The Swedish Research Council´s guide to research infrastructure 2023

Swedish
Research
Council

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Foreword

Research infrastructure is often of crucial importance for enabling high-quality research to be carried out and, for Sweden to continue to be an internationally competitive research nation, long-term, attractive and sustainable funding schemes are needed. The Swedish Research Council is currently funding a significant proportion of the national and international research infrastructures used by Swedish researchers, but other research funding bodies and higher education institutions also contribute to the funding of research infrastructure. The Swedish Research Council's guide to infrastructure is aimed both at the research community and research policy-makers, and describes the strategic assessments and recommendations the Swedish Research Council considers to be necessary to ensure that Swedish researchers in all scientific fields can continue to have access to modern, high-quality research infrastructure. For example, the investments in the large-scale infrastructures in Sweden – ESS, MAX IV and EISCAT-3D – are of great importance to Sweden and to our international visibility. It is also crucial that NAISS (the National Academic Infrastructure for Supercomputing in SWEDEN), continues to have good prerequisites for supporting Swedish research. The challenges posed by the COVID-19 pandemic, the geopolitical situation, and the weak Swedish currency have meant that the preconditions for many infrastructures have changed rapidly. We need to strengthen the long-term approach to funding, have greater flexibility in managing cost fluctuations, but also ensure that infrastructure investments are made with greater interaction between higher education institutions, the business sector, the public sector and other research funding bodies, and that they are coordinated with major investments in research. Moreover, to broaden the benefit further and provide returns in the form of knowledge and financial resources, investments focused on development and construction of advanced components connected to infrastructure developments need to increase. To further raise researchers' interest in contributing to development and operation of infrastructures, career opportunities within the infrastructures need to be strengthened. The guide also aims to provide a picture of the Swedish Research Council's work with prioritising and funding research infrastructure, including the management of research infrastructure lifecycles and the complexity that follows. Furthermore, this guide describes the Swedish Research Council's continuing strategic work towards the upcoming Government research bill, and for continued dialogue with the research community, higher education institutions and other stakeholders.

Stockholm, 1 April 2023

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Summary

This guide has been written by the Council for Research Infrastructures (RFI) at the Swedish Research Council, to highlight what is needed to secure Swedish researchers' access to high-class infrastructure, which is a prerequisite for Sweden to continue to be an internationally competitive research nation. The guide presents nine recommendations, which are all assessed as contributing to this. The guide also presents a number of suggestions aimed at improving the work on both identifying needs for new research infrastructure of national interest, and also on prioritising investments in research infrastructure. With a strained economic position, caused by factors such as the geopolitical situation and post-pandemic effects, long-term strategic prioritisations are becoming ever more important. The guide also emphasises the importance of Swedish returns, both in relation to knowledge and competence and to economic returns, via Sweden's membership of international research infrastructures. Finally, it describes the research infrastructure landscape that Swedish researchers have access to and its need for future development.

Investments in the large-scale infrastructures in Sweden – the European spallation source ESS, the synchrotron light facility MAX IV, the radar facility EISCAT-3D and the computation infrastructure NAISS – are very large and of great importance to Sweden and our international visibility. Investments in e-infrastructure are important for most research infrastructures, where increasing demands for computation capacity, storage resources, user support, security and international collaboration need to be fulfilled. Here, support for researcher and higher education institutions (HEIs) within the entire e-infrastructure area needs to be better coordinated than it is today.

Increased investment in these major infrastructures has occurred since the 2018 guide, but both the long-term approach to funding and the benefit to the Swedish research community and societal development must continue to be secured. Chapter 2 of this guide describes nine recommendations (see below for a summary) on future development needed to secure the long-term funding and use of research infrastructure of national interest.

Summary of the guide's recommendations

1. Long-term secured funding schemes for research infrastructure are needed to allow the Swedish Research Council to manage increased costs of both national and international research infrastructure. Funding directed to new research infrastructure will be based on strategic considerations, be identified via the needs inventory process and widely accepted.

2. As most research infrastructures have a very long lifecycle, there may be a need to change both the form and the level of support during its life cycle. For development and prioritisation of research infrastructures, it is very important that the research infrastructures are evaluated and weighed against the needs of research and that the development of the entire available infrastructure landscape is taken into account.

3. The processes that govern research infrastructure funding and prioritising need to recognise that changed and new needs for research infrastructure areas can arise as the research frontier moves forward. The Swedish Research Council works to recognise infrastructure needs in all scientific fields.

4. To interest the most able researchers to work in a research infrastructure, attractive career paths are needed. Opportunities for competence development must increase to address the need for advanced user support at the infrastructures.

5. Sweden will work to ensure that international research infrastructure memberships provide better returns, both in the form of competence and economic growth. The prioritisations that needs-inventories and evaluations lead to should be included in the trade-offs made in relation to the international research infrastructures.

6. Large-scale infrastructures in Sweden, such as ESS, MAX IV, SciLifeLab and NAISS, offer great potential for Swedish researchers and the business sector. Long-term resources for their operation and development needs to be secured, by the government, the HEIs and other stakeholders. Demands for the highest international standard should be placed on their operation.

7. As different research fields and different phases of an infrastructure’s lifecycle have differing funding needs, new funding schemes need to be introduced that responds to these needs.

8. Targeted financial schemes need to be made to allow infrastructures to adapt to and support increased open accessibility to research data. The work towards open access to research data must be done in a coordinated way and in collaboration between HEIs, research infrastructures and research funding bodies. When adapting Swedish legislation, attention needs to be paid to the opportunities for research to use existing data.

9. The work on a strategic agenda for research infrastructures will require an increased and broadened engagement of the research community and other actors. Such an approach will make the Swedish Research

Council a stronger research policy adviser on issues relating to research infrastructure.

1 Research infrastructure of national interest

1.1 Introduction

The Swedish Research Council's guide to infrastructure 2023 is the Swedish Research Council's roadmap for Sweden's long-term need for research infrastructure, and is aimed at the research community and research policy-makers. The purpose of the guide is to indicate needs, challenges and opportunities relating to research infrastructure aimed at strengthening Sweden as a research and knowledge nation. The Government has mandated the Swedish Research Council to support, plan and allocate funding so that Swedish research gets access to the research infrastructure required to carry out research of the highest scientific standard. The implementation of advanced research is increasingly demanding access to resources that are built up systematically over a long period of time, the operation and build-up of which normally exceed the capacity of individual teams of researchers or higher education institutions (HEIs). In many established and emerging research fields, research infrastructure is ever more crucial for the research carried out, and in many cases also provides the opportunity to ask entirely new research questions, or to deepen the questions.

Ahead of the 2021 call for grants to research infrastructure of national interest, the risk was great that a number of infrastructures important to Swedish research could lose the support from the Swedish Research Council and that no new initiatives could be made. However, with the Government's latest research bill[1], Sweden received a very much appreciated injection of funding for research infrastructure. In addition to the ordinary targeted call for grants to research infrastructure of national interest, this funding enabled a call targeted at technical development, construction and investments in existing infrastructure. Important investments have been made at the major research infrastructures situated in Sweden: MAX IV, ESS, EISCAT-3D and NAISS.

In humanities, needs identified via the needs inventory have been possible to fulfil through two new infrastructures within digital humanities being awarded support. In social sciences and medicine, the funding injection enabled a continued investment in coordinated database infrastructures and continued Swedish membership in two international infrastructures. Investments in both existing and new research infrastructure in the life science field could also be made, for example in protein production and, linking to materials science, NMR spectroscopy. Within the field of the universe's smallest components, the additional funding led to that pilot studies in fundamental and materials physics could be funded. It also provided opportunities to fund new infrastructures that

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[1] Forskning, frihet, framtid – kunskap och innovation för Sverige. Website: Regeringskansliet

enable detailed and long-term observations of air, land and water, and infrastructure of high relevance for space research and satellites. Infrastructure for research and development of fusion reactors could also be funded with the strengthened funding situation.

Overall, the strengthened funding to research infrastructures has strongly contributed in the short term to meeting the current needs of Swedish research for both existing and new research infrastructure. But for Sweden to continue being an internationally competitive research nation, long-term and stable funding is needed.

In addition to the Swedish Research Council, there are a number of actors who contribute to fulfilling the needs for infrastructure. Swedish HEIs play a central role, and have both strategic and financial responsibilities. Other research funding bodies are also very important.

The national research infrastructure landscape was investigated on in 2021 on behalf of the Swedish Government[2] and during the same period, the Swedish Research Council evaluated the return on Swedish membership of international research infrastructures[3]. Together with the latest Government research bill, this has provided new insights and perspectives on how the research infrastructure landscape can be developed going forwards. At present, however, there is no complete mapping of what infrastructures are accessible for researchers in Sweden, nor of their funding. Such a mapping would enable better understanding of how prioritisation and funding of research infrastructure could be made even more efficient. The geopolitical situation, together with effects from the pandemic, have led to cost increases and delays, which underlines the need for long-term and robust funding, as well as for strategic prioritisation of existing resources.

Reading references

The focus of the 2023 guide is to highlight general needs, describe development trends and provide recommendations for future development in the research infrastructure field. Chapter 1 provides an introduction to the development from the previous guide up to today, and a background to the processes that lead up to prioritising and funding research infrastructure. The chapter also describes the background for the different types of infrastructures that Sweden engages in, and how these are managed, and discusses the societal relevance of research infrastructures, open access to data, and aspects relating to education, career paths and the roles of the business sector and public sector. Chapter 2 presents and justifies the Swedish Research Council's nine main recommendations, and Chapter 3 presents the development and needs for research infrastructure in nine different fields. Please note that when individual research infrastructures (with the exception of large-scale research infrastructures) are mentioned by name, it

[2] Stärkt fokus på forskningens infrastruktur. Website: Regeringskansliet
[3] National benefits from Swedish membership in international research infrastructures 2016–2019

is to exemplify needs and trends. For a full list of the infrastructures that receive ongoing funding from the Swedish Research Council, please see Appendix 1. More detailed descriptions of these can be found on the Swedish Research Council's website.[4]

1.2 The Swedish Research Council's work with research infrastructure

Through its Council for Research Infrastructures (RFI), the Swedish Research Council has overall responsibility for Sweden's national research infrastructures and for Swedish participation in international research infrastructures. The aim is to give the Swedish research community the best possible prerequisites for conducting advanced research, and thereby contribute to Sweden's ambition to be a leading knowledge nation.

In addition to the Swedish Research Council, there are a number of other actors who contribute to fulfilling the needs for infrastructure. Swedish HEIs play a central role, and have both strategic and financial responsibilities. In most cases, it is also the HEIs that have responsibility for national research infrastructures. HEIs own the equipment, run the infrastructure, and are responsible for employees and premises. Besides these responsibilities, the HEIs also have the responsibility for fulfilling the needs for local infrastructure. Functioning collaboration between HEIs and the Swedish Research Council is therefore necessary, and the Universities Reference Group for Research Infrastructure (URFI) plays an important role in a strategic dialogue.

Other research funding bodies are also very important for research infrastructure. Among the governmental research funding bodies,Vinnova participates in several of the major infrastructure investments in Sweden, and is engaged in making research infrastructure accessible to Swedish industry, in particular. Several private funding bodies have made and are making important investments within a number of areas. For the field of medicine, Sweden's regions and their comprehensive healthcare registers play a central role. In addition to the research funding bodies, several public agencies also contribute with infrastructure for research. Statistics Sweden and the National Board of Health and Welfare are examples of public agencies that are responsible for registers that give researchers unique prerequisites for carrying out register-based research. Other examples of agencies that contribute funding for infrastructure for research are the Swedish Institute of Space Physics, the Swedish National Space Agency, the Swedish Energy Agency and the Swedish Polar Research Secretariat.

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[4] Finding research infrastructures that we fund. Website: Vetenskapsrådet

1.3 The Swedish Research Council's definition of research infrastructure of national interest

The Swedish Research Council's definition of what is covered by the concept of "research infrastructure of national interest" aims to define the type of research infrastructures the Swedish Research Council intends to fund.

RFI funds research infrastructure that is of a long-term nature and is of strategic importance for the Swedish research community. In addition to the definition, the Swedish Research Council therefore applies a number of criteria intended to clarify and define the type of infrastructure funded by RFI.

The Swedish Research Council's definition of research infrastructure of national interest.

Research infrastructure of national interest is intended to provide resources that enable research by several research teams and different projects within one or more research fields.

Research infrastructure of national interest shall:

- enable research of the highest scientific quality
- be openly accessible primarily to researchers, but also to the business sector, the public sector, and other relevant actors. When access is limited, prioritisation shall be based primarily on scientific excellence
- create clear national added value
- have long-term plans for the scientific operation and its development
- take long-term responsibility for management and control, funding, competencebuilding and development of the operation
- contribute to societal development, for example by enabling research that addresses issues relating to societal challenges.

1.4 Different types of infrastructures

To facilitate understanding of how prioritisation, funding and other management of research infrastructure is done today, and how it can be developed, the types of infrastructure that the Swedish Research Council funds are described below. The research infrastructures the Swedish Research Council funds vary in terms of character, funding and organisation. As is true for research as a whole, the operation of all infrastructures is always done in an international context, where the interaction between national and international interests is an important driver. A strict division into national and international research infrastructure can therefore not be done. A division based on organisation form and funding can, however, constitute a starting point for categorising and better understanding the research infrastructure landscape and its logic.

1.4.1 National infrastructures

National infrastructures carry out their operation at a central node or distributed across several HEIs. The operation of an infrastructure can be distributed for several reasons. Among those that the Swedish Research Council is currently funding, there are three categories:

- The purpose of the infrastructure is to collect data about the physical environment and is distributed to enable it to collect data from different environments.
- The purpose of the infrastructure is to coordinate and provide national access to complementary experimental techniques (often instrumentation) and expertise within a field.
- The purpose of the infrastructure is to coordinate databases within adjacent fields, to enable continuous data collection, joint metadata and documentation and, where possible, increased knowledge of data and user support to researchers to facilitate use of data.

The large majority of the national infrastructures are funded via grants in the call for “infrastructure of national interest”. Some are funded by separate arrangements (see Section 1.4.3). This applies to both MAX IV and infrastructure for computation resources (SNIC up until the end of 2022, thereafter NAISS).

1.4.2 International infrastructures

International infrastructures can advantageously be divided up based on their organisation form:

- Convention-bound infrastructures. The operation is based on conventions that Sweden has ratified. The Swedish Research Council contributes to funding the Swedish fee. This type of research infrastructure is usually large-scale, cost-intensive and very long-term.
- European Research Infrastructure Consortium (ERIC). ERIC is a separate organisation form for European research infrastructures, and has a legal right that is recognised in all EU member states and in the associated states that accept the organisation form. The Swedish Research Council contributes to funding to the Swedish operation and the membership fee, and in some cases with a national grant to the joint operation within the ERIC. Sweden hosts one ERIC; the European Spallation Source (ESS).
- Other international infrastructures, based on bi- or multilateral agreements. The operation is carried out abroad with Swedish participation, or in Sweden with foreign participation. The Swedish Research Council contributes to funding the Swedish participation.

With the large variation in operations, funding needs and organisation models, constructing a unified funding and prioritisation model is a major challenge. At the same time, it is of great importance for the transparency, predictability and equality of treatment principle that a unified system exists. The Swedish

Research Council balances this by ensuring that most of the research infrastructures are funded via a competitive call (see Chapter 1.7), while some are managed via separate arrangements. Appendix 1 lists infrastructures funded by the Swedish Research Council.

1.4.3 Large-scale research infrastructures in Sweden

Divergences from the Swedish Research Council's model for prioritising and funding research infrastructure described in Chapter 1.4 relate in particular to the national infrastructures that are the largest in termsof cost, namely MAX IV and SNIC (which is replaced by NAISS as from 2023). For both MAX IV and NAISS, reviews by international panels have led to significant changes to their respective organisation and management. ESS and SciLifeLab have other challenges and ongoing initiatives aimed at clarifying the infrastructures´ responsibilities and their respective funding situation in a long-term perspective.

MAX IV is a Swedish national synchrotron light facility hosted by Lund University, mostly financed through public funds from the Swedish Research Council, Vinnova, HEIs and regions, but also from private foundations. The fixed investment in the entire facility is expected to amount to around 6 billion SEK, and the operating budget will be almost 500 million SEK per year. MAX IV, formally opened in 2016, has just over 300 employees from more than 40 different countries and has 16 experiment stations, known as beamlines, in operation. When fully completed, MAX IV can hold up to 26 beamlines.

The European Spallation Source (ESS) ERIC is an international neutron spallation facility with 13 member countries, where Sweden and Denmark are host countries. The member countries' joint investment in ESS is currently estimated at around 30 billion SEK, where Sweden's undertaking amounts to around 10 billion SEK (both at 2013 values). ESS has just over 500 employees from 55 different countries. The construction of ESS began in 2014, and the building was completed in December 2021. Installation of scientific equipment is ongoing, and the facility is planned to be operational in 2028, with 15 instruments. The Swedish undertaking in ESS is financed via earmarked funds from the Government. The Swedish Research Council, which is carrying out considerable work on hosting and on preparations ahead of ESS being ready for research in 2027, also has earmarked funds for a call for in-kind contributions to ESS to enable Swedish researchers to participate in the development of instruments.

Broad-based use of the resources being built up at ESS and MAX IV have required a coordinated national strategy, covering the entire chain from the physical infrastructure around the facilities to reinforcement and optimal use of competences. The national strategy, which was presented by the Government in 2018[5], led to a Government mandate for the Swedish Research Council and Vinnova, which have now established a joint office among other actions[6]. The

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[5] En nationell strategi för ESS och den omgivande kunskapsmiljön. Website: Regeringskansliet

[6] National collaboration to maximise the benefit to Sweden of ESS and MAX IV

Government's goal for the investments is to create an international centre that is world-leading within materials science and life science. Wide Swedish use of the facilities is central for Swedish research and innovation, and an important component of realising the Government's goal. The Office for ESS/MAX IV will coordinate national initiatives into the facilities, so that Sweden achieves the best possible return on the investments made.

The National Academic Infrastructure for Supercomputing Sweden (NAISS) is the new national computation and storage resource that is taking over responsibility for these services from the Swedish National Infrastructure for Computing (SNIC) as from the year end 2022/2023. The overarching functions, such as management, coordination of the operation of SNIC's current resources, local user support and applications for access and other administration is transferred to NAISS. Linköping University is the host organisation för NAISS and has begun work on building up an organisation for advanced user support in collaboration with several HEIs. NAISS will in the future acquire and operate new computation and storage resources.

Science for Life Laboratory (SciLifeLab) has since 2013 been a national centre for molecular life science research, and provides advanced technologies, expensive equipment and expert competence to the research community. The infrastructure operation is distributed across around 40 facilities. SciLifeLab's organisation is regulated by a separate ordinance, and governmental funding for research, research infrastructure, medicine development and pandemic preparedness is allocated via KTH Royal Institute of Technology's letter of appropriation. In addition to the governmental basic funding, further funding to the national research infrastructure is obtained via user fees, grants from HEIs and from external funding bodies, of which the Swedish Research Council and the Knut and Alice Wallenberg Foundation are the largest ones. In 2022, the Swedish Research Council's funding of SciLifeLab-related infrastructure amounted to 159 million SEK. During autumn 2022, the Swedish Research Council evaluated three infrastructures within the life science field, and in conjunction with this, organisational aspects of the funding were considered.

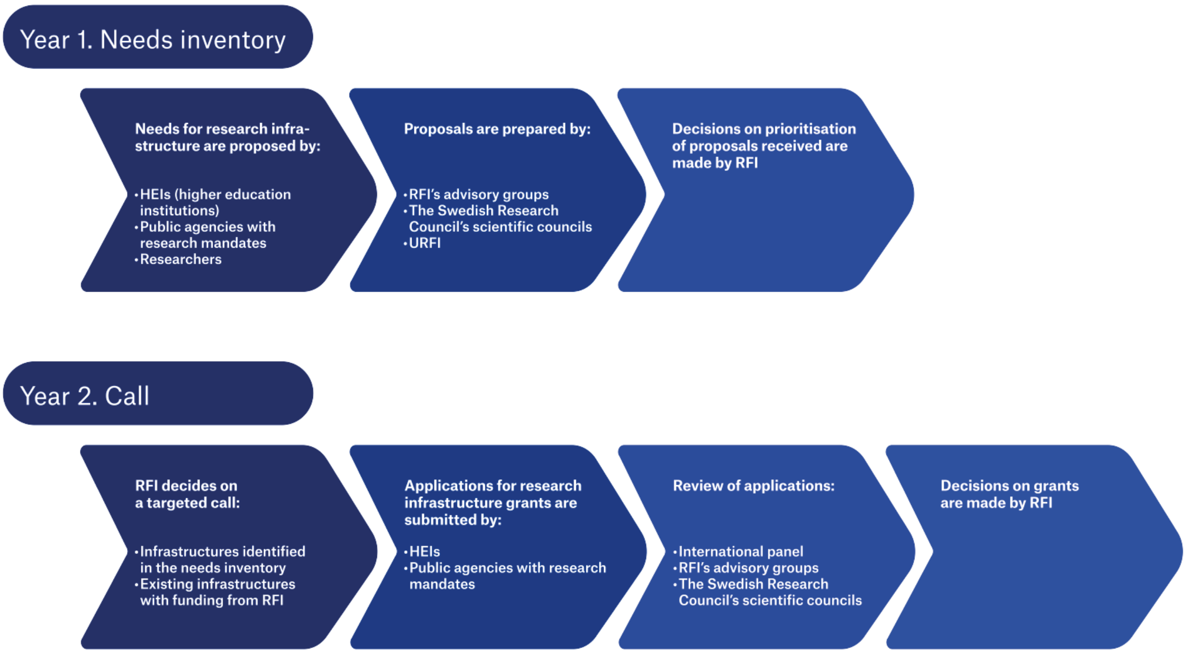
1.5 Prioritisation of research infrastructure of national interest

The overarching Government mandate for the Swedish Research Council's work with research infrastructure is to support, plan and allocate funding, so that Swedish research gets access to the research infrastructure required to carry out research of the highest scientific quality. In order for the funding to be justified, there must be researchers who are able to use and further develop the research infrastructure once it is in place. Engagement from the HEIs that host and co-fund research infrastructure of national interest is also required.

1.5.1 Needs inventory and targeted call

The Swedish Research Council's model for funding infrastructure (Figure 1) follows a two-year cycle, starting with a needs inventory and ending with a targeted call.

Figure 1. The Swedish Research Council's model for prioritising and funding research infrastructure



The purpose of the needs inventory is to identify areas with clear needs for new or developed research infrastructure. Researchers, HEIs and public agencies with research mandates are invited to submit proposals for needs for both national research infrastructures and also Swedish membership of international research infrastructures. This relates to both Swedish participation in the construction of new international infrastructure and participation in existing organisations. Via a review process – which besides RFI and RFI's advisory groups also includes the Swedish Research Council's scientific councils and committees and the Higher Education Institutions' Reference Group for Research Infrastructure (URFI) – areas are identified where research is assessed as having a great need for new or upgraded and developed infrastructure. The areas that are assessed as having the highest priority needs for research infrastructure are then included in a targeted call. However, all needs assessed as having high priority in the inventory will not automatically be covered by the call. RFI decides on which of the most highly prioritised areas will be included in the call, based on strategic considerations, such as the available budget.

In conjunction with calls for funding of new infrastructure initiatives being issued, infrastructures with ongoing grants that terminate no later than the year after the application round are usually also invited to apply for renewed funding. The budgetary situation impacts on the amount involved in the call, and on the allocation of funding between new and ongoing infrastructures eligible to apply for grants. The Swedish Research Council's assessment is that the model for prioritising and funding research infrastructure that was implemented in 2015 has created clearer management and increased predictability for those who plan and operate national research infrastructures, but there is a need to develop the process, which is also reflected in the recommendations made in the guide.

To fund infrastructure of national interest, the Swedish Research Council normally require co-funding corresponding to no less than 50 per cent of the total cost. Co-funding is a way of making it possible for Sweden to meet the increasing costs of research infrastructure and at the same time strengthen the engagement from the HEIs. This creates better prerequisites for long-term stable funding and operation of research infrastructures. The funding models vary for different types of infrastructures and scientific disciplines. For example, the use and principle of user fees varies.

As research fields develop and technological advances occur, the needs of a given research infrastructure will also develop and change. For applications for grants to infrastructure of national interest, the Swedish Research Council requires a phasing-out plan to be drawn up by each host organisation. The phasing-out plan should describe how the infrastructure will manage a situation where the support from the Swedish Research Council is terminated.

The ambition of the model for prioritising and funding research infrastructure that the Swedish Research Council applies is that needs shall be possible to capture broadly and that funding in new research infrastructure can occur in parallel with long-term funding of established national infrastructures. Even if this model serves its purpose well, there is room for improvements and adaptations. One of this relates to how technology and development projects, including in-kind grants, are to be managed, which is discussed in Chapter 1.8. Another development area is discussions between HEIs on how researchers' needs for medium-priced or medium-sized local infrastructures can be fulfilled. Yet another development area is how the coordination of distributed infrastructures that are based on already existing operations can be further developed and be made more efficient.

1.6 Membership of international research infrastructures and international funding

Large-scale international research infrastructures often entail collaborations that open the door to research that would otherwise not be possible to carry out. They are not just at the leading edge in terms of scientific questions and in the use of new technology, but are often scientific and technological drivers, and form a meeting place for the research and innovation fields they support. Swedish participation in the planning, build-up and operation of international research infrastructures therefore provides access for Swedish research, industry and the public sector to research opportunities, technical know-how and networks in a way that few other initiatives do. Even though these gains benefit all who use and actively participate in the build-up and operation of an infrastructure, the advantages for research, innovation and technical development at regional and local level are often even greater. That is why Sweden's hosting of international research infrastructures, such as the European Spallation Source neutron scattering facility, the space radar EISCAT-3D and the data centre for greenhouse gas measurement, ICOS Carbon Portal, produce major advantages for Sweden in the form of technical know-how and increased attraction for highly qualified personnel. The Swedish Research Council, together with other Swedish public and private actors, works actively to promote increased Swedish engagement in international research infrastructures. Within organisations such as ESFRI and EuroHPC, discussions are ongoing about the establishment of new research infrastructures in Europe.

The Swedish Research Council's mandate includes promoting Swedish research and innovation interests in the international infrastructures that we are contributing to, for planning, build-up and operation. In those that are being built up, the Swedish Research Council is working to ensure Swedish researchers and Swedish industry can materialise on the knowledge and competence resulting from the development, but also to ensure that Swedish HEIs and companies can deliver technically advanced products and services (Chapter 1.8). Examples of successful proactive work by the Swedish Research Council and other Swedish actors are ongoing deliveries of advanced technical components to the SKA radio telescope, and technical development and instruments to the astronomy organisation ESO's telescope.

Sometimes, it is the Government or the Parliament that makes the final decision on new membership of international infrastructures, but usually the Swedish Research Council will manage the membership thereafter, pay the membership fee and appoint representatives to governing and advisory bodies. The Swedish Research Council is continuously reviewing its international memberships. Since the previous guide to research infrastructure, an evaluation of the memberships has been carried out.[7] In addition to recommendations for the individual research infrastructures, a recommendation was made to strengthen the opportunities for increasing the number of Swedes employed at the international infrastructures. In collaboration with Big Science Sweden (BiSS) and a number of research infrastructures, the Swedish Research Council strives to increase the visibility of such opportunities.

1.6.1 International infrastructures and the geopolitical security situation

Since 2019, the geopolitical situation has changed greatly, not least through Russia's invasion of Ukraine, but also through Brexit, the COVID-19 pandemic and the increased competition between China and USA, and has contributed to a changed contemporary environment that do affect the funding and operation of research infrastructure.

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[7] National benefits from Swedish membership of international research infrastructures 2016–2019 (pdf)

Within the EU, changes resulting from Brexit are becoming more and more visible, as the United Kingdom is no longer part of the European research programme Horizon Europe. This contrasts sharply with the United Kingdom's former role as a major and important collaboration partner, both in research infrastructure and in research.

The COVID-19 pandemic created, and continues to create, problems with logistics and supply chains for everything from standardised industrial products (in particular electronics and some raw materials) to specialist products, which has led to delays to many projects, followed by increased costs and lower service levels for the users of the facilities.

Inflation has risen, which has led to many infrastructures asking for compensation, which may result in increased costs for the member countries. The price of electricity has increased sharply, which impacts particularly on accelerator-based infrastructures.

Russia's war in Ukraine has led to forceful actions against Russian state operators who are involved in European infrastructure projects. Germany did previously for many years try to tie Russia to Europe, for example via research and research infrastructure projects, but is now trying to end these. The effects of the war and the sanctions imposed are now being noticed, not least at the infrastructures where Russia is a part-owner: FAIR, XFEL and ESRF, but other projects are also impacted in different ways. Depending on the organisation form of the infrastructure, there are various options for managing the situation.

1.7 The Swedish Research Council's funding of research infrastructure

As initiatives and investments in research infrastructure are long-term, this means that large parts of the Swedish Research Council's budget for research infrastructure is bound up in international undertakings and in funding national infrastructure. Only a small part of the funding is available for new initiatives. The 2018 guide described the need for the Swedish Research Council to receive increased financial resources, for continued investment in ongoing research infrastructure and in new initiatives, aimed at meeting the major needs for research infrastructure that are predicted for the coming years. The previous guide indicated that the funds that would be released during the period 2019–2022 were smaller than the cost increases that were known even then, primarily linked to the big fall in the exchange rate of the Swedish currency since 2013, which therefore did not leave any room for national research infrastructures to apply for funding in the recurring call for grant to research infrastructure of national interest for 2021. The Swedish Research Council calculated that in order to return the funding of national infrastructure to the levels that prevailed in 2013, a considerable increase was needed to the budget for research infrastructure.

The Government's research bill from 2020 and the Government's budget bill from 2021resulted in an increased funding to the Swedish Research Council for research infrastructure of 400 million SEK for 2021, and a further 50 million SEK for the following year. The increased resources that the Swedish Research Council received allowed the targeted call in 2021 for grants to research infrastructure of national interest to be carried out, including both research infrastructures with ongoing grants from the Swedish Research Council and a number of new infrastructures prioritised in the needs inventory, for which the grant period in some cases stretches for as long as up to the end of 2028. With the increased resources, a call for neglected funding needs for investments in existing infrastructure could also be issued in 2021, for the years 2021–2025. Within the framework for the increased resources, the grant to MAX IV has increased for the period 2021–2025 according to the Government's research and innovation bill by 50 million SEK in 2021, 55 million SEK in 2022, 70 million SEK in 2023, and 80 million SEK in 2024–2025. In addition to this funding, RFI decided to add extra funding for ESS for the period 2021–2025, where 150 million SEK was set aside for Swedish in-kind supplies. For 2021, a further 160 million SEK was invested in ESS from RFI's budget. The additional funding has also paid half of Sweden's contribution to the construction of the SKA infrastructure and a number of other, smaller investments.

Because of the funding addition, the Swedish Research Council allocated a total of just over 3 billion SEK to infrastructure in 2022 (see Figure 2). A considerable proportion, 1 179 million SEK, related to investment in the construction of the European neutron source ESS, and consists of funding that the Government has directly earmarked for this purpose (1 149 million SEK) and extra funding allocated by RFI (30 million SEK).

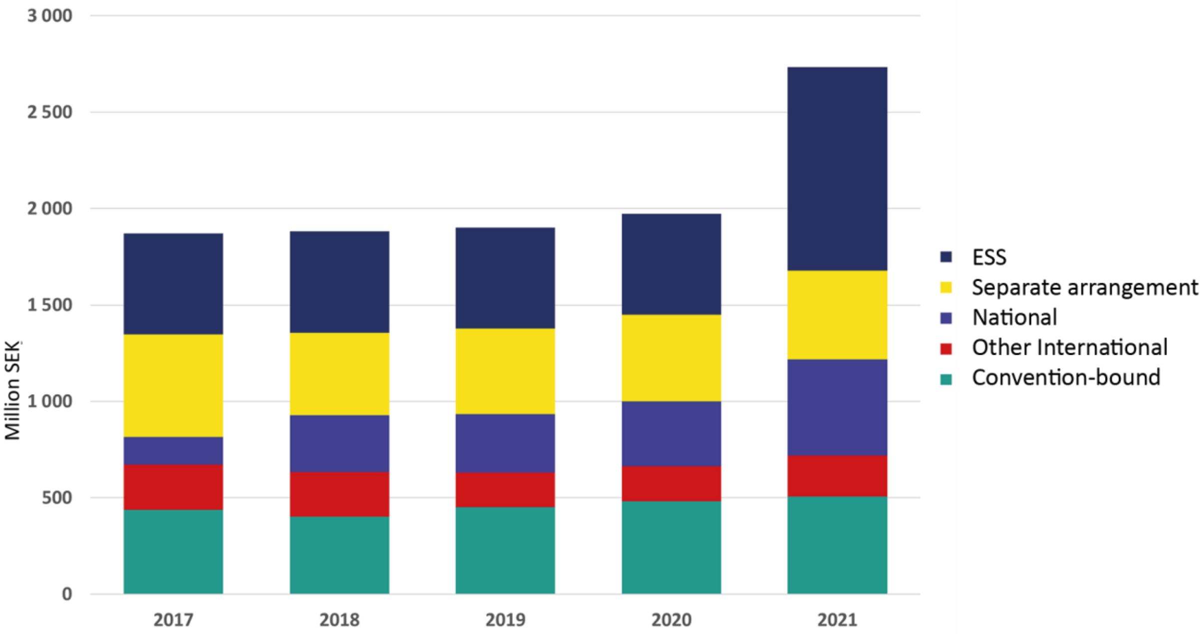
Just over 700 million SEK was used in 2022 to fund Swedish membership of international infrastructures. Of these, the European particle physics facility CERN is the largest, and the Swedish Research Council's overall expenditure on the membership fee and experiments at CERN in 2022 was almost 300 million SEK. Other international undertakings, which in 2022 covered just over 30 separate infrastructures, amounted to around 400 million SEK (see Appendix 1 for a list of all the international research infrastructures).

Figure 2. The Swedish Research Council's funding of research infrastructure in 2022 (million SEK).

Grants in million SEK to convention-bound facilities over and above those mentioned in the figure: EMBL 38, ESRF 23, XFEL 23, FAIR 18, PETRA 15, EUI 10, EMBC 8, IARC 8 and GBIF 1.

The Swedish synchrotron light facility MAX IV is the Swedish Research Council's largest individual national undertaking (see Figure 2), followed by SNIC. The grant to SNIC ended in 2022, and RFI then also decided on a grant to a new centre for large-scale computation resources, NAISS, for the period 2023–2026. During 2021, RFI decided on continued funding for MAX IV during the years 2023–2026 with a total of total 1 550 million SEK. The Swedish Research Council's grants to other national infrastructures amounted to almost 600 million SEK in 2022, which includes 159 million SEK to infrastructures linked to SciLifeLab. This is a considerable increase compared to the around 300 million SEK invested at the time of the previous guide to infrastructure from 2018 (see Figure 3). Other changes to the Swedish Research Council's grant funding have been relatively small during the period 2017–2021 (Figure 3).

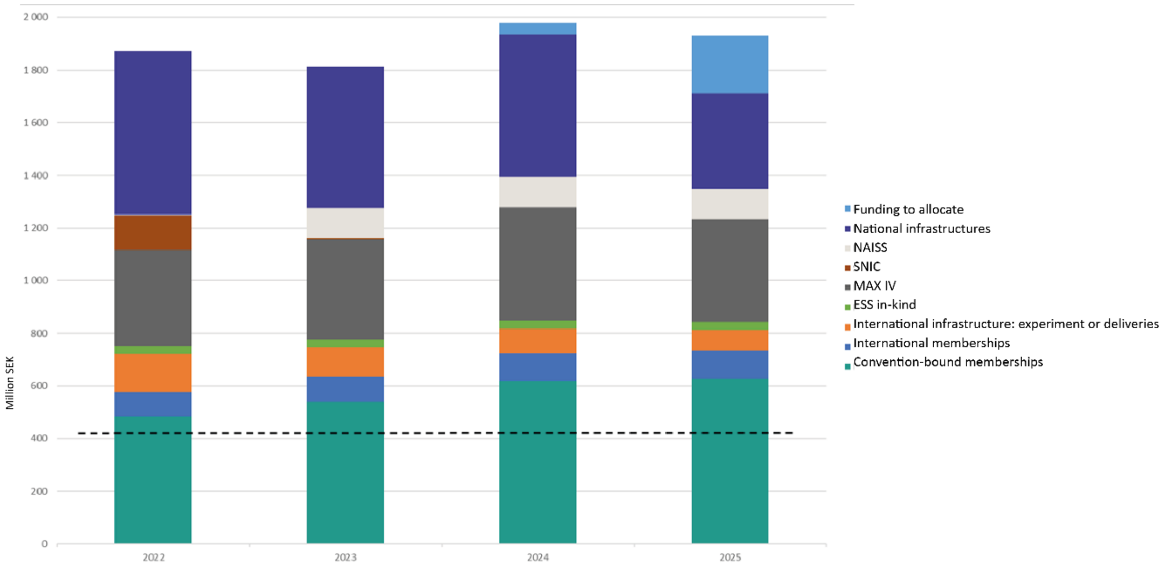
Figure 3. The Swedish Research Council's overall funding in million SEK to research infrastructure (national and international) during the years 2017–2021. Direct grants to ESS are included in the figure.



The greater part of the funding the Swedish Research Council allocates to research infrastructure is bound up in long-term undertakings, as shown in Figure 4. Over the period, funds are released as grants awarded earlier end, and in 2023–2025, the Swedish Research Council will be able to allocate around 250 million SEK in total. The greater part of the funds released is attributable to national infrastructure, and a smaller part to international undertakings. The funds made available can be used to engage in newly established research infrastructure, or to award renewed grants to research infrastructures that have previously received grants. For each grant decision, RFI must weigh up the benefit of a long-term engagement against the need for new research infrastructure. Funds released can also be included in strategic initiatives that RFI decides on.

The national and international research infrastructures are, however, facing considerable challenges in the years ahead, due to the prevailing geopolitical and economic situation in the world. The challenges are to some extent due to the pandemic, which has caused major delays to deliveries, which have seriously affected the infrastructures under construction, but mostly due to the increased costs predicted, caused by the price of electricity, the situation in Ukraine, and sharply rising inflation. For Sweden's part, the exchange rate towards foreign currency is also very worrying, as the international memberships are paid in the local currency. Most international research infrastructures are now forced to introduce considerable savings, where research projects and investments have been pushed forward in time, staffing is reduced and infrastructures may be kept closed for certain periods. As a result, this will very probably affect researchers' access to the facilities, which in the longer term will also impact on the regrowth of talent researchers and general growth. A probable development is also that the international infrastructures will work towards considerable increases in their membership fees. For the Swedish Research Council, this means that if the budget item for international membership fees increases greatly, the opportunities for national funding will be reduced. Consequently, the room indicated in Figure 4 as “funding to allocate” may reduce if the items for “convention-bound memberships” and “international memberships” increase.

Figure 4. Budget forecast for the Swedish Research Council’s grant to research infrastructure during the period 2022–2025 (million SEK).



“ESS in-kind” in the figure relates to grants received via an in-kind call issued for ESS. Direct grants to ESS are not included in the figure. The line in the diagram for the convention-bound memberships marks the funds, 420 million SEK, that the Government allocates to the Swedish Research Council for designated memberships.

1.8 Method and technology development and deliveries to research infrastructures

To enable basic scientific questions to be investigated at greater depth, make new discoveries, and provide society with new knowledge, we need more advanced prerequisites, such as more refined measuring methods and combinations of different types of data that can contribute to moving the research frontier forwards. As different types of deliveries can constitute a kind of payment instead of membership fees, technology and method development can provide double benefit to Sweden, Swedish research and the Swedish business sector.

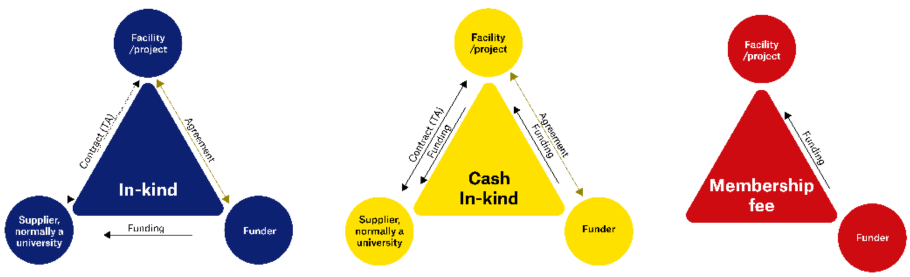
Developing methods and techniques within the framework for the research infrastructures often requires basic research. Development is done both in individual research teams, in some cases in collaboration with suppliers of equipment, but also on a larger scale, to enable the major international research infrastructures to be built up and developed. The basic needs of research become a requirement-setter to ensure methods and techniques are constantly improved. In parallel, companies get the chance to develop new products, services and business opportunities. Major research infrastructures sometimes have innovation offices to further bring on the considerable leading-edge technology that is being developed.

The development of cutting-edge technology is carried out in research teams that have specialised in instrument and method development. In the same way that successful countries manage these challenges, the opportunities to form a Swedish national competence centre for instrument and method development should be investigated.

Large-scale research infrastructures are too complex for individual research teams to build up and construct related instrumentation. Such research infrastructure is often entitled as 'Big Science'. Big Science Sweden (BiSS) is an organisation funded by the Swedish Research Council and Vinnova with the aim of identifying and increasing deliveries to Big Science, with emphasis on technical components in areas where Sweden is a leader in research terms. BiSS's task is to open doors for Swedish high-technology companies, HEIs and research institutes to broaden their contact networks and win more contracts for Big Science facilities. BiSS also acts as an advisor, with the task of motivating Swedish industry to take part in relevant procurements at research infrastructures.

In some cases, part of a membership fee can be replaced by Sweden, as a member country of an international infrastructure, delivering part of its undertaking in kind (Figure 5, blue triangle), which is an efficient way of building up competence in a field and getting greater added value from the membership. This can also happen through Sweden paying its membership in cash, and at the same time being promised that part of this funding will be used for procurement in Sweden in agreed key areas (which is known as 'cash in-kind', see Figure 5, yellow triangle).

Figure 5. Schematic illustration describing different funding routes for in-kind deliveries.



In the red triangle, the membership fee is paid straight to the facility, and no in-kind delivery is done. The research community is not directly involved in the development of equipment and software.

Several opportunities to link together research and technology development that provides advantages for the Swedish business sector are described on BiSS' website.

In the build-up of new research infrastructure, projects are normally divided up into work packages, where participating countries can take part and negotiate to carry out work packages for delivery that are advantageous for the own country. Such work packages give researchers the opportunity to carry out cutting-edge research, which in the long term provides opportunities for the business sector. Both apects can strengthen Sweden's competitiveness.

One example relates to ESS, which, according to a report from 2022[8], has entailed that Swedish companies received orders valued at just over 8.5 billion SEK (excluding value added tax) during 2015–2020, which far exceeds Sweden's cash contribution of around 5 billion SEK for the same period. In addition to this, the investment in ESS during the period 2010–2020 is estimated to have created around 37 000 annual full-time work equivalents throughout the EU, of which around 16 000 were placed in Sweden. The overall conclusion of the analysis is that the investments in ESS during the build-up period has generated positive socio-economic effects for Sweden, but that the spill-over effect in the form of technical innovation and improved competitiveness are not evident and strong. The lack of these spill-over effects are probably due to Sweden having undertaken to only provide cash contributions to ESS up until 2021, and therefore refrained from competing for in-kind deliveries of advanced technology and personnel.

Technical development projects at international infrastructures are often carried out in international collaboration between several project teams, where fluctuating exchange rates, changing requirements and price changes over long timescales means that budgets must often be adjusted and evaluated, and that extra funding may need to be added. Such problems mean that the researchers need to describe the risks, and the funding must take into account possible management of a contingency budget in a clear and transparent process, with allocation of responsibility between the researcher, HEI and the Swedish Research Council. RFI is investigating how Sweden can better handle technology development and its risks with the funding schemes.

1.9 Societal challenges and societal relevance

Research and research infrastructures form an important part of the puzzle for our understanding of and capacity to address some of today's very largest societal challenges. Among these are global warming, the depletion of biological diversity, wars and conflicts, pollution of air, land and water, and sustainable use of nature and the resources of the Earth. Agenda 2030 and the associated 17 sustainability goals forms an ever more integrated part of societal development. Active work on the agenda is a key factor for enabling us to address the societal challenges we are facing, now and in the future.

Sweden has clear ambitions and action plans for sustainable development in its three dimensions – economic, social and environmental. In its 2020 research

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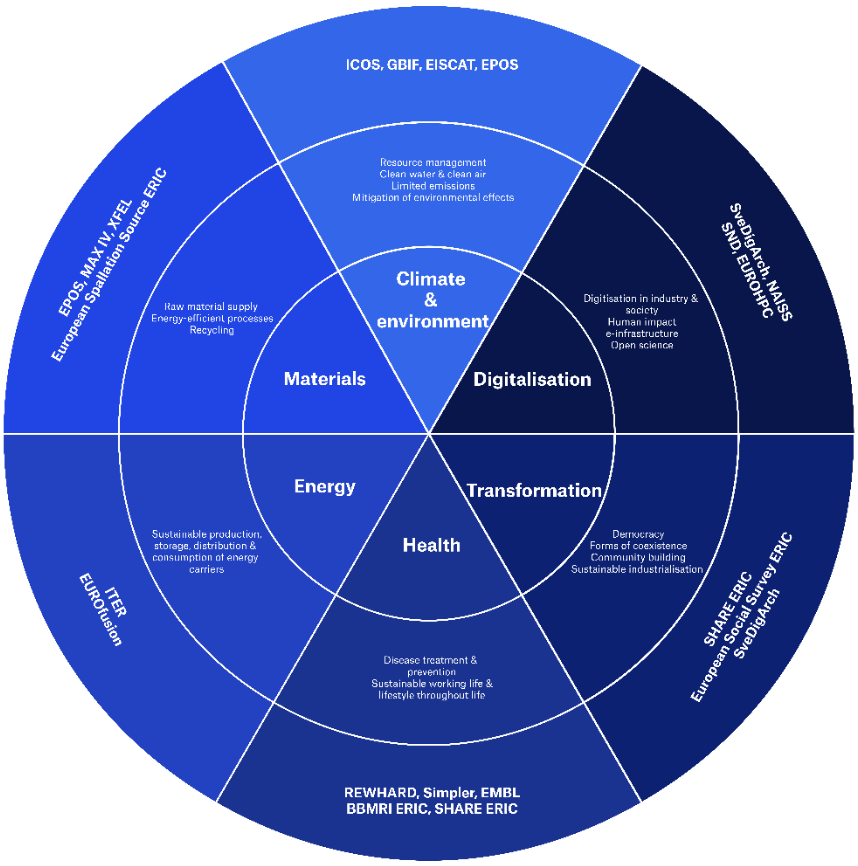
[8] Samhällsekonomiska effekter av svenska investeringar i ESS 2010–2020 (PDF).

bill[9], the Government stated that societal challenges need to be addressed with investments in strategic research of high quality and innovation initiatives in the five areas of climate and environment, health and welfare, digitisation, competence supply and working life, and a democratic and strong society. The Swedish Research Council funds research infrastructure both within Sweden and internationally that enables high-quality research relating to important societal, environmental and health issues. Many of the challenges we are facing require cross-disciplinary collaboration, and at several research infrastructures people work together across disciplinary borders. To address societal challenges in areas such as environment and natural resources, energy solutions, human health, digitisation and the human ability to adapt, we largely need new knowledge developed in collaboration with the abilities that research infrastructures provide to researchers (see Figure 6).

Figure 6. Examples of research fields (inner circle), related research questions (middle circle) and research infrastructures linked to these research fields (outer circle).



Please note that only a small sample of all research infrastructures are shown here. For a list of all the research infrastructures supported by the Swedish Research Council, see Appendix 1.

[9] Forskning, frihet, framtid – kunskap och innovation för Sverige. Website: Regeringskansliet

The COVID-19 pandemic is a topical example of a societal challenge where several national and international infrastructures have contributed to developing therapy methods and vaccines in record time. It exemplifies the importance of collaboration between different sectors that can contribute to solving the societal challenges of our times.

1.10 The business and public sectors as users, developers and suppliers

Advanced research infrastructure and associated method and technology development play a crucial role in many cases for competence build-up, not only in academia but also in business and the public sector. In today's ever more cross-disciplinary research, research infrastructures can play an important role as hubs, around which research, business and spin-off companies develop. Data collected in healthcare play an important role in research, and both the regions and the municipalities, which collect the data, are therefore central actors. Research that is ever more needs-oriented, addresses the global challenges and is conducted in collaboration with industry and the public sector places additional demands on research infrastructures.

The business and public sectors are in many cases users of research infrastructure in line with the Swedish Research Council's ambition for open access. Competence varies between users, and the Swedish Research Council has therefore on some occasions issued specific "accessibility calls", where one of the goals is to increase the use of different infrastructures by sectors outside academia. To fully realise the potential that research infrastructures offer to non-academic users, accessibility needs to increase further. This can be achieved, for example by developing the policies for accessibility the research infrastructures have in place, so that also societal and economic aspects of the research are assessed together with the scientific quality when applying for access to a research infrastructure[10].

In most cases, academics primarily use research infrastructure, while some types of research, for example in engineering science and what is known as 'practice-proximate research', there are also needs to access testbeds and demonstration facilities or other types of testing environments to fully be able to answer different research questions. Collaboration between different funding bodies and the business sector is needed to secure access to such facilities for both basic and applied research.

1.11 Open access to research data

Since 2017, the Swedish Research Council has had a Government mandate to coordinate the work relating to open access to research data, and, in 2022, this was made a permanent mandate in the Swedish Research Council's directive. The mandate includes coordinating, following up and promoting collaboration in

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[10] Diversity in use broadens the benefits of ESS

the transition to open access to research data. In the most recent report[11] on the mandate, the Swedish Research Council highlights a need for increased support tosupport the research system's transition to fully achieve open access to research data, including need to support with both technical solutions as well as with knowledge.

The national infrastructures play an important role in the transition to open access to research data in Sweden. Their activities are carried out on an organizational level between departments and HEI managements, and in their operative activities the infrastructures address the researchers' needs, the funding bodies' demands and the HEIs' policies. For example, the Swedish Research Council requires data produced by the national infrastructures funded by the Council to be openly accessible (within the framework for applicable legislation). To meet the needs of research and live up to the demands set, the infrastructures need to provide user support and educational initiatives. This changed and broadened role for the infrastructures requires personnel with specialist knowledge, both within the academic field and data management of the infrastructure and also communicative abilities for professional user support.

For one group of infrastructures, the very purpose of the activities is to make data openly accessible on equal terms for all researchers, nationally and internationally. Examples of such infrastructures are ICOS, which provides greenhouse gas data with the least possible delay via a data portal (Carbon Portal), and the European Social Survey (ESS) ERIC attitude survey. For infrastructures that provide experimental facilities, the situation is different. Here, data are created that relate to the specific research project. Although such data also will be made accessible, it requires both information about the specific context within which the data were collected, and also in consideration to the project's opportunities to publish its own research. Responsibility for the publication of data can in these cases either be assigned to the infrastructure, or be delegated to the project. The allocation of responsibility should be made clear and be stipulated in a data policy or agreement that regulates the relationship between the infrastructure and the research project. Another challenge for infrastructures' work with open access to research data relates to the management of sensitive personal data and patents, but also to other data that are covered by confidentiality and have been collected within the framework for, for example, interview and document-based surveys, observations of individuals or experiments where individuals are tested or examined, as well as data from registers, biobanks, patient data, genome sequencing and quality registers.

Since the previous guide (2018), the introduction of regulations at EU level that govern both the access to data for conducting research, and also the access to data that research has resulted in, has been implemented at national level (for example the EU's data protection regulation (GDPR) and Swedish legislation

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[11] Most recent report: Vetenskapsrådets samordningsuppdrag om öppen tillgång till forskningsdata 2022 (PDF)

governing the public sector's publication of data[12]), and more regulations are being prepared and discussed. The adaptation of Swedish legislation to these regulations needs to be done in such a way that research can use existing data, and that systematic build-up of databases is made possible. It must be possible to build up longitudinal databases with what is known as 'broad consent' from the individuals providing information to research.

The Swedish Research Council funds infrastructures whose purpose is to make research data accessible, such as the Swedish National Data Service (SND), the main purpose of which is to support accessibility, preservation and reuse of research data and related material, and Microdata OnLine Access (MONA), Statistics Sweden's platform for making microdata accessible. The Swedish Research Council also develops and funds the Register Utiliser Tool (RUT), a service that makes it easier for researchers to get a rapid and quality-assured overview of the variables that are available in Swedish registers, how suitable they are for use in a study, and whether and how they can be linked together.

A mapping within the coordination mandate showed that the majority of the national research infrastructures funded by the Swedish Research Council had a data policy, and three quarters of these policies stipulated open data. For future grant terms and conditions, a policy that manages open access to data should be a basic requirement for the national research infrastructures that the Swedish Research Council funds.

Development of machine learning and other AI methods will also increase interest in open access to data. In many cases, there is a need to link data from several sources, such as patient record data that are linked to data from national registers. To enable sharing of data for research purposes, we need opportunities to carry out analyses of shared data on secure platforms.

The cost of e-infrastructure at the infrastructures can be expected to increase, in relation to both personnel needs and needs for hardware and software, and also to storage needs for data sets produced and/or made accessible. The recommendation in the Swedish Research Council's report on the coordination mandate for open science (March 2022) indicates the need for increased financial support to achieve open access to research data. The research infrastructures will need such support to fulfill the ambitions in open science.

1.12 Needs for information, education and career paths in research infrastructure

To enable research infrastructures to be visible and accessible to users, but also attractive as workplaces, easily accessible information about the infrastructure is needed (Chapter 1.12.1). Another aspect that is fundamental for the success of most infrastructures is that they offer good career opportunities (Chapter 1.12.3). Gender-equal environments and gender-equal access to research infrastructures

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[12] Lag (2022:818) om den offentliga sektorns tillgängliggörande av data. Website: Sveriges Riksdag

are prerequisites for the best possible return on the investment in infrastructure. As from 2022, infrastructures awarded a grant shall also submit an action plan for gender equality, and thereafter follow up the development in the area in conjunction with their annual reporting. Information about gender equality and the work to develop this at the international infrastructures is more sparse[13].

HEIs, research funding bodies and the representatives of the disciplines are responsible for ensuring students and junior researchers have the opportunity to learn how to use different infrastructures in research, and that the competence of experienced researchers continually increases (Chapter 1.12.2). Seen in a longer time perspective, such educational initiatives can be crucial for Sweden's status as a research nation.

1.12.1 Information needs

For researchers, it can be a major challenge to find the right information about how to get access to an infrastructure, what services are offered, and what preparatory work is required to use a specific service. The need for an information flow adapted to the target groups to increase accessibility and broaden the use of infrastructures has increased drastically over the last few years, as development has been rapid in areas such as e-infrastructure, more advanced and specialised equipment are in use, and as a result of ever more complex and inter-disciplinary questions being addressed in research.

1.12.2 Training needs

Well-functioning infrastructures of national interest are not limited to supplying research resources, but also take responsibility for training the researchers who wish to use data. Conversely, to enable that data of highest quality is collected and optimal experiment conditions prevail, researchers also need to be involved in the selection and design of methods, tools and experimental environments. Intense collaboration between those who use the infrastructures and those who develop them is necessary. They might relate to training elements in first and second cycle higher education, as well as doctoral student courses, or direct user support.

The ongoing acceleration in the development of e-methods is making new demands on education within first, second and third cycles within HEIs, and entirely new educational programmes with emphasis on new e-science methods must be created to meet future needs.

In humanities, for example, there is an improvement potential in terms of competence-enhancing initiatives. Many disciplines within humanities focus on teaching skilled individual researchers who work with limited and comprehensible source and data sets, while the ability to work with larger and non-comprehensible data sets assumes methodology knowledge that is now in short supply. Research infrastructure initiatives within humanities show that

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[13] National benefits from Swedish membership in international research infrastructures 2016–2019 (PDF)

change is on its way, not least in languages and archaeology, and in relation to the fields that are known as ‘digital humanities’. Digital methods and tools, as well as access to and analysis of growing amounts of data, requires intensified educational initiatives in this area.

1.12.3 Career opportunities

With today’s rapid technical development, ever greater demands are being placed on infrastructures to supply the most recently developed equipment required to generate new knowledge. Along with this also follows increased demands to offer specialised and advanced user support and resources to manage and make accessible the data produced; both of which presuppose personnel with specialist competence. The room for scientifically developing and making existing infrastructure more effective needs to be expanded. This is a precondition for adapting Swedish research according to the new research needs that arise.

A long-term approach and clearer career paths are needed to enable advanced positions to be developed and maintained, and the opportunities for accruing merit within the academic systems at the HEIs need to be clear. At present, the opportunities to accrue merit are primarily focused on a traditional academic career, where merit in the form of research publications is heavily weighted. Funding aimed at junior researchers who wish to make a career in research infrastructure is sparing. At the same time, the funding agencies need to be more open than at present to taking into account merits other than strict academic ones, for example in grant applications.

The Swedish Foundation for Strategic Research (SSF) has issued a call for “SSF Research Infrastructure Fellows”[14] aimed at persons who are looking for alternative career paths at the research infrastructures. These may, for example, be research engineers, instrument managers, machine or laboratory managers – in short, persons who actively develop research infrastructures. This programme is an inspirational example, and several similar initiatives are needed in the future.

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[14] Bidrag till dig som utvecklar forskningsinfrastruktur. Website: Swedish Foundation for Strategic Research

2 Recommendations and strategic development areas 2023–2026

Below follow a number of overarching measures and recommendations relating to research infrastructure of national interest. Chapter 3 describes the current situation, future needs and challenges for research infrastructure in different scientific fields.

The recommendations are based on a vision that the Swedish Research Council's work will contribute to attractive and long-term sustainable funding in research infrastructure that creates prerequisites for Sweden to remain and continue to develop as a strong research and knowledge nation. This means that the infrastructures that the Swedish Research Council funds should be of high international standard, accessible to a broad group of users, and offer high-quality resources and user support to all users. This also means that it is necessary to have long-term undertakings, intended to enable stable funding throughout the lifecycle of the infrastructure.

The following recommendations in a number of overarching areas indicate the initiatives that are necessary for this vision to be achieved.

2.1 Coordinate actors for good and long-term funding of research infrastructure.

Long-term secured funding schemes for research infrastructure are needed to allow the Swedish Research Council to manage increased costs of both national and international research infrastructure. Funding directed to new research infrastructure will be based on strategic considerations, be identified via the needs inventory process and widely accepted.

Swedish research needs stable access to research infrastructure, which in turn requires long-term and stable funding. The most recent Governmental research bill from 2020 increased the funding for research infrastructure, which secured funding to ongoing research infrastructures and enabled several well-justified new investments in existing infrastructures. But more measures are needed to ensure a long-term stable system for funding research infrastructure.

A long-term approach is crucial for gaining full return on the funding of research infrastructure. To guarantee the long-term funding and achieve a good balance between new initiatives, further development and renewal of existing research infrastructure, the Swedish Research Council needs to be able to have greater flexibility in the funding allocation over time. It must be possible to plan important common resources for research, irrespective of the economic situation. To create bigger possibilities for responsible and long-term funding, as well as increased financial predictability, the room for saving allocated funds and appropriation credit for overspending allocated for research infrastructure needs to be increased, so as to achieve a better balance between budget years.

Active engagement from the HEIs that co-fund a large part of the national infrastructures is of the greatest importance for ensuring that funding bodies and research-conducting organisations can act in unison. In addition, there are plans for increased dialogue about the long-term strategic prioritisations to ensure that Sweden can act pro-actively in international contexts and obtain the best possible return on the national resources.

Costs of technology-intensive international infrastructures, where Sweden's undertakings are very long-term, have risen sharply during the last year, primarily due to increased energy costs, more expensive components and exchange rate fluctuations (see Chapter 1.7). In order to cover the increased costs to some extent in the budget allocation, the use by Swedish researchers of infrastructures with high usage-based membership or user fees may in some cases have to be limited. To this complicated equation must also be added that Sweden's actions in relation to investments in international research infrastructures may also impact on the willingness of other countries to invest in infrastructures in Sweden, such as the ESS, and it is therefore important to adopt an overall view of the research infrastructure landscape.

2.2 Take the entire lifecycle of infrastructure into account when prioritising and allocating funding

As most research infrastructures have a very long life cycle, there may be a need to change both the form and the level of support during its life cycle. For development and prioritisation of research infrastructure t, it is very important that the research infrastructures are evaluated and weighed against the needs of research and that the development of the entire available infrastructure landscape is taken into account.

Research infrastructures are built up and operated as long-term strategic investments, and Sweden's engagements in international infrastructures are often of a particularly long-term nature. Withdrawing from an infrastructure is often complicated and requires long lead-time. It is therefore important to make a detailed analysis of the long-term needs for Swedish research, and to compare different alternatives, before any decision is taken about Swedish membership of an international research infrastructure.

When it comes to national infrastructures, the Swedish Research Council is not dependent on the decisions of other countries, but the entire infrastructure lifecycle still needs to be considered for these undertakings. Consideration also needs to be paid not just of the level of funding, but also what type of funding is needed during the different phases of the infrastructure – from planning via construction and operation to, in some cases, eventual phase-out of the Swedish Research Council's support or close-down of the infrastructure.

Prioritisations and strategic discussions of needs for new infrastructure and continued support to infrastructure with ongoing funding from the Swedish Research Council need to be conducted continuously. Continued work will address the lifecycle approach more clearly than is done today, the settlement plans that all infrastructure funded by the Swedish Research Council have drawn up need to be taken into account in the continuing development of an infrastructure.

Evaluation is an important tool for developing the operation of an infrastructure, and a complement to annual reporting. An evaluation is intended to promote quality, both for funding bodies and for administrating organisations. Evaluation can also be a tool for supporting decisions relating to the funding level. When assessing applications from infrastructures with ongoing funding from the Swedish Research Council, greater weight will in the future be placed on how well the research infrastructure has developed during the previous funding period.

2.3 Strengthen the link between research and research infrastructure in all scientific fields

The processes that govern research infrastructure funding and prioritising need to recognise that changed and new needs for research infrastructure areas can arise as the research frontier moves forward. The Swedish Research Council works to recognise infrastructure needs in all scientific fields.

As research develops, the need for access to research infrastructure also increases. Research infrastructures in all scientific fields need to be developed continuously, and be reinforced when justified. Conversely, research infrastructure operation can lead to new areas of application being identified, and to the needs of already established user groups may be changing. There are today areas that identify infrastructure needs more than they traditionally did. Among them are parts of humanities, artistic research, engineering sciences and what is known as 'practice-proximate' research.

In humanities, there is great potential in the ongoing digitisation of collections in archives, libraries and museums (the 'ABM sector'). In order for the material to be useful to research, coordination and agreement is needed between the interests of the ABM sector and of research.

In social sciences, there is currently an increasing need for digitisation initiatives and data collection from interview surveys, e-infrastructure, data coordination, technical specialist competence, operational support, and method and tool development, for example.

In natural and engineering sciences, instrument-heavy infrastructures are a common feature of the research. The needs for these infrastructures remain, and they are constantly developing, with more refined measuring methods, new technologies, and so on.

The almost explosive increase in access to different types of data in all fields, together with the increasing intradisciplinary character of research, are also expected to lead to new and increased needs for infrastructure. To more clearly meet the research needs, the Swedish Research Council's work must become more coordinated between RFI and the Council's other scientific councils and committees. The Swedish Research Council intends to develop the current needs-inventory, to make it more strategic in order to be able to further strengthen the link between research and research infrastructure.

2.4 Create clear career paths and competence development for personnel at research infrastructures

To interest the most able researchers to work in a research infrastructure, attractive career paths are needed. Opportunities for competence development must increase to address the need for advanced user support at the infrastructures.

In order for the infrastructures to be accessible to all users, it is crucial that they assist with expert advice and advanced user support, so that the researchers using the research infrastructures get maximum benefit from them. For researchers to choose to engage in the build-up and development of infrastructures, clearer incentives are needed than is the case today. For example, merits from the build-up, development and operation of research infrastructures should be more appreciated and taken into account in appointments. When assessing a researcher's merits, both research funding bodies and HEIs, when applicable, should more clearly value merits accrued from working with research infrastructure, irrespective of whether the funding is for a project or for infrastructure.

There is a need for support forms and funding schemes that promote increased interest in careers at research infrastructures. One example is the grant for research infrastructure fellows that SSF is offering. Graduate schools in conjunction with infrastructures serve two purposes: firstly, the doctoral students become knowledgeable users, and secondly, they gain insight into what a career at a research infrastructure can offer.

2.5 Work towards increased benefit from Swedish membership of international infrastructures

Sweden will work to ensure that international research infrastructure memberships provide better returns, both in the form of competence and economic growth. The prioritisations that needs-inventories and evaluations lead to should be included in the trade-offs made in relation to the international research infrastructures.

Sweden's memberships of international infrastructures give researchers access to a large number of advanced international infrastructures that complement and strengthen the range of national ones. Swedish participation in international infrastructures should continously to be evaluated by RFI, and be prioritised according to their benefit to the research infrastructure landscape that Swedish researchers have access to.

Through the memberships, Sweden contributes to both the build-up and development of international infrastructures. In many fields, such as social sciences research, Sweden is an important partner, as Sweden is often used as a comparison country in research relating to areas such as reforms in gender equality, parental insurance and pensions.

At the same time as the international infrastructures provide great opportunities for Swedish researchers, the influence of individual researchers on their development is often limited. Apart from using the research infrastructure's resources, increased participation should be encouraged as a way for researchers to broaden their skill sets, and thereby gain more benefit of the memberships, for example by taking part in development projects (including those that can be credited as in-kind), or by becoming employed at an infrastructure.

The international research infrastructures, as the national ones, are not just of importance to academia. For example, actors from the business sector and research institutes take part in developing instruments and methods. Big Science Sweden (BiSS) plays an important role in increasing the benefit to the business sector of the research infrastructures (see Chapter 1.8). Swedish HEIs and Swedish industry should also, to a greater degree than at present, utilise the opportunities to take part in procurements and development projects, including in-kind projects. To achieve better returns and identify these opportunities in time, a more strategic and proactive way of working needs to be developed, to identify the contracts or development areas with the greatest potential for the Swedish research community, and for Swedish business. Here, engagement by the HEIs plays an important role. Where needs can be fulfilled through in-kind deliveries, Sweden should strive to increase the number of in-kind contracts, to reduce the Swedish cash contribution to the infrastructure.

The Swedish Research Council's evaluations of the Swedish returns on membership of international infrastructures have generally shown high scientific returns, and at the same time highlighted the need for international coordination. The most recent report, published in 2021[15], did, however, show that while the level of usage was often high, awareness of what was accessible to Swedish researchers within the international research infrastructures needs to be increased.

2.6 Utilise the potential of large-scale infrastructure in Sweden

Large-scale infrastructures in Sweden, such as ESS, MAX IV, SciLifeLab and NAISS, offer great potential for Swedish researchers and the business sector. Long-term resources for their operation and development needs to be secured, by the government, the HEIs and other stakeholders. Demands for the highest international standard should be placed on their operation.

ESS, MAX IV, SciLifeLab and NAISS, the infrastructure for national computation resources (SNIC up to the end of 2022) are major infrastructures of broad national interest. ESS, MAX IV and SciLifeLab receive significant parts of their funding straight from the government budget, while the Swedish Research Council adds funding via competitive calls or by special arrangement. Development, evaluation and prioritising of grants to parts of these infrastructures' operations need to be strengthened.

A common factor for these large-scale infrastructures is that they lead to unique opportunities for Swedish researchers, at the same time as they take up a significant part of the Swedish research infrastructure budget. For these infrastructures to provide maximum benefit to the Swedish research community, they need to be given the prerequisites for long-term work.

The establishment of the national synchrotron light facility MAX IV and the international neutron facility ESS in Lund have entailed, and are entailing, major undertakings for Sweden as a research nation, at the same time as their establishment gives Sweden opportunities to be an international centre for research using synchrotron and neutron techniques. The coordination that is already taking place with support from the Swedish Research Council's and Vinnova's Office for ESS/MAX IV will in the future further increase the possibilities to best utilise the opportunities that hosting ESS provide. Considerable opportunities for collaboration between the business sector and academia are linked to these infrastructures; a fact that the Swedish Research

[15] National benefits from Swedish membership in international research infrastructures 2016-2019 (PDF)

Council's targeted calls for accessibility has intended to stimulate, as has the development within the Science Village[16] and the upcoming 'SPIRIT technology park' facility[17].

The Swedish Research Council and SciLifeLab co-fund a number of national infrastructures, but have differing funding cycles and governance models, and also differing demarcations for what is included in each infrastructure. This creates a lack of clarity in what is considered as a unified national infrastructure, and also entails great difficulty in following up what the various initiatives result in, and whether their services are nationally equivalent and internationally competitive. For this reason, public funding of the life science infrastructures should be reviewed to ensure that multiple organisation forms for a single service do not make things more difficult for the infrastructures and their users. Furthermore, the international competitiveness of SciLifeLab-related infrastructures should be evaluated.

Data and different types of digital information are crucial for developing all research. The generation of data and need to store data in various ways are increasing rapidly, at the same time as issues relating to accessibility to data are growing. The development of an infrastructure for national computation resources that can fulfil the future needs efficiently is of the utmost importance and an important task for NAISS, as it takes over national responsibility from SNIC as from 1 January 2023. Computation resources, storage of data, accessibility of data and development of support need to address all types of users and be prepared for changing needs.

2.7 Develop grant and funding schemes for needs in different research fields

As different research fields and different phases of an infrastructure's lifecycle have differing funding needs, new funding schemes need to be introduced that responds to these needs.

RFI's prioritising and funding of research infrastructures is currently done primarily via a needs-inventory, followed by a call for applications for grants to research infrastructure of national interest, where both national and international infrastructure can be included. Over the last few years, it has become even clearer that the current prioritisation and funding model needs to be supplemented to meet the needs of research and of society.

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16 Science Village Scandinavia AB. Website: Science Village

17 SPIRIT – Swedish Platforms for advanced Infrastructures in Research, Innovation, and Technology. Website: SPIRIT

The infrastructures of some research fields are inexpensive in terms of investment in facilities and technology, while the same infrastructures' other costs, for operation or data collection, can be considerable. What is to be considered infrastructure costs therefore has to be based on the needs of the different infrastructure areas.

Now and then, situations arise where Sweden has to make a rapid decision relating to funding of research infrastructure; usually in an international context. These include memberships of international research infrastructures, collaboration projects between Swedish researchers and researchers at the infrastructures, for example for the purpose of developing advanced technology and methods, but also grants for participation in the build-up and operation of international infrastructure, for example through in-kind contributions. Here, greater flexibility is needed, for example by issuing calls outside the two-year cycle or by creating specific forms of support.

Within the framework for Swedish participation in international infrastructures, not least in conjunction with build-up or development projects, it is not unusual for delays and increased costs to arise. It is therefore urgent that risk analyses and contingency budgets, and allocating responsibility for these, are included already in the application procedure, and that they are followed up to enable any changes arising to be dealt with together with the administrating organisation.

In the Swedish system for funding research infrastructures, difficulties have been identified for researchers to get funding via their HEIs for procurement and development of medium-sized equipment and databases, and for the personnel that is required to maintain and operate them. HEIs that have established internal processes for securing such needs today could serve as good examples.

2.8 Provide better prerequisites for research through open access to research data

Targeted financial schemes need to be made to allow infrastructures to adapt to and support increased open accessibility to research data. The work towards open access to research data must be done in a coordinated way and in collaboration between HEIs, research infrastructures and research funding bodies. When adapting Swedish legislation, attention needs to be paid to the opportunities for research to use existing data.

Increased demands for open access to research data will have a major impact on research infrastructures that already often generate, manage or make accessible large data volumes. To increase the accessibility of open data, both technical development and economic resources are needed, as well as access to expertise on ethical and legal issues relating to openness. Principles must be developed for which data can be made openly accessible, and data management of open data needs to comply with the FAIR principles to a greater extent, so that the investment in open data also results in data that can be widely reused.

In the EU's data strategy from 2020, the European Open Science Cloud (EOSC) plays a central role for research and innovation. The ambition is that EOSC shall link together and continue building on existing solutions and infrastructures in the EU to create a joint, virtual environment that provides services for storage, management, sharing, analysis and reuse of research data. Sweden's engagement in this project is strategically important, and contributes to developing the national work on open access to research data. Seamless sharing of research data and associated services across national borders and research disciplines has an enormous potential to drive the development of research forward. More Swedish HEIs and research infrastructures should become engaged in the initiative.

2.9 Develop coordination and prioritisation of research infrastructure of national interest

The work on a strategic agenda for research infrastructures will require an increased and broadened engagement of the research community and other actors. Such an approach will make the Swedish Research Council a stronger research policy adviser on issues relating to research infrastructure.

Both the report into strengthened focus on the research infrastructure of the future[18] and questions arising during RFI's work on the needs-inventory and guide points towards a continued need to develop the Swedish Research Council's work on research infrastructures. Both the long-term and the strategic importance of the infrastructures underline the need for structured interaction, both between RFI and the Swedish Research Council's other decision-making bodies, including the Board, and with external stakeholders, such as HEIs, regions, the business sector and other research funding bodies. Such interaction should enable a stronger strategic agenda and better documented research policy input in relation to needs and prioritisation of research infrastructure.

The current budgetary constraints and geopolitical situation reinforce the need for clear prioritisation of the investments in infrastructure and underline the importance of a strategic way of working. At the same time, there is a need to simplify the work, as the current processes are relatively complicated, and sometimes unclear about roles, responsibilities and mandates.

When prioritising research infrastructure, ongoing and future societal challenges and the opportunity to carry out research of particular importance to Sweden may be weighed into the prioritisation, without lowering the requirement for the highest scientific quality. Here, dialogue and interaction with other actors, such

[18] Stärkt fokus på forskningens infrastruktur (PDF)

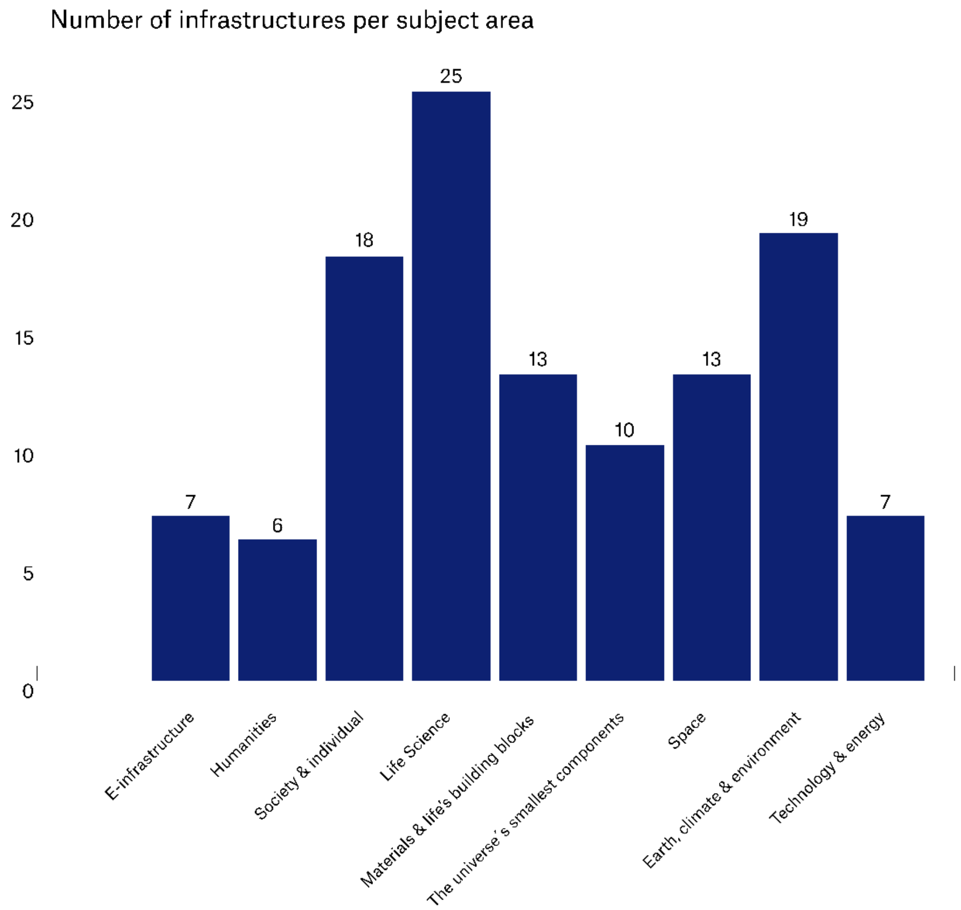
as research-funding and research-conducting organisations as well as the business sector and the regions, need to be developed and deepened.

At present, there is limited interaction with the business sector in the development of long-term strategies as well as in the operation of and participation in the development of research infrastructures. There are difficulties, such as competition aspects, but also an untapped potential. Great potential can also be found in the interaction with regions and municipalities, not least within medical and clinical therapy research. For such interaction, accessibility of data is a crucial issue.

3 Development and needs within subject areas

The Swedish Research Council funds, to differing degrees, a large number of research infrastructures of national interest, both national and international. Appendix 1 has a list of research infrastructures with ongoing support from the Swedish Research Council. The list shows that while some research infrastructures are aimed at a specific scientific field, others are relevant to several fields. In the figure below, the number of research infrastructures with ongoing support from the Swedish Research Council is divided up per subject area (Figure 7). As shown in the figure, life science is the field that where the highest number of infrastructures are available (25 infrastructures), followed by earth, climate and environment (19), and society and individuals (18). The infrastructures used by humanities, e-infrastructure, and engineering and energy are fewer in number.

Figure 7 Number of infrastructures supported by the Swedish Research Council divided up by subject area, November 2022.



Chapters 3.1–3.9 below describe both the current situation and development and also future needs and challenges for each subject area. Each chapter begins with a brief description of important advances in priority areas since the 2018 guide.

3.1 E-infrastructure

The 2018 guide highlights the importance of securing access to networks, storage, computer resources and user support, and for Sweden to participate actively in international contexts. Since then, a decision has been made about a new organisation for national computation and storage resources, NAISS. The Swedish engagement in EOSC and Euro-HPC has intensified.

The need for e-infrastructure in research is continually increasing. Driving forces for the increased needs include technical development, which enables more comprehensive questions in traditionally computation-intensive research fields, as well as new experimental equipment that allow greater resolution. This gives rise to substantially larger data sets, which entail new e-infrastructure challenges for storage and analysis. The development is also driven by rapidly expanding digitisation of scientific fields that have traditionally not had particularly great needs, for example humanities, social sciences, ecology and clinical medical research. There is increased interest in data-driven research, and the use of methods such as machine learning and artificial intelligence, which contribute to the increased needs in e-infrastructure.

E-infrastructure refers to equipment, services and resources that enable computation, analysis, communication, processing and access to data. It includes computational systems, storage, networks, infrastructure for providing digital services and tools, as well as expertise and user support to ensure these resources are utilised in the best possible way. e-infrastructure is provided by specialised infrastructures, as part of subject-specific infrastructures, by HEIs, by international organisations and by commercial stakeholders. In addition to being a prerequisite for research in practically all scientific fields, e-infrastructure is also an area that is developing rapidly, and the border between what researchers, research projects, universities and national/international infrastructures are responsible for is not clear in all cases.

e-infrastructure includes equipment and services for digital analysis of information in many subject areas. Opportunities for and experience of accessibility and processing of data vary greatly and must be carried out carefully, in some cases confidentially, to protect individuals, research teams and industrial representatives. Research and practice in cyber security is of great importance for guaranteeing the confidentiality, accessibility and integrity of services and data. This is both to prevent data from being abused or modified, and also to guarantee the digital integrity of users and suppliers. The value of research data, its preservation, quality assurance and accessibility put new demands on well-functioning and user-friendly e-infrastructure.

Research in e-infrastructure range widely, from more traditional computer architecture and algorithm development via user interfaces to entirely new technologies, such as quantum computers. Some of this research is done within strategic e-science centres, but a lot is also carried out within subject-specific areas motivated by specific research questions.

3.1.1 Current situation and development

The existing e-infrastructure landscape for research is undergoing a major process of change. At the international level, important initiatives are being established, such as the European partnerships EOSC, for publishing, finding and re-using research data, tools and services, and the EuroHPC Joint Undertaking (JU), for making Europe competitive within high performance computing (HPC). Guidelines and legislation for data management are continuously being developed, which have consequences for research, and new research infrastructures generate ever growing amounts of data that need to be transported, stored and analysed. Sweden participates actively in EuroHPC JU, both in the form of investments in HPC (the super-computer LUMI, which is co-owned by EuroHPC JU and a consortium of 10 countries) and via participation in research programmes and competence-enhancing initiatives, where the

Swedish Research Council and Vinnova co-fund projects with Swedish participation. The first implementation phase of EOSC is in progress, with the aim of making it accessible to researchers in 2025.

Internationalisation and digitisation of research lead to new ways and methods of working, and to increased coordination of IT systems within many research fields. Cloud-based services are used to an increasing extent, and in some cases replace traditional use of HPC. Basic preconditions are coordination and standardisation of electronic identities, where the umbrella organisation GÉANT plays an important role.

In medicine and life sciences, for example, several initiatives are in progress on standardising and sharing biological and clinical data, with major technical and legal challenges in terms of sensitive data, data formats and management. Sweden takes part in global initiatives, such as GA4GH, and European initiatives in EMBL/EBI and ELIXIR, for example. At national level, there is the metadata tool RUT for searching and combining metadata from registers held by regions and public agencies. In some research fields, there are successful Nordic e-infrastructure collaborations, such as projects within the framework for NeIC (Nordic e-Infrastructure Collaboration) and NordForsk's initiative Nordic Commons, which works towards a secure infrastructure for health data.

National services for management and storage of data are continuously developed. For example, SND together with the HEIs' local units for data management and SUNET have developed a service for storage and access to research data, DORIS. SUNET also has other storage services for different types of needs in its range of services. SciLifeLab has an initiative for subject-specific data nodes, as part of the programme Data Driven Life Science. The Swedish Research Council, via SUNET, provides a service for creating data management plans that HEIs can join.

A new organisation for management, governance and funding of national computation resources and associated services, NAISS (formerly SNIC), has been in place since the beginning of 2023. Of great importance is continuous support for the large amount of research that is dependent on these resources, which requires an adaptive organisation with good ability to both capture the needs of researchers and to adapt to the rapid development of technology and the international e-infrastructure landscape.

The need for e-infrastructure in research infrastructures is increasing. In many cases, an important part is the need for e-infrastructure competence within the infrastructure, to secure cost-effective and broad use. One example is ICOS Carbon Portal, where an overall approach is taken for user interfaces and aggregated data for researchers with differing backgrounds and needs.

As new instruments and new facilities begin to generate data (such as MAX IV, ESS, SKA), and with the development within data-driven research, artificial intelligence, machine learning and quantum computers, with initiatives such as SciLifeLab and the Wallenberg Foundation's National Programmes (DDLS, WASP, WQCQT, WISE, and so on), rapid changes in the research landscape are happening that lead to greater and broader e-infrastructure needs in the form of hardware, advanced user support, training and coordination.

3.1.2 Future needs and challenges

The demand for e-infrastructure is great, and will increase in the future along with a broader research base. The landscape is changing rapidly, and both long-term planning and rapid adaptation to the world around us is necessary to ensure Swedish research remains at or reaches the research frontier.

A general trend is that new experiments generate large amounts of data (increased detector coverage, sampling frequency, and so on), and data processing is therefore becoming increasingly complex, and requires access to storage and computer resources that are normally not available to individual user groups. For this reason, strategies, infrastructure and user support in the management of large data amounts need further development. Preparatory work ahead of the introduction of open access to research data should also be carried out. Satisfactory access to powerful national super-computer resources and efficient storage for analysis of data generated to continue developing computation-intensive research must be secured. Just as in many other areas, life sciences are producing ever greater and ever more complex data quantities, and therefore the needs of research for help and support in bioinformatics are also growing. The great demands placed on knowledge and computer capacity for analysing and storing data were highlighted already in the previous guide, and as these data are in many cases potentially sensitive data from individuals, there is also specific requirements for the data to be handled securely.

Continued engagement in international initiatives, such as EuroHPC and EOSC, are important to continue fulfilling the needs of the research community. Engagement is important, both for getting access to resources and for monitoring and participating in the development of new services, standards and cyber security measures, but also for providing good opportunities for Swedish research teams to participate in international projects. In line with this, we need to strengthen collaboration at the Nordic level to increase the possibilities for influencing activities at the European and international levels.

Increased coordination and interaction between research infrastructures, HEIs and the public sector in terms of management, quality assurance and accessibility of data is needed to enable new research and to create coordination and efficiency gains. In areas such as medicine and life sciences, there are ethical and practical challenges to coordinating biobanks and databases, where initiatives at Nordic and European levels may show the way forward. Similar challenges also exist within social sciences and humanities. Research questions within these areas have led to work starting on improving coordination between different types of data sources, and on using large-scale data for research in an efficient way. The work is partly about coordinating and sharing information between regions and countries without challenging data security. The borders between different disciplines are also in the process of being erased, and researchers in different fields will increasingly be dependent on the same e-infrastructures.

There is a continued and increasing need to ensure that advanced user support and parts of software development are included in research infrastructures to achieve cost-effective and broadened use. In areas such as climate, environment and health, research data can then be made accessible for use by society and industry, to assist in reaching the UN's sustainability goals.

Coordination between the Swedish Research Council, the Knut and Alice Wallenberg Foundation and other major initiatives in the e-infrastructure area is needed to create the best possible environment for researchers, and thereby increase the potential of strengthening both the base and the leading edge of research.

3.2 Humanities

The 2018 guide highlights humanities as a field experiencing strong development and needing research infrastructure to utilise and coordinate data and make it accessible, and to create tools and methods for humanities research. With the increased funding for research infrastructure via the most recent Government research bill, RFI was able to award grants to two new research infrastructures in humanities: SveDigArk and Huminfra. These initiatives will, for example, enable complex data-driven analyses to be performed on data that have previously not been accessible or coordinated. This, in turn, enables research to be conducted that is unique and very important to today's societal challenges, for example the interaction between humans, the environment and culture.

Research in humanities helps to understand and explain how human expressions, thoughts and interactions function today, in the past, and in the future. Through new knowledge, perspectives and innovations, the field contributes to managing the multiplicity of societal challenges and opportunities that the world is facing today. Such issues are also dealt with in other scientific fields, but through the long time perspectives, broad linguistic competences and critical distance, humanities play a crucial role in addressing them.

Research infrastructures are of great importance for new ground-breaking research also in humanities. The amount of material of relevance to humanities research is increasing and is digitised at archives, libraries and museums. Ever more people are spending their lives online, and ever more cultural expressions are produced and consumed digitally (debate, literature, music, art, games, video and so on). Data collection, coordination and analysis require infrastructure resources over and above what individual research projects can provide. As in other scientific fields, humanities need access to tools and methods for enabling good and effective analysis of large data sets. Humanities research is also becoming more interdisciplinary, and in several subject areas experimental techniques and methods from natural sciences and medicine are used to collect and analyse research data. In language technology research, digital technology and AI are used to develop algorithms to identify disinformation on the internet – a modern example of source criticism. Brain imaging methods (MR, MEG, EEG) are important in language and cognition research to better understand how the human brain processes information. In this way, new tools can be developed to facilitate things like language learning and other cognitive abilities. In archaeological and historical research, synchrotron and neutron sources are used to investigate different types of old objects.

The ability to digitise and coordinate different data collections into interrelated databases contributes to developing and changing questions and interpretations of historical and contemporary sequences of events. Digital text and image analysis contribute to the ability to read and see patterns in large amounts of text, music and images. Through a combination of GIS technology and a time scale, data can be visualised in time and space. Using 3D modelling, past or fictitious environments and artefacts can be recreated. Together, these techniques contribute to new questions and interpretations relating to changes in place over time.

For humanities research, it is important, within the framework of national and international research infrastructures, to coordinate and utilise data from several countries and time periods for comparative studies. When researchers working in humanities coordinate themselves and in a dedicated and structural manner define new problem areas, which can be matched by relevant infrastructures, this provides increased opportunities for ground-breaking research.

3.2.1 Current situation and development

In humanities, modern research infrastructures consist of digitised material, digital tools and adapted research methods, which jointly enable cross-disciplinary and cross-methodological research in several research fields. The insights of humanities researchers into archiving principles, preservation issues and not least source criticism and issues relating to personal integrity and ethics contribute in a crucial manner to the build-up of high-quality infrastructures.

There is, at the same time, a great need for unified solutions for production, coordination, accessibility and long-term preservation of digital and digitised material for research purposes. Ongoing initiatives to strengthen research via improved databases in fields such as language, history and cultural science, as well as a systematic digitisation of collections in archives, libraries and museums, are important elements of this. This can, however, only be done if the major data-producing actors collaborate on methods, tools, technology and exchange of data. Within the field of archaeology, methods and tools from natural science disciplines have long been used, which are now developing rapidly and result in ever better knowledge about pre-histori developments and their chronology, and also about the interaction between humans, nature and climate. Humanities laboratories contribute with digital instruments and expertise, allowing analysis of and experimentation with research data in innovative ways, in areas such as digital text analysis, spatio-temporal and 3D data visualisation.

In terms of international research infrastructure, Sweden is for example a member of CLARIN ERIC, a consortium aimed at creating and maintaining language technology tools and collections of digital material. CLARIN ERIC was created based on a vision that all our digital language resources and tools, both in Europe and outside, should be accessible via an on-line environment to support researchers in humanities and social sciences in particular. SWE-Clarin is the Swedish node of the consortium, and is funded by the Swedish Research Council. Since 2018, the Swedish Research Council has also been funding the research infrastructure SwedPop, which coordinates the most important, and unique in the world, historical population databases in Sweden into a joint resource for research. SwedPop will not just be important for researchers in humanities, but also in social sciences and, to some extent, medicine.

In the previous guide and appendix, we pointed out a need for national infrastructures for humanities laboratories and digital archaeology. As from 2022, the Swedish Research Council is funding two new research infrastructures in humanities, Huminfra and SveDigArk. Huminfra aims to promote Swedish research in humanities and artistic research in particular, by coordinating and developing existing digital resources and competences, methods, tools and educational opportunities in Sweden. The aim is to create a joint platform for increased interoperability and better and more strategic resource use in the field of humanities. SweDigArk, a national infrastructure for archaeology, has great opportunities for making Swedish research influential, both by improving the quality of data already collected, and by coordinating data for the purpose of providing access to an entirely new generation of research data that can form the foundation for new knowledge. The research infrastructure also enables increased national and international collaboration between archaeological research and research in areas such as ancient DNA, climatology, history, quaternary geology, agrarian history, geography and osteology.

3.2.2 Future needs and challenges

A growing proportion of humanities research is becoming ever more quantitative, experimental, multidisciplinary and methodologically advanced. Researchers within art and the humanities are increasingly basing their work on information in digital format (such as digitised texts, artefacts in various cultural heritage collections, data from social media and other internet-based platforms) and associated services, tools and research methods. The field often designated as ‘digital humanities’ in particular is seeing considerable development work, in terms of both research methods and research tools. The development in this area is very rapid, and points to a qualitative transition in terms of methodology and the amount of processable data. The need for infrastructures and tools that support humanities researchers who need to handle digital and digitised material is therefore increasing.

As stated in the Government’s research bill from 2020, humanities play an important role in cross-disciplinary research aimed at increasing and developing

Sweden’s abilities in areas such as information and cyber security. Various national research infrastructures, such as Huminfra, SWE-Clarin, SweDigArk, and the cross-disciplinary infrastructure InfraVis apply and make new technologies accessible for developing tools and methods for processing, analysing and visualising different types of data. There is a need to increase investments in this area.

Sweden’s cultural heritage institutions and HEIs are already managing large and particularly valuable infrastructures for research in the form of archives, libraries and registers. The collections at these institutions is largely not yet digitised, and only a small proportion has been made machine readable and thereby become accessible for new research methods. There is therefore a continued major need for cultural heritage digitisation on a broad and unified front. For example, Swedish research libraries are now laying the foundation for joint digitisation of all Swedish printed material. If funding and issues relating to copyright for this could be solved, they would constitute a unique research resource for large sections of the humanities field. Furthermore, in recent years, various research funding bodies have carried out initiatives for making already digitised cultural heritage accessible and harmonised. The initiatives are laudable, but it is still of the utmost importance that cultural heritage data are coordinated in relation to research questions and problem areas, for example by digitisation initiatives responding to areas for infrastructural initiatives formulated by research needs. In order for digital cultural heritage data to be useful now and in the future, there also has to be over-arching infrastructures to support formatting, harmonisation and aggregation, as well as exchange and long-term maintenance of both data and meta-data. Without such curation, and despite digital formatting, cultural heritage data risk soon becoming out-of-date.

Digitisation of areas such as cultural heritage material has often been carried out at the initiative of and within the framework for individual research projects, or by individual research teams. On the one hand, this has meant that research and infrastructure have in many cases been developed hand-in-hand, which has also led to new research questions, combined methods and competences developing at the same rate as the new research results that have been possible to obtain using the infrastructure. On the other hand, it has also meant that the humanities infrastructure as a whole is partially fragmented, and that its use is unevenly distributed geographically and subject-wise. At the HEIs, there are major needs for specific infrastructure competence to enable access to and facilitate correct use of research infrastructure. Huminfra, which was awarded infrastructure support from the Swedish Research Council in 2021, is one example of an infrastructure that can contribute to this.

3.3 Society and individual

The Swedish Research Council’s analysis that formed the basis for its input to the Government’s research policy (Vetenskapsrådets analys som underlag till regeringens forskningspolitik 2019) pointed out the need to secure researchers' access to necessary infrastructure and the consequences that risked occurring if the funding of research infrastructure did not increase. For example, the current initiative for and coordination of databases of individuals in social sciences and medicine would have to be terminated, which would risk disrupting important data collection, and the work on making data material accessible to a broader user base would be without funding. There was also a risk of Sweden having to leave the ESS (European Social Survey) ERIC and SHARE ERIC. As funding was provided for the Swedish Research Council's work with research infrastructure via the most recent Government research bill, this important investment in databases covering individuals could continue, and data could still be collected and made accessible within the framework of a large number of longitudinal surveys.

The 2018 guide described the need to coordinate existing context databases, that is, data relating to institutional circumstances, legislation, democracy, organisation of welfare policy, armed conflicts, and so on. In 2019 and 2021, the Swedish Research Council awarded funding to the Demscore research infrastructure to establish its operation. Thereby its continuous collection of data could be secured.

Social sciences research helps us to explain how our societies work and affect us. This provides understanding of how individuals, and also groups of individuals, react to changes in society, but also of how societal institutions and governance systems function. Social sciences research is, however, not limited to social structures and individual actions, but is also of crucial importance for challenges as widely differing as climate change and pandemics. To manage such fundamental challenges in the best way, we need not just technical and medical knowledge, but also understanding of societal processes and broad knowledge about the role of the individual in society.

Research infrastructures for social sciences can differ very much in appearance. They might, for example, be large surveys of living conditions, attitudes and political activity, but can also consist of register data collected and summarised by different public agencies. It is important to underline that research in social sciences, humanities and medicine have in many ways grown closer to each other, not least when it comes to research at individual and register data level. For example, to understand the link between genetically determined prerequisites and social outcomes at individual level, data with genetic information has to be linked to social science data. This has been facilitated by the research infrastructures built up over the last few years – for example, the coordination initiative of databases covering individuals in social sciences and medicine carried out by the Swedish Research Council in 2017 (see below).

Infrastructures in social sciences also consist of broad collections of contextual data describing how our societal institutions function and develop over time. A link between such databases and databases covering individuals is often of great benefit to research. Context data cover the economic, social and value-related contexts and structures that individuals live and work in, and can relate to households, companies, schools, and countries, but also factors such as exposure to poor working environments, air pollution or other environmental components. To this can be added digital contexts, such as different types of internet-based environments, such as YouTube and Twitter. In many cases, build-up of databases and systems for making them accessible are required, with the option of linking individuals to the context they live and work in.

3.3.1 Current situation and development

Social sciences research both generates and needs access to research data of different types. Sweden and the other Nordic countries are in a unique position, as data on individuals can often be gathered from existing public registers and longitudinal databases that in some cases stretch back as far as the 17th century. Register data are limited in content, however, and many social sciences questions require new data to be collected for specific research purposes, for example by asking people directly about their attitudes or behaviours.

An investigation was carried out on behalf of RFI in 2012 about the opportunities for and benefits of a possible coordination of surveys and longitudinal studies. The investigation showed a divided landscape, and a need to coordinate databases covering individuals. As a result, the Swedish Research Council issued in 2015 a call for two-year operation and coordination grants, which representatives of database infrastructures with ongoing grants from the Swedish Research Council could apply for. This resulted in a number of coordination initiatives, which were awarded grants for research infrastructure of national interest in 2017, and since 2018 the Swedish Research Council has funded the infrastructures (coordination initiatives) CORS (coordinates and supplies survey-based research infrastructure for social sciences research), NEAR (national e-infrastructure for research into different aspects of ageing), REWHARD (enables research into work and living conditions and individuals' heath), and SwedPop (coordinates the most important historical population databases in Sweden into a joint resource for research). Within the framework for this initiative for databases of individuals, the educational science infrastructure (UGU) and the Swedish Twin Register were also awarded funding. In 2021, the Swedish Research Council awarded these infrastructures continued funding, providing opportunities for continued operation and build-up (including data collection) of each operation, but also for researchers to use the data made accessible. The investment in register-based research and the build-up of the search and metadata tool RUT, which the Swedish Research Council is developing as part of its Government mandate to make register-based data more accessible, form other important parts of the context. Within the framework of the mandate, we are now planning for RUT, in the long term, to also include information about researcher-generated data in cases where they include personal data.

Enabling collection of data on individuals from several countries for comparative studies is also very important for research, not least linked to the need to understand the effect of the country-specific context and to place

Swedish circumstances into an international perspective. In this respect, Sweden’s participation in international infrastructures is important. Sweden is often regarded as an interesting study object in relation to the labour market and working life, gender equality, and family circumstances and policies, both in Swedish and international research. Sweden is a member of SHARE ERIC (Survey of Health, Ageing and Retirement in Europe), ESS ERIC (European Social Survey), and CESSDA ERIC (Consortium of European Social Science Data Archives). SHARE-SE and ESS-SE are Swedish nodes of the respective ERICs, while the Swedish National Data Service (SND) is a Service Provider in CESSDA ERIC.

Context data is data at a higher level (such as in a ‘context’) that are relevant to link to data about analysis objects at a lower level (such as individuals, companies, etc.). Swedish researchers have managed to build up several databases for context-based data, which include items such as systematically collected information about democratic institutions, armed conflicts, corruption, the quality of governmental governance, and social security. There is great potential for coordinating and linking different databases to create synergy effects that can facilitate ground-breaking research. Examples are global challenges, such as the UN’s sustainable development goals for 2030, but also regional and local analyses in which great contextual variation may exist in relation to factors such as population composition, political actions and regulatory frameworks. The research infrastructure DEMSCORE (Research Infrastructure for Democracy, Environment, Migration, Social policy, Conflict, and Representation), the purpose of which is to increase access to data by coordinating a number of context databases, received grants from the Swedish Research Council in 2020 and 2021.

The need to contextualise individual data is expected to grow, in order to enable analysis of more complex questions. Rapid technology and methodology development are occurring in social sciences, meaning that different types of data can be analysed simultaneously. For example, numerical data from surveys can be combined with large-scale non-numerical data sets, based on texts, artefacts, images and sound. Machine learning is, for example, used to combine information from survey data and satellite images that show levels of light in order to provide a better understanding of living conditions in low income countries. The development also provides new opportunities for data visualisation aimed at communicating research results to a broader public. Furthermore, in cross-disciplinary research, where humanities and social sciences researchers study human cognition (for example in linguistics, psychology and cognition research), different types of brain imaging form a central research methodology for increasing understanding of how humans process different types of information and disinformation. There is an increasing need in humanities and social sciences to have access to and process data produced with the help of various non-invasive brain imaging methods.

3.3.2 Future needs and challenges

Respect for the integrity of individuals and research that is conducted according to applicable legislation and ethical guidelines are both self-evident. It is important that research can use existing data in an optimal way, and that systematic build-up of databases is made possible. At the same time, it is important to research that data on social and medical interventions can also be used for research purposes. In its mapping of data sets of national interest, the National Board of Health and Welfare has indicated several areas where the eligibility of data currently is more or less limited in ways that impact the opportunities not just for national follow-ups, but also for research. Examples of such areas include child and pupil health, mental health, interventions by social services, municipal health and medical care, and data relating to cancer screening. Here, it is important to underline that research is ever more dependent on longitudinal data, where individuals are monitored over long periods. This type of database is typically of the kind that may be covered by the Swedish Research Council's definition of a national research infrastructure, which means that it can be used by several research teams for different projects within one or more fields of research. As research is a dynamic process, this means that it must be possible to assemble longitudinal databases with broad consent from the individuals providing information to research. The increased need for longitudinal studies of individuals also raises the potential conflict between the requirement to protect the integrity of sensitive personal data and the needs for and opportunities of open science, where data may also be made accessible during peer review of scientific publication.

3.4 Life science

Due to the increased funding for research infrastructure the Swedish Research Council was allocated in the most recent Government research bill, RFI was able to award grants in 2021 to a number of new research infrastructures in life science. Protein Production Sweden is a new national distributed research infrastructure that coordinates expertise and a range of services within recombinant protein production. The research infrastructure will support research in many biomolecular research disciplines, as well as in targeted development of medicines and diagnostics and in biotechnology applications. The Swedish Research Council is now also contributing to the development of the national research infrastructures Chemical Biology Consortium Sweden, which offers expertise and methods in chemical biology, aimed at understanding and being able to influence cellular processes at molecular level, and SwedNMR, which coordinates expertise and instruments in NMR spectroscopy. Both Chemical Biology Consortium Sweden and SwedNMR are also active within SciLifeLab's platforms for chemical biology and structural biology. In 2021, RFI also awarded grants to upgrade eight national infrastructures in life science through a special call for investments in existing infrastructures. Since the previous guide, Sweden has become a member of two international infrastructures, Euro-Bioimaging ERIC and EU-OPENSCREEN ERIC.

Life science research is central to our understanding of fundamental life processes and methodology and methods for studying these are developing rapidly. For this reason, investment is necessary in national research infrastructures, where advanced technology can be used and be broadly accessible. National and international research infrastructures described in this chapter contribute to important initiatives in health and welfare and also in climate and the environment. Our understanding of fundamental life processes can be applied in many different sectors, and thereby widely impact society, for example health and medical care, the chemical industry, agriculture, forestry and the pulp-making industry, and the food industry.

Life science is a broad concept, which might be described as the scientific field that in a wide sense studies living organisms. Curiosity-driven basic research in the field forms the basis for a broad spectrum of bioscience and biological disciplines. These include medical research, which provides knowledge of how the human body works and how disease can be prevented, how it arises, and is treated, but also covers veterinary medicine, organism biology, ecology and other fields within biology, as well as biotechnology. Life science includes cross-disciplinary research together with engineering sciences, ethics, social sciences and humanities.

In medicine, Sweden has a unique source of knowledge in longitudinal personal registration number-based registers with data at population level within the research fields of medicine/public health science and social sciences. Data from different public agency and quality registers should also be possible to combine with data from biobanks, for example, but to facilitate the use of register data and interoperability of registers we need well-documented register data management according to the FAIR principles[19]. By mandating several different public agencies, the Government has placed great focus on registers and other data from health and medical care having to become more accessible. However, the various initiatives need to be coordinated, and accessibility needs to be improved, in order for the overall information to become a strategic resource for research, innovation and follow-up.

Research in the life science field also contributes to knowledge accumulation in biotechnology, where work is in progress on biofuels and biochemicals produced by recombinant micro-organisms, new types of biomaterials and green transition of industry, where for example designed enzymes that replace chemical synthesis contribute to reducing the environmental impact. Our way of life has

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[19] The FAIR Guiding Principles for scientific data management and stewardship. Website: Nature

impoverished biodiversity in the world, and therefore major efforts and understanding of the underlying mechanisms are needed.

To quickly find new knowledge within the life science field, accessibility to advanced analysis methods and searchable databases is also needed. COVID-19 is a topical example of a societal challenge where several national and international infrastructures have contributed to developing diagnostic tools, therapy methods and vaccines in record time.

3.4.1 Current situation and development

Major investments in national research infrastructures for basic research in life science are being made. These provide access to expertise and instrumentation in optical imaging techniques, structural biology techniques, including cryo-EM, mass spectrometry and sequencing technologies, for example. In addition, there are large-scale 'omics' technologies implemented, where miniaturised parallel experiments are carried out in areas such as genomics, proteomics and metabolomics. These system biology tools have broad areas of application. An area that has expanded greatly in recent years is techniques for analysis of single cells and mapping of the molecular landscape in healthy and sick tissues by measuring the level of RNA, proteins and small molecules (metabolome) on tissue sections. The opportunity to analyse gene expressions in individual cells can lead to entirely new insights in everything from the course of illnesses and ecology to large-scale biotechnology processes. The Swedish Research Council supports access to national research infrastructure in this field through grants to areas such as the Swedish National Infrastructure for Biological Mass Spectrometry (BioMs), the National Microscopy Infrastructure (NMI), the National Genomics Infrastructure (NGI), the nuclear magnetic resonance infrastructure SwedNMR, and the Chemical Biology Consortium Sweden (CBCS). In addition to this, the Swedish Research Council supports the life science field via infrastructures as discussed in Chapter 3.5.

Basic research has led the way for patient-proximate applications of national research infrastructure in medicine and health. Precision medicine, a field seeing very strong growth, means that therapeutic inputs are increasingly tailored, based on specific knowledge about the individual's condition. There are now several well-developed platforms for clinical genomics, which produce large amounts of data, both for clinical use and in important basic medical research. Clinical proteomics and metabolomics are also being developed continuously, and play an increasing role in research and therapy. Since 2015, the Swedish Research Council has also been allocating funds for coordination to Clinical Studies Sweden, a national collaboration that supports and develops the conditions for carrying out clinical studies, with regional contact points to expertise within the field.

A prerequisite for high-quality research and reproducible results is always that the material and the samples used in analyses are of a high standard and suitable for the intended investigation. This puts great demands on both the biological samples collected and on the biomolecules that have been isolated and purified.

For biobank samples to be used optimally, harmonised collection, documentation and storage are required, as well as opportunities to withdraw and analyse samples. This task is central for Biobank Sweden, which functions as an umbrella organisation for biobanks and sample collection within both HEIs and health and medical care. Sweden's membership of the international infrastructure BBMRI-ERIC also contributes to harmonisation within the field at the European level.

Just as in many other areas, life science is producing ever greater and ever more complex data sets, and the research needs of help and support in bioinformatics are growing. The great demands placed on knowledge and computer capacity for analysing and storing data were highlighted already in the previous guide, and as these data are in many cases potentially sensitive data from individuals, there is a requirement for the data to be handled securely. The need to reinforce competence within statistics and bioinformatics for analysis of large data sets remains. The national infrastructure National Bioinformatics Infrastructure Sweden (NBIS) offers researchers support in the analysis process, including standards for data management, access to data and software, as well as help with analysis and storage of data. Despite a broadening of the competence within NBIS, many research infrastructures and research groupings have employed their own bioinformaticians, with specialist competence to ensure that planning, collection and analysis of data are done in the way that is best for the discipline. Coordination and interaction are important for a unified bioinformatics environment. At the European level, international organisations, such as Elixir, work with standardisation issues and interoperability as well, and also provide a large number of tools and databases.

Accessibility and interoperability are also of the greatest importance within the medical/public health science and social sciences research fields, and form an important issue for the infrastructures that link together health with factors such as lifestyle and genes. Examples of such infrastructures that the Swedish Research Council cofunds are the Swedish Twin Register, the National e-infrastructure for Aging Research (NEAR), and the Swedish Infrastructure for Medical Population-Based Life-Course and Environmental Research (SIMPLER).

SciLifeLab is a major actor within the life science field, which in addition to its research programmes also provides national research infrastructure with support from the government, HEIs, the Knut and Alice Wallenberg Foundation and the Swedish Research Council. The range of services is currently provided by 45 distributed service units across all of Sweden, but primarily located in Stockholm and Uppsala. The emphasis is on the large-scale 'omics' technologies, bioinformatics and biomedical imaging, and there is also a platform for developing academic medical projects. As mentioned in Chapter 2, the Swedish Research Council and SciLifeLab co-fund a number of national infrastructures, but differing organisation forms and terminology creates some uncertainty about what can be regarded as a unified national infrastructure. Increased coordination in this area would be valuable.

As also mentioned in Chapter 2, Swedish memberships of various international infrastructure organisations add access to great opportunities for Swedish researchers. One of these is EMBL, which operates within cell and molecular biology and climate-related research, and which, via the European Bioinformatics Institute's (EBI) data resources, plays a crucial role in the life science field. In general, however, awareness of what is being made accessible within the international research infrastructures needs to be increased, when it comes to available services and opportunities to take part in research programmes relating to infrastructures such as EMBL. Since the previous guide in 2018, Sweden has become a member of Euro-BioImaging ERIC and EU-OPENSCREEN ERIC, which strengthen the opportunities for Swedish researchers in biomedical imaging and chemical biology, in terms of both instrumentation and competence development.

3.4.2 Future needs and challenges

In life science, there are many important infrastructures that may be accessed. For researchers, it is still a major challenge to find the right information about what services are offered, and what preparatory work is required to use a specific service. Sample management, preparation and storage can be crucial for obtaining high-quality data, and the requirements vary between different methods that are applied.

In precision medicine, more and more large-scale data are used, produced from clinical samples, within both basic and translational research. This area of individual-adapted therapy is continuing to grow rapidly, both internationally and nationally. With this follow challenges relating to linking and integration of different types of data, such as disease-related information from patients and genetic and molecular data from basic research. For this to be done in a secure and efficient way, issues relating to ethics and data security play a central role. There must also be an establishment of competences within bioinformatics, statistics and mathematics that is combined with the understanding of basic questions within life science and clinical research. One example is a new initiative for data-drive life science (DDLS) within SciLifeLab. Work has started on improving coordination between different types of data sources, and on using large-scale clinical data for research in an efficient way.

Digital infrastructure and functioning biobanks are essential for developments in life science. In order for these infrastructures to function optimally in the future, it will be necessary to coordinate both samples and data into larger collections, and in the longer term, to coordinate these in larger infrastructures with a clear national focus. It is important that both existing and new biobanks standardise both methods and formats for sample collection and metadata. Services for users, such as joint internet portals, should be developed to make things easier for users and to increase accessibility. Biobank Sweden's work on improving its process for the use of samples and communication with clinics when collecting these is of the greatest importance.

Increased sample collection, data production and analysis, as well as opportunities for new clinical applications, will place greater demands on coordination between research and clinical work, and on coordination and prioritisation of research questions both within and between regions.

Another important discussion is how the business sector's use of research infrastructure can be promoted to contribute to the development of health and medical care. Here there is a need for collaboration between different research funding bodies, such as the Swedish Research Council, Formas and Vinnova, as well as industry, to enable research infrastructures to benefit the many.

As mentioned above, development in the 'omics' area is rapid, and Swedish researchers are in the international forefront in several areas. There is a need to continue having strong national infrastructures in areas such as genomics and proteomics, and to establish new ones in particularly strong fields. One such example is spatial analysis of cells and tissues, where the molecular landscape in an individual cell or in tissues can be determined.

3.5 Materials and the building blocks of life

The 2018 guide described the needs for equipment, in particular in areas where RFI had already invested both nationally and for participation in international infrastructures. Special mention was made of the investments into large-scale X-ray and neutron scattering. Other investments, such as Myfab, where the clean room network gives many researchers access to advanced tools, and NMR spectroscopy (Swedish NMR Centre) and cryo-EM-microscopy (built up within SciLifeLab) have been possible to continue as a result of the 2020 Government research bill.

Investments in the X-ray area, in particular MAX IV, but also the international memberships, such as ESRF, the Swedish beamline at PETRA III and XFEL, are now operational and serve the users. The guide described the need to continue investing in the build-up of MAX IV. Today, the facility has 16 beamlines, which receive researchers from all over the world in strong competition. Swedish use of other X-ray sources is also relatively high, and XFEL in particular should be mentioned here, as Swedish researchers get a large proportion of the time available in very strong competition.

Much in our daily life is affected by materials and their characteristics. Life itself, with its cells and molecules, is also an advanced form of material. Studies of materials are central in a number of research fields, such as engineering sciences, physics, chemistry, geology, biology, medicine and archaeology. Innovations within the areas of materials and medicine are also important for the continued competitiveness of Swedish industry.

In the work on the materials of the future, materials that can form part of a circular economy will be in greater focus. The unique characteristics of recycled materials must be possible to evaluate at several levels; from atomic level to compound molecules and materials. For example, the development of chemical recycling has meant that textiles and plastics can now be broken down into their original molecules, which can then be used to build up another material or another product of the same quality.

Multi-functional materials, where several characteristics, such as magnetic, catalytic and electric are combined, are an important research field where the limits of our knowledge are constantly moved forward. This type of new materials can, for example, be important in the development of high-technology products that are necessary for transforming, transporting and storing energy in sustainable energy systems. Following rapid biochemical processes in real time, for example how plants convert sunlight into energy using photosynthesis, will probably become possible. The opportunities that have opened up for designing nanomaterials will be central for fields such as energy, the environment, and medicine and health.

In life science and medical research, several methods are playing an increasing role in understanding biological processes in detail. Some of these are structural definitions at the molecular and atomic levels, studies of protein dynamics, biological imaging, studies of surfaces, such as membranes and other bioactive surfaces, and of complexes in solution, for example protons and water molecules in the ‘active sites’ of enzymes. Hybrid methods for determining the structure and dynamics of macro-molecules across several orders of magnitude in time and place are being developed, and will have a major impact on our ability to understand and influence biological processes.

3.5.1 Current situation and development

To meet the needs of research, investment is needed in advanced infrastructure, such as large-scale X-ray sources (synchrotrons and free electron lasers), neutron sources, advanced microscopes, mass spectrometers and laser systems. Sweden continues to make major investments in this area, and not least the investments in MAX IV and ESS are opening up opportunities for experiments that were previously not possible. Sweden is also part of investments in infrastructures such as the European XFEL, the world’s most advanced free electron laser. These investments also need to include the opportunity for both methodological and data analysis development, as well as development of the Swedish user base for these facilities. As many of the investments are very large and resource-intensive, membership of other countries’ investments in research infrastructure, both within the European system and separate investments, offer opportunities for researchers to use resources that are today not available in Sweden. The Swedish Research Council is therefore a member of the X-ray facilities ESRF, European XFEL and PETRA III, and of the neutron sources ILL and ISIS.

In the area of structural biology, a national infrastructure for cryo-electron microscopy has been built up within SciLifeLab, with considerable support from the Knut and Alice Wallenberg Foundation and others. Together with the Swedish NMR Centre, which is part of both SciLifeLab and, since 2022, the distributed infrastructure SweNMR supported by the Swedish Research Council, these facilities enable studies of structures and dynamics of a broad spectrum of biological samples. For many analyses, the research process requires a combination of different methods and instruments. Examples of this are complementary use of X-ray technology, electron microscopy and neutron scattering. In some cases, the experiments can be carried out via remote access, which has increased markedly as a result of the COVID-19 pandemic.

The use of this type of facility often requires access to additional infrastructure in the form of laboratories and clean rooms to prepare samples and carry out preparatory studies. In many cases, these resources will be of a local character; in other cases, advanced clean rooms are needed, which are coordinated nationally by Myfab, for producing and characterising materials.

3.5.2 Future needs and challenges

To realise the potential of MAX IV, long-term funding of maintenance and operation as well as further investments into beamlines will be required. The Swedish user base should be increased and broadened to include new fields, and also involve industry to a larger extent than today. MAX IV should aim to be world-leading within a number of profile areas that use the unique features of the synchrotron. At the same time, it is important to respond to broad-based needs of the Swedish research community, even if the facility cannot fulfil all the synchrotron needs of Swedish researchers.

Sweden, being the host country for ESS, entails a major responsibility for both the construction of the facility and its future operation. Swedish research within the neutron area has been reinforced, and Swedish use of existing neutron facilities, such as ILL in France and ISIS in the United Kingdom, is increasing. It is important that this development continues, and that when ESS has become operational, there is a strong Swedish user base that can be switched over to ESS from ILL and ISIS. Sweden should also put effort into ensuring further Swedish engagement in the upcoming instrumentation of ESS, in particular via in-kind contributions.

The fact that MAX IV and ESS are co-located in Lund creates opportunities for the development of a dynamic research environment that includes academia, institutes and industry. Engagement in the facilities, both their funding and their use, is of national concern. To ensure that this happens efficiently, a coordinated national strategy is needed that covers the entire chain from the physical infrastructure around the facilities to the build-up and optimal use of competences and human resources throughout Sweden. Recently, the Knut and Alice Wallenberg Foundation made a major investment in materials science, aimed at creating knowledge about sustainable materials. Such an investment is expected to increase the demand for research infrastructure, and to speed up the development of new methodology and instrumentation.

3.6 The universe's smallest components

The 2018 guide highlighted both the Swedish research community's dependence on large-scale research facilities in this field, primarily CERN and FAIR, but also diversification towards other types of facilities, such as ESS. A preliminary study for a fundamental physics experiment at ESS, HIBEAM (High-Intensity Baryon Extraction and Measurement), has been funded. In the build-up of FAIR, which has been surrounded by delays and cost increases, Sweden has been an active partner and taken early funding decisions. At CERN, the upgrading programmes of the ATLAS and ALICE experiments are continuing, with funds from RFI. The need for coordination and a unified strategy within the field was highlighted in the previous guide, and the Swedish Research Council implemented a major review of accelerator-based particle and nuclear physics during 2019–2020, at RFI's request.[20]

Subatomic physics has revolutionised how we look at our universe in the strive to better understand matter and radiation. The best description of how the fundamental forces of the universe interact with its smallest components is the 'standard model'. The focus in subatomic physics is on how this model should be expanded to explain features such as dark matter and the relationship between matter and anti-matter. Prevailing theories are tested by calculating and measuring with high precision the characteristics of already-known particles. In high energy physics, the energy of the experimental collision processes is also gradually increased, to expand the search area for elementary particles that have so far remained undiscovered. In the future, a combination of upgrades of existing research infrastructures and new experiments is needed. One identified challenge in this field is the large amounts of data that will be produced and require management.

In today's curiosity-driven nuclear and hadron physics research, the focus is on understanding how the strong nuclear force holds together the subatomic particles in our elements. In this way, we can also understand how the elements were formed, and how the strong force interacts with other forces in macroscopic objects.

3.6.1 Current situation and development

Researchers in subatomic physics are in many cases entirely dependent on access to large-scale infrastructures. These are often too expensive and complex for a single country to develop and operate, which means that there is a long tradition of international collaboration.

As a member of CERN, Sweden is participating in and supporting the upgrade of the Large Hadron Collider (LHC) within the High Luminosity programme (HL-LHC). Sweden is also participating in the experiments ATLAS, ALICE and

[20] Accelerator-based infrastructures in the fields of particle and nuclear physics (pdf)

the upgrades that are in progress to make the experiments ready for HL-LHC. Full utilisation of LHC, including detector upgrades ahead of HL-LHC, is of the highest priority in Europe and is the focus of the updated European particle physics strategy published in 2020 – a view that is also broadly shared by Swedish particle physicists. The physics programme HL-LHC will, for example, enable observation of pair production of Higgs particles, which will provide unique knowledge about the Higgs field's characteristics, at the same time as the precision also allows other processes in the standard model to be tested. The large resource-demanding data set also significantly increases the chances of discovering new particles.

At CERN, Sweden is also engaged in the ISOLDE facility for hadron and nuclear physics. Through its many upgrades since the start in 1960, ISOLDE has remained at the cutting edge of international facilities in these fields, where the still ongoing upgrade towards HIE-ISOLDE (High Intensity and Energy ISOLDE) greatly expands the experimental possibilities.

At the same time, development is still in progress of the international nuclear physics Facility for Antiproton and Ion Research (FAIR), where Sweden is a member of a consortium together with Finland. FAIR is in part complementary to CERN and, with its high intensities, will be the most advanced facility for hadron and nuclear physics. FAIR will offer a broad research programme that includes detailed studies of strong nuclear force at both quark and gluon level, as well as at nucleus level. The combination of high intensity and high precision provides a unique chance to study fundamental symmetries and the multiplicity of heavy ion and particle beams means that the characteristics of the matter can be measured under extreme conditions of temperature, density and pressure. Swedish groups are involved in the planning and completion of several accelerator and detector components, largely via in-kind contributions. For a long period, FAIR has been suffering from delays and increasing costs, and is currently expected to be at an early operational stage in 2027–2028. Parts of the future research programmes are, however, already possible to complete within the 'Phase 0' programme, where new detector components are used within the already existing accelerator infrastructure at the host laboratory GSI. The Nuclear Physics European Collaboration Committee (NuPECC) is an expert committee for the European Science Foundation, which in its strategy for 2017[1] states that the completion of FAIR is of the greatest strategic importance for European nuclear physics.
There is potential to use ESS for particle physics, and Swedish researchers are currently involved in initiatives to enable the construction of experiment stations for these purposes at ESS in the future. In a targeted call, RFI has recently funded a pilot study of HIBEAM, which is a possible future instrument at ESS within the expansion of the facility's instrument suite.

[1] An update is expected in 2023.

3.6.2 Future needs and challenges

Research in sub-atomic physics spans very long timescales. Already when an experiment is in progress, the next generation of facilities has to be planned. Funding research and development projects (R&D) is an important first piece of the puzzle of driving development forward and ensuring that Sweden can play a leading role if the project is realised. Swedish research councils' general support for R&D at a very early stage, together with later support for planning and development of the LHC and FAIR experiments, was crucial for Sweden's large contribution to the detector development at these facilities. The same type of support will be important for future initiatives in this field.

Greater energy and intensity, together with improved measuring methods, open the door to observations of unknown particles beyond the standard model. To achieve energies beyond those that can be achieved in HL-LHC, the opportunities to implement a further upgrade of LHC, as well as the opportunities to construct an entirely new particle collider, are being studied. This includes both more powerful hadron colliders that achieve higher energies and also lepton colliders, where the heaviest particles in the standard model, such as the Higgs boson, can be studied with high precision. The updated European particle physics strategy emphasises the importance of continued work on illuminating the technical and financial opportunities for a Future Circular Collider (FCC), which is done in a technical study that continues until the end of 2025.

Processes beyond the standard model do not just have to make themselves known via phenomena at high energies, but may also include difficult-to-discover phenomena at lower energies. There is therefore a continued need to conduct complementary search programmes at lower energies within fields such as neutrino physics and detection of dark matter. The Swedish Research Council currently does not support any infrastructure for this particular purpose, but researchers can still participate in experiments, research and development and construction through international agreements. Key issues are which infrastructures Sweden can and should currently support, besides LHC and HL-LHC.

For FAIR, new and refined methods need to be developed to compress data, and this need will increase as the intensity of the experiments is gradually scaled up. Another challenge is to achieve the high-resolution particle beams and compact, localised beam targets that play a crucial role for precision measurements in hadron physics.

FAIR is planned to be in use for at least ten years. With upgrades in the form of higher intensity, new instrumentation and polarised beams and beam targets, it could be significantly longer, however. Beyond FAIR, there are plans for a new European facility with high intensity, known as EURISOL. This could either be created through upgrades of some existing facility, or be based on future technological breakthroughs. The aim is to form improved models of the creation of new nucleuses in stars and the formation of supernovas. Better understanding of this can also lead to effects on applications relevant to the broader society, for example in energy storage. The completion of ESS, with its high intensity, may open the door to new opportunities in the borderland between nuclear physics and particle physics.

In sub-atomic physics, where research is carried out across large time scales, a long-term approach is very important. For this reason, a unified, well-established national strategy is needed for prioritising Swedish engagement in research infrastructure, preconditions for related technology development, and review of the relatively uncoordinated funding landscape. Within the Swedish Research Council, there is a need to better link infrastructure activities to the research grants awarded by the scientific fields. At the moment, RFI assumes long-term funding responsibility for the build-up and operation of major international infrastructures in sub-atomic physics, while the researchers who will use the infrastructure must rely on shorter project grants. Research funding is primarily done through short-term project grants to individuals, which does not always suit research fields based on a long-term approach and large-scale collaboration. It is a challenge to obtain support for necessary work on developing instruments, methods and software, which therefore risks being the weakest link in undertakings at major facilities. It is therefore important to have a funding system that allows research across different time scales, and with different organisational models.

3.7 Space

In the 2018 guide, RFI underlined that engagement in international infrastructures is a prerequisite for research in astronomy and questions about the structure, development and origin of the universe, and for fundamental physics. Since then, a lot has happened within research-relevant space activities; for example, the US Webb Space Telescope has been launched into space, and will be delivering data on entirely new phenomena over (at least) the next ten years. From the Swedish Research Council's perspective, an agreement has been reached for the radio telescope SKA, all components have been delivered to EISCAT-3D for installation during this year, and the work on ESO's next large telescope, ELT, is progressing, albeit with delays, primarily as a result of the pandemic.

In the calls in 2019 and 2020, grants were awarded for Swedish participation in SKA, upgrading of IceCube, participation in the ELT instrument MOSAIC, the Swedish solar telescope SST and planning of the proposed European successor, EST. In the separate investment call, funding of relevance for space research was also awarded.

The concept of "space" here refers to astronomy, astrophysics (including solar physics), astroparticle physics and space physics. Research in this field aims to understand the structure, origin and development of the universe, including characteristics of the objects it contains, such as planets, stars and galaxies. It also studies the development of the planetary system, preconditions for life on other objects in the solar system, and how the space environment impacts on the development of the planets and their atmospheres. The research also tries to explain how the Sun and the Earth interact, and what effects this might have on the Earth's upper atmosphere.

The Earth's local environment in space is dominated by the Earth's magnetic field. The upper atmosphere is ionised by UV light from the Sun, and the solar wind's interaction with the Earth's magnetosphere gives rise to phenomena such as magnetic storms, northern lights, and atmosphere escape. Some topical questions are how the energy of the solar wind is transferred to the magnetosphere, how energy is stored there and then suddenly released, and what processes contribute primarily to acceleration and heating of the ionised gas, the plasma.

Research into our solar system (planets, moons, asteroids, comets, and so on) is about understanding how such different objects have been able to develop, and what characterises them today. Areas studied here include the effect that the spatial environment has had on the development of surfaces and atmospheres, and what is crucial for determining whether life can arise on a planet or a moon.

Full understanding of the lives of stars and the link to the cosmic gas cycle is still lacking. Research is being done on the processes that govern the birth of stars and their last stages of development, when elements are formed that will later be part of new generations of stars. The chemical composition of the cosmic gas clouds is also studied, as this may be linked to the planetary atmospheres' characteristics and, by extension, to the origin of life.

The majority of all stars in the universe are gathered together into galaxies of the most varying shapes and sizes, and are in turn part of galaxy groups or clusters. How this large-scale structure have arisen and developed is today a 'hot' research area. In this context, the understanding of the composition and characteristics of dark matter and dark energy, which are still largely unknown, is of crucial importance.

High-energy phenomena in our universe, such as supernova explosions or the impact of compact objects on their surroundings, are particularly interesting to study. These phenomena are often of a transient nature and require special observation methods. They also provide opportunities to study fundamental physics under conditions that can never be created in laboratories on Earth. The development of new research infrastructures has led to ground-breaking "multi-messenger astronomy", that is, use of other information carriers than electromagnetic radiation, such as cosmic radiation, neutrinos and, recently, gravitational waves.

3.7.1 Current situation and development

For space-related research, most of the Swedish funding of space-based research infrastructure, including the membership of the space organisation ESA, comes from the Swedish National Space Agency, while the larger part of the ground-based infrastructure is funded by the Swedish Research Council. The two public agencies collaborate to some extent, but the formats for collaboration should be developed further, so as to avoid unnecessary demarcation between ground-based and space-based research infrastructure. The Institute of Space Physics (IRF), which is responsible for a large proportion of Swedish research in space physics, has access to long measurement series and collaborates with several of the ESA's space missions, is also a central actor here.

Within ground-based infrastructure, there is the European Southern Observatory (ESO), where Sweden via its membership contributes to the operation and development of telescopes in Chile, among them the radio telescope ALMA, the optical telescope VLT, and the optical giant telescope ELT, which is under construction. Onsala Space Observatory is a national facility for radio astronomy and a Swedish node for international collaborations within the radio area, such as ALMA, LOFAR, the future SKA, and long-base interferometry (VLBI). The Institute for Solar Physics operate the Swedish Solar Telescope (SST) on La Palma, and participates in the planning ahead of the European Solar Telescope (EST). Within astroparticle physics, Sweden participates in the operation and development of the neutrino observatory IceCube at the South Pole. The Sweden-based international space radar facility EISCAT, which is now being developed into EISCAT-3D, will provide new opportunities for studies of near space and the upper atmosphere. The Swedish space base Esrange is used for launching probe rockets and balloons, as well as test flights. It is also developing new test facilities and the ability to launch satellites into orbit.

Examples of infrastructures moving in space of great importance to Swedish research that have become operational in the last few years are the solar probe Solar Orbiter, the Mercury probe Bepi-Colombo, and the exo-planet telescope Cheops. The astrometry telescope Gaia and the recently launched Webb Space Telescope should also be mentioned as projects with a particular large impact in space research. Other examples where Swedish researchers are participating are the magnetosphere constellation MMS, the Mars probe Mars Express, and the high-energy telescope Fermi.

3.7.2 Future needs and challenges

Development of measuring methods, models, data management and advanced technology for infrastructures is of great importance in all areas of space research, and Sweden should continue to participate in all areas where Swedish research and development is competitive, in some cases via in-kind contributions. Research in the field of space requires access to a broad range of complementary national and international research infrastructures. Many central research questions also require a combination of ground-based and space-based observations. For increased knowledge about our own solar system, remote analysis needs to be combined with measurements in situ. Here, it is important to have simultaneous observations of neutral and electrically charged particles within a broad energy spectrum, as well as in stationary and varying magnetic and electric fields. Astronomical research needs access to data from the entire electromagnetic wavelength spectrum, where some areas can only be studied via satellites, but is also dependent on studies of cosmic particles and gravitational waves. Infrastructures in this field also constitute tools for studies of fundamental physics.

Through continued Swedish participation in international collaborations, such as ESO, SKA, IceCube, EISCAT-3D and ESA, Sweden can maintain and develop its strong position in space research. Future challenges will require increased collaboration between infrastructures in different disciplines, both on the ground and in space. Given this, strategic prioritisations of Sweden's engagement in the international collaborations are required, in terms of both personnel and financial resources in the long term. It will also require increased national cooperation between different funding bodies. The situation for the planned European solar telescope EST should be clarified within the next few years, and it is desirable to establish a Swedish strategy for solar physics. EST is expected to replace the Swedish solar telescope SST in the longer term.

Areas where Sweden already has a strong position to continue building on exist in areas such as radio astronomy, with the infrastructures ALMA, SKA and EISCAT-3D, and in the space area via IRF, for example. In addition, Swedish researchers and companies are participating in the development of instruments for the optical telescope ELT and equipment for the IceCube neutrino observatory. Calls for grants for technology development and investments, similar to those issued by the Swedish Research Council in 2021, are important for this field.

Space research and its infrastructures often generate enormous data sets; this applies in particular for observatories. Artificial intelligence and other advanced methods are being developed and used to an increasing extent to make the data management more efficient. For instruments moving through space, autonomous computation onboard (known as 'edge computing') is even contemplated, in order to find the relevant information and in this way avoid problems with limited bandwidth.

National nodes will continue to be of great importance in the future, and should – in addition to supporting and to some extent supplementing the major international facilities – also function as a Swedish knowledge base for user support and technology development. In addition, Sweden needs to support competence enhancement for new users of the infrastructures that are now being built up, such as SKA, EISCAT-3D, ELT and new generations of IceCube. The capacity of these facilities are several magnitudes greater than those that are accessible today, and open the door to entirely new areas of use.

The increased importance of space in several societal sectors also provides new opportunities for research, for example via access to data from satellites for communication, such as Galileo, or for space weather. Increased accessibility to space leads to opportunities for new actors, including researchers, but also to major problems for certain types of research. Over the next ten-year period, around 100 000 commercial satellites may be launched into the Earth's orbit. Several astronomy and space organisations are involved in a dialogue with the companies to try to reduce the disruption from satellites, and Swedish stakeholders should also work towards this goalin relevant contexts. Observatories are working on developing algorithms to manage the satellite passes, and are reviewing the planning of observation times to secure opportunities for continued discoveries. With an increased number of satellites follows an increasing problem with space junk, which increases the risks for sectors that rely on satellites.

For both society as a whole and for certain types of research, in particular applied research, a central need is to collect current information about the situation in space, including the threats that exist both to infrastructure in space and on the ground, into a complete space situation picture. Sweden contributes, together with other countries, to the work of identifying, cataloguing and monitoring satellites, and to analysing risks of events such as collisions. To be a good collaboration partner in this field, Sweden would have to develop its national abilities, as it is really only in the field of space weather that we have a good overview. But increased knowledge is needed here too, about how the sun’s activity affects satellites, electricity networks, and communication systems.

3.8 Earth, climate and environment

The 2018 guide emphasised the importance of obtaining data from detailed and long-term observations of air, land and water. The increased funding for research infrastructure in the latest Government research bill provided opportunities for funding several new infrastructures for this purpose: the distributed infrastructure ACTRIS, focusing on aerosols and trace gases in the atmosphere, and data processing and data accessibility within the geological and geophysical field that came with membership of the European Plate Observing System (EPOS-ERIC). Funding was also allocated to renewed and increased instrumentation on the ice-breaker Oden.

Research in this field answers questions about structures, conditions and processes above, on, and below the crust of the Earth, from very short to extremely longtime scales, and from the centre of the Earth to the Earth’s ionosphere and magnetosphere. The research is crucial for understanding the development and dynamics of the Earth, and for discovering, understanding and acting on the changes to the environment caused both by human beings’ activities or by natural processes.

To get the highest possible scientific return in this field, the ability to integrate and develop knowledge across traditional disciplinary and environmental borders is required, where research infrastructures contribute with basic facts and form important nodes for collaboration and knowledge production. Research infrastructures therefore become ever more important for our understanding of and capacity to manage some of today’s very greatest societal challenges.

Among these are global warming, the depletion of biological diversity, pollution of air, land and water, and sustainable use of nature and the resources of the Earth's crust. These directly correspond to several of the UN's sustainability goals, most of the Swedish environmental goals, and link clearly to several of the indicated missions within Horizon Europe (Adaption to Climate Change, Restore our Oceans and Waters by 2030).

3.8.1 Current situation and development

Large sections of Sweden's economy are based on the use of biological and geological natural resources, and well-adapted research infrastructures are a precondition for the necessary development within these areas. Sweden's many environment types and climate zones offer very good research opportunities and makes Swedish environmental research important in comparative national and international studies. At the same time, this underlines the importance of maintaining high-quality Swedish research, as it can provide major knowledge contributions that future generations across the world will need.

In-situ measurements below, or close to ground and sea levels, are important complements to the large amounts of data delivered by satellite platforms, for example within the ESA's Copernicus programme, in order to enable verified spatial analyses of high quality across large spatial scales. Here, as for most questions relating to environmental and climate research, it is crucial to collect data that well represent different environment types and the natural variation. This entails a need for both advanced stationary and portable measuring equipment that can be used in many types of environments.

The distributed European research infrastructures are important for securing the long-term supply of data. Greenhouse gas measurements within ICOS, which has an established network of stations in Sweden, will receive corresponding equipment for short-lived climate-impacting gases and aerosols via the funding of ACTRIS Sweden and Swedish membership of ACTRIS-ERIC from 2022. The co-location of several of the stations within ICOS and ACTRIS provide research advantages through rich data collection from the same places. Several of the stations are also co-located with research stations within SITES, which means that the research projects conducted at these stations are given access to an exceptional range of environmental data over time, which may be crucial for the interpretation of the projects' own investigations and experiments in the natural environment around the research stations.

On the marine side, Sweden has in recent years obtained two new research and investigation vessels, via *Svea* (Swedish University of Agricultural Sciences) and *Skagerak* (University of Gothenburg), which are replacing previous vessels. The total Swedish marine infrastructure, consisting of vessels, research stations, unmanned vessels and stationary measuring buoys, are operated locally by the universities, and there is currently no national coordination. As from 2022, Sweden is a member of EMBRC-ERIC, and the Swedish operation gathers most Swedish HEIs conducting marine biology research together. For research in the Arctic, the ice-breaker Oden plays a crucial role for understanding how the

Arctic is affected by climate change, which gives Sweden a strong position internationally.

Following a merger between two earlier infrastructures, there has been one national infrastructure for biodiversity data since 2021, the Swedish Biodiversity Data Infrastructure (SBDI), which gathers together almost 50 different data sources in its data portal and offers user support and analysis services. Collection of the data offered via SBDI is done using sources such as the national environmental monitoring programs, which represents important and long-term data sources for research in the entire field.

The environmental sample banks that are found in Sweden are also included in the infrastructures. They collect dead and living material, and provide opportunities to give quick answers to questions such as how, when and why changes have occurred, and give knowledge of time series when new methods become available.

Onsala Space Observatory collects comprehensive data in order to measure the Earth and its movements, sea level changes and the Earth's gravity field, which provides datafor studies of the Earth's composition and dynamics. Through the funding of Swedish participation in EPOS starting in 2022, access will be given to a range of data sets relating to the solid ground. The Swedish data documentation will be harmonised so that it can be made openly accessible at European level via EPOS-ERIC. Sampling at below-ground level is necessary for studying areas such as the development of the planet, the origin and development of life and its prerequisites, groundwater and water quality, and also mineral resources. At the national level, there is the drilling platform Riksriggen, which is also a desirable infrastructure at the international level within the Integrated Conservation and Development Projects (ICDP) collaboration for collecting drill cores.

The radar system EISCAT-3D, which started to be built in 2022, will provide unique opportunities for continuous and three-dimensional studies of the atmosphere in the polar regions above Scandinavia.

Understanding of how climate systems function is achieved by combining studies based on observations with mathematical numerical modelling. Climate research has been a driver behind the development of large-scale computation and integration of data sources, which have been a precondition for producing the International Panel on Climate Change's (IPPC) reports on the climate of the future. Society's need to understand changes to the climate and their effects means that future requirements for e-infrastructure are expected to increase.

Understanding of the earth requires detailed knowledge about what materials the Earth consist of. Analysis instruments for this purpose with high precision and resolution that can be accessed via Nordsim/Vega or other infrastructures for material analysis are urgently needed to map structures and the chemical composition of minerals and other materials in order to provide answers to questions on the cycle of elements and the long-term development of the Earth and of life.

3.8.2 Future needs and challenges

Research within the field relating to processes and changes across time and space will continue to need detailed and long-term observations of ecosystems, air, land, bedrock and water to fulfil the need for data for analyses and modelling. Moreover, experimental investigation under field-like conditions will be central for enabling simulation of future changes to environmental conditions and for predicting how these impact organisms and ecosystem functions.

To collect necessary data in an efficient way, sensors need to be developed – both fixed and mobile, with high operational reliability, long functional life, and designed for automated use. These would make it possible to monitor environmental parameters continuously across large areas, including in hard-to-reach environments.

It is important for Swedish research to have the opportunity to participate in the rapid development of the ever more advanced instrumentation that is needed in the area, with increased costs as a result. One way of responding to this is to make portable instruments accessible via nationally coordinated instrument pools.

There is a need for continued development and coordination of experimental platforms, where future environmental conditions can be simulated. The value of experimental investigations of ecosystems in situ increases the longer their term is, and the greater their ability to cover many environmental conditions, and such ecosystem experiments are therefore advantageously run within research infrastructures. A unified inventory of Swedish environmental sample banks would be very valuable, and, as a first step, there is a need to investigate the preconditions for increasing the coordination of these.

For Sweden’s marine research infrastructures, both in the form of research vessels and marine field stations, there is potential to increase the national use and offer open access to measurement series and other data through a higher degree of coordination. The ice-breaker Oden is expected to have a remaining useful life of ten years at most, and there is a great need to replace Oden to ensure continued access to a Swedish research ice-breaker. At the same time, a stable model for the operation of a new vessel for research purposes must be found.

With the increasing importance of research infrastructures for data collection across discipline borders, the need for specialised user support is increasing. For this reason, sufficient funding of personnel must also accompany funding of equipment and instruments for infrastructures. Management and publication of the data produced at the infrastructures also require specialist personnel, who are familiar with the research field.

3.9 Engineering and energy

The 2018 guide highlights engineering science as a field that includes both basic and applied research, and also consists of many different research subjects. With the funding addition that the Swedish Research Council was allocated in the most recent Government research bill, RFI was able to award grants to investments in the research infrastructures SpaceLab and the Kollberg laboratory, increased HPC service with private cloud services, and new equipment for the FREIA laboratory for developing new accelerators and instruments for research. These investments will, among other things, in a useful way open the door for Sweden to supply instrumentation for space research and satellites to researchers in the terahertz area, and the development of new, more effective accelerators and instrumentation.

Securing environmentally sustainable energy supply is one of the most important issues of our time. In the fusion field, infrastructure for research and development of fusion reactors, ITER and DEMO, have received funding.

Sweden's prosperity is largely built on high-technology know-how, which has produced world-leading industries in fields such as IT, transport and energy. Engineering sciences is a field that covers both basic and applied research within most sectors of importance for Swedish industry. The field covers many different research subjects that can strive to implement basic research and also predict process outcomes and functions of products. Engineering and applied research play an important role within areas such as energy technology, metallurgy, light-weight materials and materials from renewable raw materials such as from forestry.

Basic understanding of the characteristics of materials and components, and the development of efficient manufacturing processes, are fundamental components of engineering sciences and their applications. Researchers are therefore major users of synchrotron radiation and neutron scattering facilities, but also have great need of laboratories for developing and testing materials, components and processes. Research infrastructures aimed directly at engineering sciences are often dedicated to a specific area, and often of a regional or local character. To broaden access, utilise synergies and stimulate competence development, such regional and local initiatives should be encouraged to coordinate, to form national distributed infrastructures, such as the Atomic Resolution TEM infrastructure (ARTEMI), the Swedish NMR Centre, and Myfab, These may also hold pilot or testing facilities, where research is an integrated part of the facility itself.

Securing an environmentally sustainable energy supply is one of the most important issues of our time. Energy research concerns the entire chain from production and distribution to consumption of electricity or other forms of energy, as well as recycling of the materials included in a circular economy. Development of renewable energy sources, such as solar energy, wind power and bioenergy, is an important aspect. The same applies to research aimed at further developing energy sources such as hydro power and nuclear power. A transition to a sustainable society includes the development of technologies for energy storage, for example in the form of hydrogen gas. It also includes more energy-dense batteries with a smaller environmental footprint, as well as related pilot and test facilities.

3.9.1 Current situation and development

In engineering sciences, there is also the problem that the need for infrastructure borders on or overlaps the need for pilot type facilities, where research and development in materials, processes, methods and techniques are an integrated part of the facility itself. The multi-disciplinary nature of such projects is today reflected in the fact that several different funding bodies (private and public) often are involved. This, in turn, means that there is a risk that no funder takes the responsibility for the funding of the facilities. To secure that engineering sciences in Sweden can develop and be in the forefront, coordination is needed between different funding bodies.

Today's national and international infrastructures for research into chemistry, applied physics, materials science, engineering and life science include X-ray and neutron technologies and access to clean rooms. A general trend is that research is ever more needs-oriented, addresses the global challenges and is often done in interaction with industry and public operations. In engineering sciences, it can be noted that accelerator physics is developing with more efficient approaches, where the infrastructure SINBAD in Germany is one example of a facility commissioned for and dedicated to the development of new methods in this area. Another example is EUPRAXIA, which is included in ESFRI's road map. Energy research is also largely dependent on advanced research infrastructures for understanding and developing materials with specific characteristics, and for understanding the environmental consequences of energy production. The conclusion is that, for a major part of energy research, specific trial and demonstration facilities for developing and testing new technology are needed. The research spans the areas of responsibility of several funding bodies and public agencies, which in turn demands both increased coordination and clarification of areas of responsibility.

In fusion research, the European and Swedish focus is on the construction and future operation of ITER, which is an experimental reactor for indicating fusion as a possibility for future electricity production. Currently, Swedish researchers are active at other international fusion facilities, both in the preparation for ITER but also in current research projects. Swedish participation in the coordinated EU-based fusion research area in the framework programme in Horizon Europe, EUROfusion, has been renewed and aims to secure current activities until ITER becomes operational.

In fission research, there is increased focus on the development of small modular reactors (SMR). It is also important for user groups from fission research that access is secured to international facilities, such as Jules-Horowitz, Pallas and MYRRHA, where radiation and local chemical environments can be combined, and in this way pave the road for the next generation of reactors.

3.9.2 Future needs and challenges

Sweden is at the leading edge of the circular economy area, and by taking an environmental overall approach in our striving for a circular society, we are also strengthening Swedish industry and its competitiveness. This field is also expected to become ever more important in future EU directives. As different components of the energy system are part of a complex interplay, better interaction between different research fields and actors is worth striving for. Development of renewable energy sources is an important aspect. The same applies to research aimed at increasing efficiency and improving traditional energy sources, such as hydro power and nuclear power. For the fusion area, ITER is expected to start production in December 2025. In nuclear fission research, development of the next generation of reactors, such as Generation IV, accelerator-driven systems and SMR requires new materials and diagnostics.

It is important that research in strategically important areas is given access to relevant infrastructure, and also that access to and the development of instrumentation can be secured long term, both for instruments of nano-technology type manufactured using clean room methods, and for instrumentation of 'big science' character. This might relate to instrumentation for quantum computers and quantum communication, accelerator physics or detector equipment for astronomy.

In parallel with the methods offered by the large-scale facilities, there are a number of other experimental methods that are crucial for research in engineering and energy. These are usually accessible at all research-intensive HEIs, and form important local infrastructure, but the most advanced instruments in areas such as electron microscopy or NMR are today very expensive. To safeguard the prerequisites for engineering science in Sweden, coordination is needed at all levels that takes into account the actual and specific needs of engineering science and energy research.

In engineering science and also in energy research, it continues to be important to clearly define the roles and responsibilities of stakeholders (HEIs, governmental funding bodies and the business sector) to improve the coordination of participation and funding of national research infrastructures, taking into account the long timescales that often prevails within these research fields.

4 Appendix 1. Table of infrastructures

The table lists infrastructures that in 2022 received some kind of grant from the Swedish Research Council, or where Sweden is a member and pays a membership fee. For more information about the infrastructures, please see the Swedish Research Council's website and the websites of the individual infrastructures.

National infrastructures – the operation is carried out at a central unit or as an operation distributed across several HEIs.

Convention-bound infrastructures – the operation is based on conventions that Sweden has ratified.

ERIC, European Research Infrastructure Consortium – the operation is carried out through a separate organisation form for European research infrastructure, and has a legal right that is recognised in all EU member states and in the associated states that accept ERIC.

Other international infrastructure – the operation is based on bilateral or multilateral agreements, and is carried out abroad with Swedish participation, or in Sweden with foreign participation.

For an explanation of the different organisation types, please see Chapter 1.4 of the guide.

Infrastructures managed by the Swedish Research Council

*The fee for Sweden's membership in EATRIS ERIC is paid by Vinnova

**The fee for Sweden's membership in EMBRC is paid by HEIs

***The fee for Sweden's membership in Euro-Bioimaging ERIC is paid by HEIs

Acronym	**Name**	**Area of use**	**Organisation type**	**First grant or member-ship year**
AB-ITC	Ion Technology Centre	Materials and the constituents of life	National	2012
ACTRIS	ACTRIS Sweden	Earth, climate and environment	ERIC with national node	2022
ALICE	A Large Ion Collider Experiment	E-infrastructure & Universe's smallest components	Other international	1998
ANDES	ANDES - instrumentation for ELT (previously HIRES)	Space	Other international	2017
APPA	Atomic, Plasma Physics and Applications	Universe's smallest components & Space	Other international	2010
ARTEMI	Atomic Resolution TEM Infrastructure of Sweden	Materials and the constituents of life	National	2022
Astronet	Astronet	Space	Other international	2017
ATLAS	A Toroidal LHC Apparatus	E-infrastructure & Universe's smallest components	Other international	1998
BBMRI-ERIC	Biobanking and Biomolecular Resources Research Infrastructure	Life science	ERIC with national node	2013
BioMS	Swedish National Infrastructure for Biological Mass Spectrometry	Life science	National distributed	2016

Acronym	**Name**	**Area of use**	**Organisation type**	**First grant or member-ship year**
BIS	Biobank Sweden	Life science	National distributed	2018
CBCS	Chemical Biology Consortium Sweden	Life science	National distributed	2010
CERN	Conseil Européen pour la Recherche Nucléaire	E-infrastructure & Universe's smallest components	Convention	1954
CESSDA-ERIC	Consortium of European Social Science Data Archives ERIC	Society and individual	ERIC with national node	2014
CEXS	Center for X-rays in Swedish Materials Science	Materials and the constituents of life	National	2017
CLARIN-ERIC	Common Language Resources and Technology Infrastructure ERIC	Humanities & Society and individual & Life science	ERIC with national node	2014
CORS	Comparative Research Center Sweden	Society and individual	National distributed	2018
DEMSCORE	Democracy, Environment, Migration, Social Policy, Conflict, and Representation	Society and individual	National distributed	2020
DESIREE	Double Electrostatic Ion Ring Experiment	Universe's smallest components	National	2002
EATRIS ERIC*	European Infrastructure for Translational Medicine	Life science	ERIC	2015
ECORD	European Consortium for Ocean Research Drilling	Earth, climate and environment	Other international	2003
EISCAT	European Incoherent Scatter Scientific Association	Space & Earth, climate and environment	Other international	1981
ELIXIR	ELIXIR	Life science	Other international	2013

Acronym	Name	Area of use	Organisation type	First grant or member-ship year
EMBC	European Molecular Biology Conference	Life science	Convention	1969
EMBL	European Molecular Biology Laboratory	Life science & Earth, climate and environment	Convention	1974
EMBRC**	European Marine Biological Resource Centre	Earth, climate and environment	ERIC	2022
EPOS	European Plate Observing System	Earth, climate and environment	ERIC with national node	2022
ESO	European Southern Observatory	Space	Convention	1964
ESRF	European Synchrotron Radiation Facility.	Life science & Materials and the constituents of life & Earth, climate and environment & Engineering and energy	Convention	1988
ESS-ERIC	European Social Survey ERIC	Society and individual	ERIC with national node	2013
ESS ERIC	European Spallation Source ERIC	Life science & Materials and the constituents of life & Universe's smallest components & Earth, climate and environment & Engineering and energy	ERIC	2015
EST	European Solar Telescope	Space	Other international	2022
EuBI-ERIC***	Euro-BioImaging ERIC	Life science	ERIC with national node	2019
EUI	European University Institute	Humanities & Society and individual	Convention	1997

Acronym	Name	Area of use	Organisation type	First grant or member-ship year
EU-OPEN-SCREEN	EU-OPEN-SCREEN ERIC	Life science	ERIC with national node	2022
EUROFusion	EUROFusion	Engineering and energy	Other international	2014
EuroHPC JU / LUMI	European High Performance Computing Joint Undertaking	E-infrastructure	Other international	2019
FAIR	Facility for Antiproton and Ion Research in Europe	Universe's smallest components & Space	Convention	2010
GBIF	Global Biodiversity Information Facility	Earth, climate and environment	Other international	2001
HUMINFRA	Infrastructure for digital humanities	E-infrastructure & Humanities	National distributed	2022
IARC	International Agency for Research on Cancer	Life science	International	1979
IASC	International Arctic Science Committee	Society and individual & Earth, climate and environment	Other international	1990
ICDP	International Continental Drilling Program	Earth, climate and environment	Other international	2008
IceCube	South Pole Neutrino Observatory	Universe's smallest components & Space	Other international	2005
ICOS	Integrated Carbon Observing System	Earth, climate and environment	ERIC with national node	2016
ILL	Institute Laue-Langevin.	Life science & Materials and the constituents of life & Universe's smallest components & Earth, climate and	Other international	2010

Acronym	Name	Area of use	Organisation type	First grant or member-ship year
		environment & Engineering and energy		
InfraVis	Infrastructure for Visualisation of Data	Humanities & Society and individual & Life science & Materials and the constituents of life & Universe’s smallest components & Space & Earth, climate and environment & Engineering and energy	National distributed	2022
ISIS	ISIS Neutron and Muon Source	Life science & Materials and the constituents of life & Universe’s smallest components & Earth, climate and environment & Engineering and energy	Other international	2010
ISOLDE	Isotope Mass Separator On-Line facility	Universe’s smallest components	Other international	1967
ITER & DEMO	International Thermonuclear Experimental Reactor, Demonstration Power Plant	Engineering and energy	Other international	2002
JIVE	Joint Institute for VLBI ERIC	Space	ERIC with national node	1993
MAX IV	MAX IV Laboratory	Humanities & Life science & Materials and the constituents of life & Earth, climate and environment	National	2011

Acronym	Name	Area of use	Organisation type	First grant or member-ship year
		& Engineering and energy		
MONA	Microdata On-Line Access (Statistics Sweden)	Society and individual	National	2006
MOSAIC	MOSAIC – Instrumentation for Extremely Large Telescope (ELT)	Space	Other international	2023
Myfab	Myfab – the Swedish research infrastructure for micro- and nanofabrication	Materials and the constituents of life & Engineering and energy	National distributed	2010
NBIS	National Bioinformatics Infrastructure Sweden (formerly BILS)	Life science	National distributed	2009
NEAR	National E-Infrastructure for Ageing Research	E-infrastructure & Society and individual & Life science	National distributed	2018
NEIC	Nordic E-infrastructure Collaboration	E-infrastructure	Other international	2012
NGI	National Genomics Infrastructure (formerly SNISS)	Life science	National distributed	2010
NMI	National Infrastructure for Microscopy in Life Sciences	Life science	National distributed	2016
NordSIMS	NordSIMS-Vegacenter	Earth, climate and environment	National	1993
NUSTAR	Nuclear Structure, Astrophysics and Reactions	Universe's smallest components & Space	Other international	2010

Acronym	Name	Area of use	Organisation type	First grant or member-ship year
Oden	Oden ice-breaker	Earth, climate and environment	National	2022
OSO	Onsala Space Observatory	Space & Earth, climate and environment	National	1990
PANDA	Antiproton Annihilation at Darmstadt	Space & Earth, climate and environment	Other international	2010
PETRA III	Petra III Swedish node	Materials and the constituents of life	Other international	2011
PPS	Protein Production Sweden	Life science	National distributed	2022
PRACE	Partnership for Advanced Computing in Europe	E-infrastructure	Other international	2010
REWHARD	National Infrastructure for Research about Social Relations, Work and Health across the Life-course	Society and individual & Life science	National distributed	2018
Riksriggen	Riksriggen	Earth, climate and environment	National	2018
SBDI	Swedish Biodiversity Data Infrastructure (formerly BAS and LifeWatch)	Earth, climate and environment	National distributed	2021
SCAR	Scientific Committee of Antarctic Research	Society and individual & Earth, climate and environment	Other international	1988
SHARE-ERIC	Survey of Health, Ageing and Retirement in Europe ERIC	Society and individual & Life science	ERIC with national node	2014
SIMPLER	Swedish Infrastructure for Medical Population-based Life-course and Environmental Research	Society and individual & Life science	National distributed	2018

Acronym	Name	Area of use	Organisation type	First grant or membership year
SITES	Swedish Infrastructure for Ecosystem Science	Earth, climate and environment	National distributed	2013
SKA	Square Kilometre Array Observatory	Space	Other international	2016
SND	Swedish National Data Service	E-infrastructure & Humanities & Society and individual & Life science & Earth, climate and environment	National	2008
SNIC	Swedish National Infrastructure for Computing (replaced as from 2023 by NAISS)	E-infrastructure	National	2005
SST	Swedish Solar Telescope	Space	National	2013
STR	Swedish Twin Register	Society and individual & Life science	National	2018
Superadam	Superadam	Materials and the constituents of life	Other international	2009
SveDigArch	Swedish National Infrastructure for Digital Archaeology	E-infrastructure & Humanities	National distributed	2022
SwedNMR	SwedNMR	Life science & Materials and the constituents of life	National distributed	2022
SwedPop	Swedish Population Databases for Research	Humanities & Society and individual & Life science	National distributed	2018
UGU	Evaluation Through Follow-up	Society and individual	National	2012
XFEL	European X-ray Free Electron Laser	Life science & Materials and the	Convention	2010

Acronym	Name	Area of use	Organisation type	First grant or membership year
		constituents of life & Earth, climate and environment & Engineering and energy		