Socio-Economic Impact of the Creation and Operation of Mega-Science Projects

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Abstract: Challenges of development facing society and states require efforts consolidation, in the research field in particular. Therefore, to organize international cooperation and to conduct basic and applied research, mega-science infrastructures are being created and implemented all over the world. Currently, research facilities of the mega-science class are being created in the Russian Federation. They play an important role in the development of science and the innovation process. The competitiveness of Russian science is a determining factor for ensuring the safety and technological independence of Russia. Therefore, the Federal program for the development of Synchrotron and Neutron research and research infrastructure for 2019-2027 was approved in March 2020.

In the present article, the concept of the socio-economic impact of the operation of large-scale research infrastructure is revealed. The authors refer to the materials on the socio-economic impact analysis, which was based on the data on the Swedish neutron source (European Spallation Source). The article provides a generalized idea of the main indicators for assessing the potential of the research infrastructure as well as their application to characterize the research facilities in the Russian Federation. It is worth highlighting that each large research facility is unique and it is not possible to unify the analysis of the socio-economic impact. However, the obtained results can be used for a similar analysis of research infrastructures, based on the same physical principles and created to solve general scientific problems.

Keywords: Mega-science, large-scale research infrastructure, socio-economic impact, research infrastructure, mega-science projects.

1. INTRODUCTION

Nowadays, large – scale research facilities (RIs) are created and operated around the world, playing an increasingly important role in the development of basic and applied research and innovation process stimulation. The ultimate goal of creating a large-scale research infrastructure is the ability to respond to great challenges facing society. One of the means to respond to these challenges is to provide research teams around the world with the opportunity to research at the most advanced facilities.

Research infrastructures must be considered as an object of long-term strategic investments, which are indispensable both for implementation and development of the best practices in relevant scientific fields and for as key players' contribution to the competitiveness. The long-term benefits of research infrastructures for society as a whole are beyond doubt, regardless of the size or scientific focus of the facilities. RIs are typically operational for several decades so they require continuous and stable support. History shows that a robust long-term vision is the most important prerequisite to successfully and sustainably build and operate a RI (Long – term sustainability of research infrastructures).

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Inadvertent discoveries resulting from long-term work in a research infrastructure can have the same impact as anticipated scientific achievements. Large research facilities influence the whole region of their location, playing a significant role not only in competitiveness improvement but also in integration plans development. A large research infrastructure also has a substantial impact on the specialists' skills, thereby increasing the employees, researchers, and students' competence. Moreover, due to the wide enrollment of the students, the perception and understanding of science and technology in society as a whole is improved (Report on Methodology and Criteria for Socio-Economic Impact Assessment of ESS During Construction and Operations).

In terms of the country's scientific and technological development, the most important component of large-scale research infrastructure, that contains unique scientific facilities of the mega-science class, are sources of synchrotron and neutron radiation (Decree of the Government of the Russian Federation).

The solution of the relevant tasks requires such significant changes in organization and financing that will contribute to the accumulation and effective use of the available intellectual, material, and financial resources. It is extremely important not to scatter funds, although to support those projects and objects of research infrastructure (creation and operation) that correspond to the list of critical technologies and top-

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priority fundamental and applied areas of research, including those relevant to Russia (Trubnikov, G.V. 2016)

Research conducted using neutrons has a significant impact on such areas as healthcare and the environment. Besides, it can be applied for the production of batteries, plastic, textiles, computer chips, etc. Therefore, the potential of neutron research is important for society.

In this regard, the study and assessment of the socio-economic impact (SEI) is an increasingly popular issue for conferences and European research projects.

Large-scale research infrastructures include the concept of a *fair return* "in their assessment. Thus, the investments made by different countries, regions, and other investors are distributed differently. Statistics from European research infrastructures show that the host country has the greatest benefits from research infrastructure in terms of labor, knowledge, competencies, and contracts.

For the evaluation of economic benefits, econometric studies are used, which show that all types of research infrastructure activities, including the cost of goods and services, planned upgrades, suppliers, and job creation, contribute to direct and indirect benefits for the local economy and the relevant global network.

Assessment of the socio-economic impact is especially important for the following categories of the process participants: shareholders, investors, society as a whole, and employees of the organization managing the facility. It is worth highlighting the importance of SEI for universities, as it demonstrates the successful conduct of scientific research at large research facilities.

Additionally, assessment of the socio-economic impact of research infrastructures allows us to determine how their activities contribute to the users' training and their involvement in science, influencing society over the long term.

This paper is organized as follows. Section 2 contains a literature review of the most relevant publications regarding the socio-economic impact and mega-science projects. Section 3 presents the methodology of the study. Section 4 and 5 describe the socio-economic impact and the importance of its analysis for the implementation of large-scale infrastructure projects.

Finally, Section 6 presents the conclusions.

2. LITERATURE REVIEW

The analysis of the socio-economic impact of the creation and functioning of large-scale research infrastructure is not sufficiently revealed in the scientific publications.

Among the works devoted to the analysis of the socio-economic impact and the problems of the implementation of research infrastructure projects, it is necessary to emphasize reports and forecasts on research infrastructures [Long – term sustainability of research infrastructures, Marko Hajdinjak, 2019, OECD 2019, Reid *et al*. 2015).

Thus, in the framework of the European BrightnESS Project, a report was prepared on the study of the socio-economic impact of the research facility on the European spallation source (The Impacts of Large Research Infrastructures on Economic Innovation and on society 2014). Within the framework of the Organization for Economic Co-operation and Development (OECD), a report was conducted on the activity of the European Center for Nuclear Research (CERN) and its influence on society and economy (Zuijdam, *et al.* 2011).

The issues of development and implementation of large-scale research infrastructures are also revealed in the works of Russian researchers (Prytkov *et al.* 2017, Nurakhov N, 2019, Nurakhov *et al.* 2019, Trubnikov GV, 2016).

3. METHODOLOGY

The uniqueness of large-scale research facilities and mega-science projects requires an individual approach to the analysis of the socio-economic impact.

The present research is based on the descriptive method, which includes observation, comparison, and generalization. The authors regard this article as a small empirical study, which could be of concern to the specialists in the management of large-scale research infrastructures. We consider the present study rather qualitative than quantitative. The results of investments in science and large-scale research infrastructures are often assessed by the number of PhDs and peer-reviewed scientific publications. These results have some advantages related to the simplicity of measurement, although they do not always meet the requirements of the politicians for making decisions on the implementation of research projects. The study was based on two sources of information, i.e., reports on the activities of research facilities and articles devoted to the implementation of mega-science projects (listed in the list of references).

The analysis of the socio-economic impact of a particular research facility allowed us to make some generalization according to the criteria that can be used for future analysis of the projects, which are based on the same physical principles, or from allied science fields.

4. RESULTS

The term «socio-economic impact» implies a comprehensive overview of all benefits, advantages, and risks, which arise when creating the large-scale research infrastructure. In particular, SEI includes the assessment of scientific impact, technological impact, and impact on innovation, direct and indirect economic impacts, impact on human resources, political impact, and impact on the environment. The assessment of SEI is of particular importance for large-scale research infrastructure and mega-science projects since creation requires significant financial expenses, industry involvement, and sometimes efforts of other countries.

Assessment of the socio-economic impact is a tool that helps to forecast the impact of research infrastructure. As a result, it is possible to develop strategies for minimizing the negative effect of the research infrastructure and for enhancing the positive one. An SEI assessment is also necessary to obtain and substantiate the funding that research infrastructures receive. For policymakers, this assessment is important for improving the planning, creation, and financing of large-scale research infrastructures (Report on Methodology and Criteria for Socio-Economic Impact Assessment of ESS During Construction and Operations).

There are two main ways to measure the socio-economic impact (SEI):

- through quantitative indicators based on the results of the activity of the research infrastructure;
- through qualitative impact assessment based on the best practices and successful initiatives.

Following the strategic missions of the created or operated facility, the indicators can be conveniently classified. The following list is presented and used in the Report on Methodology and Criteria for Socio-Economic Impact (Report on Methodology and Criteria for Socio-Economic Impact Assessment of ESS During Construction and Operations).

Assessment of ESS During Construction and Operations

1. scientific impact: scientific articles, citation, number of users, scientific awards;
2. economic impact: local and regional costs, additional benefit, impact on regional tourism;
3. technological impact: the number of patents, cooperation with industry, the instrumental base availability;
4. structural impact: the structuring of scientific and technological collaboration networks;
5. social impact: traffic statistics, number of open access events, number of visitors, media events;
6. educational impact: the number of PhDs, the number of employees, funding amount, quantity, and quality of the educational programs.

These six categories of indicators demonstrate the socio-economic impact of infrastructure at the local, regional, and global levels. Also, this classification provides a better understanding of how the research facility fulfills its long-term goals.

In particular, a large-scale research facility supports economic activity, promotes education, training, and leadership in science. Moreover, it creates a center of attraction and develops transport infrastructure. Thus, the potential impact on society, not only on science, should be taken into account and evaluated to demonstrate that large-scale research infrastructure is not oriented only towards science for scientists, but also towards science for society (Reid, *et al*. 2015).

Assessment of the socio-economic impact of the creation and operation of large research infrastructures is a complex task with numerous problems and several hidden traps:

- in most cases SEI can be observed only after several years of hard work when the first (scientific) results have already been achieved;

- often, it is difficult to collect the required data;
- SEI of research infrastructure can be direct and indirect, intentional and unintentional, expected and unexpected, positive and negative;
- SEI of different research infrastructures must not be directly compared, since each facility is unique;
- SEI is also significantly influenced by numerous external factors; therefore, neither positive nor negative result fully depends on the research infrastructure.
- Some effects may be caused by the indirect use of research infrastructure, which makes their assessment even more difficult.
- Some SEI indicators are more relevant for definite research infrastructures and less for others. For each research infrastructure, it is necessary to choose appropriate indicators and assessment methods based on their own specific goals and taking into account the strategic vision.

It is also worth highlighting that despite the significance, indicators for SEI assessment are only part of the entire set of indicators necessary for the successful management of the research infrastructure (Report on Methodology and Criteria for Socio-Economic Impact Assessment of ESS During Construction and Operations).

However, the above-mentioned difficulties should not stop specialists in the field of research infrastructure management from assessing the socio-economic impact. On the contrary, such an assessment is necessary. Most major research projects are funded by state funds. Therefore, SEI assessment is the best tool to demonstrate that research facilities bring numerous benefits to society and that their significance goes far beyond pure science. It also worth emphasizing that the assessment also helps managers plan the work of their research facilities and ensure their long-term financial sustainability (Marko Hajdinjak 2019).

A comprehensive analysis of the socio-economic impact was carried out for the research facility European Spallation Source (ESS) that is currently under development. The authors of the research consider it is useful for mega-science projects that are being created in the Russian Federation.

In 2013, a group of experts specially established by the Commission's Directorate-General for Research and Innovation examined the prospects of Russian megascience projects. International Center for Neutron Research based on a high-flux research reactor PIK (ICNR PIK) was positively assessed and was provided with the recommendations for development. The key recommendation that emphasizes the importance of creating ICNR PIK in Europe was the following: "It is highly recommended that ICNR PIK develop a joint strategy for scientific and technological cooperation with other European large neutron facilities such as the Institut Laue-Langevin (ILL) in Grenoble, France and the European Neutron Source (ESS ERIC) in Lund (Sweden). The goal of the cooperation is the creation of the "European Neutron Triangle: ILL - ICNR PIK - ESS ERIC", which would provide all the necessary research support for Russia, as well as the European and world community in the field of neutron physics for the coming decades, as well as provide synergistic technological cooperation in the field of neutron technology creation".

The European Neutron Scattering Association (ENSA) with the support of the Institut Laue-Langevin stated the necessity to create a large advanced neutron research center in 1993. In 2002, an international group of experts examined the scientific, economic, and technical possibilities for creating such an object and invited interested parties to develop the project. A new concept of the facility design was adopted in 2003. The construction of the European Spallation Source began in 2014.

The European source of neutron scattering of a "spallation"- type is a powerful neutron source for studying micro- and nano-phenomena in condensed matter physics. The ESS research infrastructure includes a proton driver, which is a linear proton 2 GeV accelerator with an average beam power of 5 MW. This linear accelerator will be the most powerful in the world in its class. A high-intensity proton beam is directed at a 4.9-ton tungsten target. As a result of the nuclear spallation reaction, a high-power neutron flux is generated, which will be directed to the 24 planned neutron experimental stations for research.

The legal status of ESS was determined in 2010. It is a public limited liability company under the Swedish law ESS AB, with 75% of the shares belonging to Sweden and 25% to Denmark. Starting October 1, 2015, the legal form was converted into ESS ERIC (European Spallation Source European Research

Infrastructure Consortium) to facilitate the joint creation and management of the pan-European research infrastructure ESS. The founders of the ESS are the Czech Republic, Denmark, Estonia, France, Germany, Hungary, Italy, Norway, Poland, Spain, Sweden, Switzerland, and the United Kingdom.

ESS is an important part of the future landscape of global research infrastructures, providing experimental opportunities for researchers from the academic world and industry. Neutron scattering can be applied to several scientific issues in the fields of physics, chemistry, geology, biology, and medicine. Neutrons are a unique method for determining the structure and impact of a substance. The use of neutrons for research allows us to explore the world, as well as to develop new materials and processes to meet the needs of society. Neutrons can also help respond to the Big Challenges, develop new solutions for the healthcare system, environment, pollution-free energy, information technology, etc. ESS tends not only to inform about the socio-economic impact but also to take it into account in the decision-making process. (Report on Methodology and Criteria for Socio-Economic Impact Assessment of ESS During Construction and Operations).

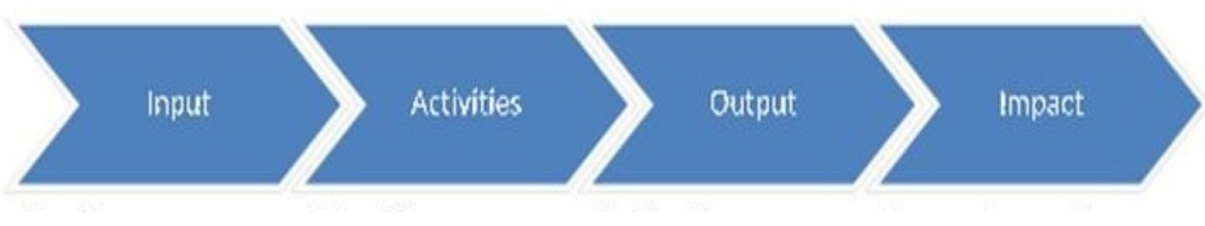
The creation of the ESS facility is determined by the research needs of the European scientific community. Research using neutrons is often carried out in the following areas:

- Engineering materials, Geoscience, Archeology, and Heritage Preservation, as well as the use of fast neutrons;
- Particle Physics;
- Life Science and the study of soft condensed matter;
- Materials Chemistry, magnetics, and electronic phenomena.

The socio-economic impact of ESS was assessed according to the model introduced in the OECD review "Reference framework for assessing the scientific and socio-economic impact of research infrastructures" (OECD 2019).

This model also reflects the basic activities of ESS. For example, the number of publications in journals with a high impact factor can serve as an indicator of international scientific influence, while the number of employees as an indicator of the impact on the local economy.

It is worth highlighting that the analysis of a large data set to assess the socio-economic impact of the research infrastructure is a long process. The indicators for assessment are correlated with strategic objectives and cover various aspects, namely: economic, human resources (or training), innovation (technological), scientific and social. It should also be clarified that the socio-economic impact is not direct. A large research facility is a tool for achieving the best scientific results. Over the long term, science affects everyone's life. In the short term, ESS, as a large employer in the region, influences the economic activity directly, i.e., tourism, construction, etc. In the long run, it is generally believed that each created job



funding	scientific	publications	economic growth
co-investment	training	collaborations	innovation for society
other sources	industrial	knowledge transfer	social capital
		knowledge creation	increased innovative performance (region)
		job creation	better health
			better environment

Figure 1: How to measure impacts (OECD 2019).

contributes to the production of two or three indirect employment (OECD 2019).

The socio-economic impact of ESS creation can be more difficult to determine. The impact of research on society can be tracked by the attractiveness and impact of ESS on the public. Usually, the following data are applied to determine this indicator: the number of events organized by ESS for the community, the number of open days, the number of followers on various social networks, as well as the number of visitors on the websites.

ESS cannot perform as a leading research center yet. However, during the construction period, ESS scientists organized international cooperation to create and form measuring instruments in ESS. The facility generates research, innovation, and technological developments. Most articles are devoted to the instrument base.

ESS is mainly represented through research communities. Research infrastructure also tends to be accessible to the public (through the media) to inspire people and to demonstrate the progress of neutron science and its potential for society. The more accessible the research facility is, the more significant is its symbolic influence on society, and children in particular, so that they become researchers, etc. (Report on Methodology and Criteria for Socio-Economic Impact Assessment of ESS During Construction and Operations).

At the stage of the design and construction of the ESS facility, a wide range of technical knowledge is applied. Thus, physical construction attracts many companies, from building materials suppliers to technical services providers. Local companies participate in the procurement of basic construction services, which generate additional income and expand employment opportunities in the region. Many of these costs can have a significant multiplicative impact on the local economy, as well as on the economies of other countries.

Joint research conducted at ESS can involve both regional and international researchers using equipment for shorter or longer periods. Funding from service fees charged by research teams will allow reinvestment in equipment and influence both the ESS and the local economy. Quantitative indicators have been developed to compare the placement of ESS in its research networks. Social networks provide new forms of interaction between participants in the innovation system, stimulate the learning environment, and improve the users' awareness (potential and existing) of the amount of knowledge available in research infrastructures (Report on Methodology and Criteria for Socio-Economic Impact Assessment of ESS During Construction and Operations).

Human capital strengthening is a major challenge for global research infrastructure. The activity of a large research facility can attract talents (researchers, engineers, students); and the promotion of knowledge gained by managers, operators, and users of ESS can be of significant social value. Thus, skills on research commercialization acquired by managers and experts at ESS are important benefits with far-reaching effects for the local innovation system. Close formal and informal social interaction enhances interpersonal reliance and knowledge sharing. Therefore, it increases the amount and variety of knowledge available to users. People's mobility and the emergence of new cooperation networks are the basic mechanism implemented for knowledge sharing and economic benefits distribution (Report on Methodology and Criteria for Socio-Economic Impact Assessment of ESS During Construction and Operations).

As a large international research infrastructure, ESS must promote new and innovative working methods for its employees, researchers, and users. The first innovative way of working is to make the study available to a wider audience, especially in countries where access to magazines may be difficult. An open-access journal promotes knowledge dissemination among research communities and can improve citation rates.

The international significance of ESS is proved with the variability of the staff, represented with nearly 50 different nations. ESS is part of an international network and is closely associated with universities and industrial partners, who contribute to the project through their experience, staff, and knowledge, or directly in kind. The first researchers are expected in 2023. About from 2000 to 3000 researchers will annually come to ESS to carry out experiments for industries, universities, and institutes

The facility influences the region positively directly and through additional efforts. First of all, the ESS should be considered as an object for investment. In this regard, ESS considers large financial costs for the construction of the facility, involvement of highly qualified specialists from the region, and annual maintenance costs. Among the secondary effects of investing in ESS, it should be noted the impact on construction activity in the region, housing costs, and infrastructure development (Report on Methodology and Criteria for Socio-Economic Impact Assessment of ESS During Construction and Operations).

Considering the ESS as a new opportunity, it is worth highlighting that it can serve as a platform for new types of economic activity in the region, attracting investments and competencies, as well as the improvement of the region's global relevance. Besides, the research facility can serve as a symbol of the region.

There is a successful experience in creating a scientific and technological cluster in Lund, which contains two large research infrastructures in the field of the neutron (ESS ERIC) and photon (MAX IV) science with different legal statuses. In addition to the scientific and technical component, it is necessary to note infrastructure solutions for the construction of "science village" (Science Village Scandinavia), where the personnel of ESS ERIC and MAX IV facilities can be accommodated, and "science road" (The Science Road) as the main transport hub. Science Village Scandinavia is located in the northeast of Lund and forms part of a new district of Brunnshög. It is planned to build about 250 thousand m^2 of premises for business, research, and education in the field of materials science and innovation on a total area of 18 hectares. A university campus, guest housing, research institutes, services, sports centers, restaurants, and cafes are to be built on this site. It is planned to build seven and eight-storied buildings of various architectural styles. Science Village Scandinavia will turn into a dynamic, creative, and sustainable urban area that will stimulate world-class research and become a space for interaction with society. The Science Road will connect Lund city center with Science Village Scandinavia and new research facilities. The road will unite academic institutions such as Skane University Hospital, Lund University, Ideon, and Medicon Villages. At present, about 25 thousand people work in the area of the future, The Science Road.

The analysis of the socio-economic impact for the ESS facility is preliminary, as the creation has not been completed yet. However, a similar analysis can be implemented to assess the socio-economic impact of other neutron sources.

Additionally, successful scientific, technical, and infrastructure solutions in terms of the implementation of the main stages of the development of the scientific and technological cluster in Lund can be applied for the creation of facilities within the framework of the Federal Program for the Development of Synchrotron and Neutron Research and Research Infrastructure for 2019-2027 (Decree of the Government of the Russian Federation).

5. DISCUSSION

Large-scale research facilities are critical for both basic research and applied research. Speaking of applied research, it is worth mentioning the conduct of research in the field of biology and medicine, the need for which increased in 2020 due to the COVID-19 pandemic. Analysis of SEI is one of the important steps towards the creation of large-scale facilities and the realization of Mega science projects.

Since the characteristics and research capacity of every mega-science project are unique, it is necessary to take into account the project's specifics and the necessity to collect comprehensive data.

The current status of the project is significant for conducting such an analysis. The general parameters for the facility's assessment should include the following:

1. The scientific component of the research facility. It can be used for the scientific superiority determination;
2. The economic impact on the local and regional economy;
3. Possible strategic breakthroughs and their impact on society. This indicator assesses the attractiveness of the facility for society, i.e., awareness on the opportunities and potential impact on everyday life;
4. Development of relations and cooperation in the relevant scientific field;
5. Development of cooperation with other research facilities;
6. The staff. The number of employees has a direct and indirect influence on the local economy, contributing to the economic activity increase;
7. Security, i.e., measures to ensure the safety of the personnel and training on security issues;

Table 1: The Assessment of the Socio-Economic Impact and its Significance for Various Actors

Politicians and Investors	- helps to understand how the results of state-funded research can be helpful for the national economy, influence the citizens' lives, and solve important social problems - provides proper financing strategy for research projects - should be suggested as an obligatory component for decision-making.
Managers of Large-scale Research Infrastructure Specialists	- are a practical tool for measuring objectives' fulfillment, problems identification, and development of necessary corrective actions - provides an overview of the potential direct and indirect benefits of research infrastructure implementation - can be used as reasoning to convince decision-makers to provide public funding for the operation, maintenance, and modernization of research infrastructure -helps to step outside the problems of cost-effectiveness and optimize organizational structures, procedures, and internal policies, which, in turn, maximizes the socio-economic results without affecting the main objectives of the research
Personnel of the Large-scale Research Infrastructure	- provides an opportunity to master new knowledge and skills - may provide career opportunities
Other actors	- determines opportunities for collaboration between research projects and business - helps to raise awareness in the political environment, media, and public about the importance/necessity of investment and support of the creation of large research infrastructure.

8. The project budget and reporting to taxpayers;
9. An innovative component of the working process organization.

The obtained data will be relevant for the particular project being evaluated since the analysis does not imply the comparison with other similar projects. Particular attention should be paid to data deterioration and the necessity to update the information when preparing reports or other documents containing SEI analysis (Marko Hajdinjak 2019).

There are two major limitations in this study that could be addressed in future research. First, even though the concept of socio-economic effect has a clear definition, prior research studies that are relevant to the topic of SEI in the context of large-scale research infrastructure are limited. In this case, the authors of this paper had to identify gaps in the prior literature and select several full-scale studies, which became a case-study for this paper.

Second, the most critical issue for the analysis of socio-economic impact is the uniqueness of the large-scale facilities and their limited number. This condition complicates the analysis and the possibility of using its results for future research facilities, which are created on different physical principles and with different characteristics. This limitation should be taken into account for the further research of the topic.

6. CONCLUSIONS

The conducted analysis of the concept of "socio-economic impact" of the creation and implementation of large research infrastructures and projects of the mega-science class, allowed us to reveal main indicators that can be applied to analyze the SEI of the facilities being created and those that have been already put into operation. The analysis and assessment of SEI for Russian research facilities were not carried out, although it is necessary to highlight the studies of the facilities that are based on similar physical principles. The analysis of SEI for large-scale research infrastructure is significant both for the decision-making on its creation and for its effectiveness evaluation.

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