS, specific knowledge areas will be advanced and require new educational offers. It is in this context important with stakeholders grouped around knowledge exchange, knowledge nodes, research institutes and universities and the high-tech industry. Knowledge ecosystems therefore emphasise new knowledge where research institutes, universities and entrepreneurs in technology plays important roles in these ecosystems.

5 Discussion

The current empirical study demonstrated that large-scale RIs often possess both national and international orientations, and are based on collaborations between researchers in academia and industry or research institutes. These facilities are mainly accessed in collaboration with public knowledge institutions; collaboration is therefore advantageous for several stakeholders. Furthermore, studies have revealed that large-scale research facilities that act as hubs within social networks and a learning environment, where different stakeholders share knowledge, are essential; such ecosystems aid in fostering growth, interaction, and startups around knowledge hubs, where the financial network is considered to be critical (Clarysse et al., 2014; Engel & Del-Palacio, 2011). The increased industrial interest and focus on collaboration also open up new possibilities for building academic-industrial constellations around scientific domains, with regard to MAX IV and ESS. Furthermore, scientific knowledge, results, and technological progress need to be more integrated with industry; this can be achieved by including scientists and encouraging industry collaboration. However, there are well-known limits restricting the collaboration of researchers and academics in solving industrial problems.

The formal goals, basic governance and financing of MAX IV were outlined in an agreement between Lund University, the Swedish Research Council, the Swedish Governmental Agency for Innovation Systems and Region Skåne. However, the ESS is a pan-European project with 13 nations as members, including the host nations Sweden and Denmark; this supports the notion that RIs can only be realised through multinational collaboration and public support, which involve dialogue between several actors (Autio et al., 1996, 2004). Utilisation and the development of RIs also depend on other compatible resources (Carayol & Matt, 2004). Collaborative innovation can be influenced by the proximity characterising the stakeholders and actors involved. Different stakeholders should be more aware of the existing potential for cooperation where business and industry may become research-facilities-oriented. However, improved awareness is a key requirement. The role of intermediaries is essential to strengthening the cooperation among research facilities, universities and industry. There are also other types of stakeholders such as business angels, venture capital firms, and high-tech firms, which can be considered and also require adequate innovation, entrepreneurial skills, and financial resources.

Governing large-scale RIs presents a broad set of challenges. Research areas range from coordination and strategies to economic evaluations of the facilities and develop a knowledge ecosystem to access, share and create knowledge. Previous scholars have discussed the ecosystem concept (Autio & Thomas, 2019; Jacobides et al., 2018), where the ecosystem needs to be coordinated by a central player (Adner, 2017; Dattée et al., 2018; Kapoor, 2018; Moore, 1993, 1996) because each ecosystem and the actors will have different goals, but must develop connections to other actors (Kapoor, 2018; Masucci et al., 2020). The literature and empirical findings show that building social capital is important for developing a knowledge ecosystem around the two large-scale research facilities MAX IV and ESS to have an impact on science, economics, and society. The concept of social capital normally refers to the benefits from networks.

The empirical contribution in this study is based on data representing the perspectives from actors from academia, industry, and policy. Autio et al. (1996) developed a comparable conceptual framework based on actors' motivations to study CERN grounded on three main actors that collaborate in large-scale research facilities: academia, government, and industry and their framework comprises six basic dimensions: Technological, epistemic, financial, educational, political and strategic dimensions. These dimensions are mainly viewed from the industrial and from the scientific perspective, but partly from the public perspective.

Valkokari (2015) states that knowledge ecosystems have their main interest in creation of new knowledge through linked research work and collaboration, or the development of a knowledge base. Ecosystems can therefore be created in several ways: geographical, temporal, by permeability and for different types of flow (knowledge, material etc.). A knowledge ecosystem around MAX IV and ESS is grounded on ecosystem concepts based on knowledge flows between different actors. In comparison with industrial clusters where there is a focus on competitive advantage on a regional level, concentration and locality (Peltoniemi, 2006 and how clustered organisations get advantages from localisations and collaboration (Clarysse et al., 2014; Coughlan, 2014). Pointing out the network nodes is important because new knowledge is the principal outcome of a knowledge ecosystem based on a knowledge platform. In the definition of a knowledge ecosystem in this study, we use *knowledge creation, exploration and dissemination*. However, the main focus of a knowledge ecosystem including MAX IV and ESS, the dominant focus is exploration of knowledge which includes actors with both geographical co-location and virtual proximity.

Considering several actors' perspectives and other actors on different levels in a knowledge ecosystem around MAX IV and ESS, a common value proposition has to be developed. In this context, Adner (2017) and Jacobides et al. (2018) have pointed out that the value proposition is important in building an ecosystem. Afuah and Tucci (2012) pointed out a so-called 'orchestror's knowledge', which should be related to the value proposition for building an ecosystem focusing on knowledge. Building knowledge normally takes time, especially considering that several perspectives are included, and many actors are involved (Meulman et al., 2018). There are distances between many actors, and distance is, therefore,

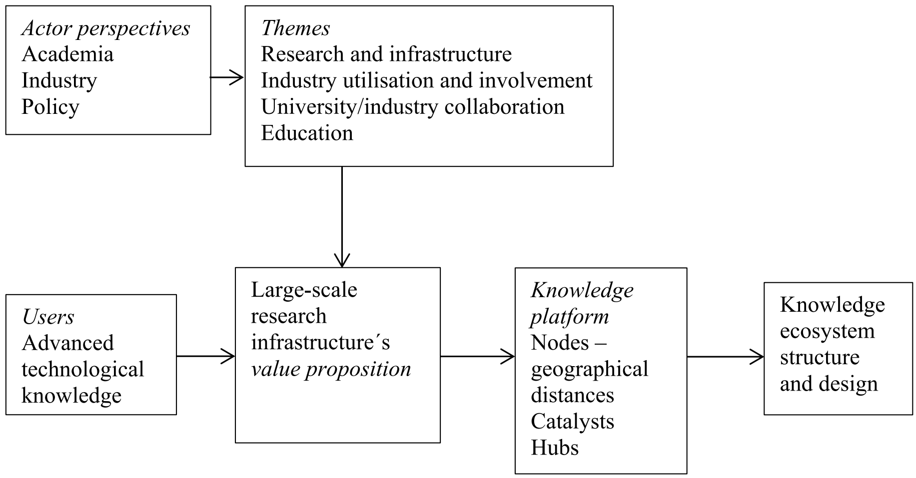

Fig. 2 Conceptual framework regarding structure and design of a knowledge ecosystem around large-scale research infrastructure

one dimension. However, the geographical area around MAX IV and ESS is limited, and a new facility, Science Village, will be built.

Figure 2 illustrates a conceptual framework about a knowledge ecosystem in large-scale research facilities. Large-scale RIs are occasionally necessary to achieve scientific goals or technological breakthroughs. They are also often a focal point for multi-disciplinary research, and they are the core of the *value proposition* of large-scale RIs. Research is becoming increasingly multi-disciplinary because scientific and social problems nowadays are so complex that it is difficult to answer them from a single scientific perspective. A large-scale RI is an output of strategic, long-term, and policy-related planning where government, local authorities and scientists are involved. The first box in Fig. 2 illustrates the prerequisite that a knowledge ecosystem is built on users; it focuses on advanced technological knowledge.

It is in this context that new business networks between the economic and social stakeholders, such as private industrial firms and policy decision-makers, are important. Science parks and mediator firms are important as catalysts, and the mediator role should be defined and developed in relation to the large-scale RIs. The governance dimension of MAX IV and ESS needs to be operated at several levels: (i) national level, with a national coordinating function system, (ii) regional or ecosystem level around the large-scale RIs with different nodes, (iii) international network level connecting to other relevant knowledge and/or business ecosystems, or actors from such systems. Some collaboration between academia and industrial firms is international and national or between or in universities or between and within industrial firms. One important issue is how to strike a balance among the organisational, regional, national, and international levels.

6 Conclusions

How large-scale RIs can contribute and assist development in the private industry is important in developing R&D and ensuring an economic impact. It is directly connected to the research question in this study. Not all innovations will lead to increased business performances but innovation is key to ensuring a competitive advantage for many firms in the high-tech sector. Innovation can refer to new materials or renewing products or processes. It can be a stimulant for new high-tech firms' growth and sustainability in a changing and hostile business environment. It can also ensure a long-term view and value of large-scale RIs. Innovation can also allow the high-tech firm to change its business model and adapt to the changes in the business environment. Research data from large-scale RIs represent financial assets and business opportunities. Economic values can be measured in several ways: new venture concepts, increased level of new startups, increased level of spin-offs, increased firm growth and increased level of innovation and product development. Previous studies have concluded that large-scale RIs benefit the local and national economy, suggesting that MAX IV and ESS may also be beneficial.

Several conclusions can be drawn from this study. A knowledge ecosystem around the large-scale infrastructure may strongly enable transfer of the technological advances and provide access to different types of networks, science parks, incubators, venture capitalists, and policy-makers. One possible way is to have agreements with incubators or science parks to support startups based on large-scale facilities. Large industrial firms can seek collaboration with the universities and attempt to solve problems of technological progress. However, one main problem is finding a match between academia and industrial firms. The framework implies that the three actor perspectives and four themes, together with advanced technological knowledge, will affect the value proposition of the large-scale RIs and geographical distances (nodes), catalysts (science parks, mediator firms), platforms, and hubs analysed in this study. In turn, they will affect the structure and design of a knowledge ecosystem. Thus, this developed framework explains knowledge ecosystem structure and design. Some effort should be made regarding the value proposition of large-scale RIs for decision-makers in academia, industry, and policy. An important central actor—a catalyst—in the knowledge ecosystem is the science park and business incubation activities with important business support functions. Catalysts can also help identify commercial ideas.

This study has several limitations. The analysis is based on a single study, including just two cases, MAX IV and ESS, and ESS is not operational yet. There is a special context around these two large-scale research facilities, including many actors on different levels; ESS also has an international dimension. There are also some problems with definitions, such as RI; this phenomenon is under-theorised. While our findings provide fruitful insights into MAX IV and ESS and future knowledge ecosystems, future research should develop theoretical foundations on knowledge ecosystems based on the framework in this study.

Appendix

See Table 8.

Table 8 Interview guide

1. Introduction
What is your view regarding the knowledge creation, exploration and dissemination of the facilities?
The distribution between university/institute/business?
Why this distribution? What is important?
How do you work to achieve this distribution?
What is your view regarding the importance of knowledge creation, exploration and dissemination of these research facilities in creating competitiveness and innovation in the industrial sectors such as life science and material development?
2. Research—education—knowledge creation, exploration and dissemination
Research facilities' relevance for the industry and business
Is it important?
How to work with it?
Who has this function/role?
What is the role of business/industry around MAX IV and ESS?
Which actors participate from the business community?
What is your view regarding the (entrepreneurial) milieu/environment around these research facilities?
About the environment
Structural elements: business angels, crowdfunding, venture capital, start-up academics, networking elements, entrepreneurship programmes, recruitment of talent, innovation challenges
How do you define 'outcome', entrepreneurial networks, new venture concepts, new technology-based firms, firm growth?
Do you have any examples of successful milieus that can be implemented?
What is the role of universities regarding new education programmes in relation to the two research facilities?
Do you have any examples of such new education programmes?
Who are the other relevant stakeholders for developing the research facilities?
Are these relevant stakeholders already involved? If so, how?
Which meeting places exist for discussion of the research facilities? Discussion forums? What are the type of interactions between the stakeholders?
How should a national structure that integrates academia, policy, and business be developed? What is missing?

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