The Swedish Research Council's Guide to Research Infrastructure

Swedish Research Council

2018

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VR1811
ISBN 978-91-7307-369-1

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Foreword

The Swedish Research Council's Guide to Research Infrastructure 2018 is a roadmap for the continued development of Swedish research infrastructure. The purpose of the Guide is to indicate needs, challenges and opportunities related to research infrastructure, and to propose recommendations aimed at strengthening Swedish research and thus societal development as a whole. The Guide also forms part of the knowledge documentation assembled by the Swedish Research Council as a contribution towards the decision-making documentation for upcoming Government research bills, and for prioritisations within scientific councils, councils and committees.

Through its Council for Research Infrastructures (RFI), the Swedish Research Council has overall responsibility for Sweden's national research infrastructure and for Swedish participation in international research infrastructure. As infrastructure projects are relatively few in number, but at the same time large-scale, costly and long-term, collaboration is necessary between organisations, scientific fields and in many cases countries. The Swedish Research Council therefore regards itself as one of several actors responsible for providing Swedish research with the necessary infrastructure, and the need for collaboration between funding bodies and higher education institutions is clearly reflected in this Guide. It is our hope that the 2018 Guide to Research Infrastructure will form a foundation for further strengthening the collaboration and clarifying the work allocation in the Swedish research system. As it is the needs of research that direct the needs for research infrastructure, we also hope that the Guide will contribute to discussions and engagement in infrastructure issues among researchers active in Sweden.

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Summary

Sweden has the ambition to be one of the very most advanced knowledge nations. A prerequisite for achieving this is that researchers active in Sweden are given the best opportunities to conduct prominent research. One such prerequisite is access to advanced research infrastructure.

The needs for research infrastructure – large research facilities, laboratory environments, experimental workshops, complex digital research systems and comprehensive databases – are increasingly rapidly within most research fields. Technical developments and ever more complex scientific questions are simultaneously driving this development forward. The requirements on being able to study changes and their causes are increasing, which in turn presupposes observations that cover long time periods. This applies not least within environment and climate research, humanities, social sciences and major parts of medical research. Fundamental knowledge about our universe, the characteristics of materials, the function of cells and internal characteristics of matter demands advanced instruments. Complex questions also require data and observations from several sources to be combined. Moreover, a common feature of all research fields is that the need to store, transfer and analyse large amounts of data is increasing very rapidly. In many cases, the development means that barriers between research disciplines is breaking down, and that the need for international collaboration is increasing. Advanced research infrastructure also constitutes a resource for industry, and is in many cases a prerequisite for collaboration between industry and academia.

To meet this development, increased investment in research infrastructure is needed. At the same time, we also need clearer prioritisation, better coordination, and more efficient use of Swedish research infrastructure and collaboration in international ventures. In order to achieve this, the Swedish Research Council has started to apply a new model for prioritising infrastructure investments through strengthening the dialogue with Swedish higher education institutions, which are important funding bodies for research infrastructure, and other funding bodies. This work must continue and deepen. It is also necessary to add financial resources to enable the Swedish Research Council to take overall national responsibility for Sweden's national research infrastructure, and for Swedish participation in international infrastructures.

Investment in research infrastructure is directed by the needs of research, but at the same time, advanced infrastructure creates the prerequisites for the development of research. Investment in research infrastructure is therefore always of importance for research strategy. The work of coordinating investments in infrastructure and investments in research and education must therefore be further intensified. Well-designed user guides and educational input are necessary. Considerable inputs are

needed, not least at our higher education institutions, to build up the competence that is needed in order that Swedish research can benefit from the opportunities offered by advanced infrastructure.

Stimulating researchers to engage in the development and operation of research infrastructure is necessary in order to build up and operate advanced research infrastructures. The persons who work at the infrastructures must also be offered good working conditions, competence development and career opportunities. Merits from building up and operating research infrastructures must be upgraded and recognised when appointing personnel. The discussion on researchers' career paths and earning of merits needs to be held in a coordinated way, both at Swedish higher education institutions and among research funding bodies.

Participation in infrastructure projects provides opportunities for Swedish researchers and Swedish industry to participate in instrument and technology development. Active participation by Swedish industry needs to be encouraged and supported. A clear funding model for supplies to research infrastructures should be organised. In order to achieve this, we need collaboration with industry and clearer coordination between research funding bodies, the ministries involved and higher education institutions.

The major investments made into MAX IV and ESS are outstanding from a Swedish perspective. In conjunction with MAX IV moving from the construction phase to becoming operational, long-term funding of the facility must be safe-guarded. At the same time, Sweden must fulfil the undertaking to host ESS in the best way possible, and prepare the Swedish research community for the facility becoming operational. It is very important that funds continue to be contributed to manage these undertakings without hazarding other necessary investments in research and research infrastructure.

Investments in e-infrastructure – computer resources for calculation, analysis, storage and digital communication – must increase to meet rapidly growing data volumes and the need for research to analyse ever increasing and more complex data amounts. Investments in user support and training need to permeate the entire research system and include general competence enhancement and increased access to expertise at the higher education institutions. National actors, such as the Swedish Research Council and Swedish higher education institutions, need to continue developing funding models for e-infrastructure. Sweden should also take active part in many of the international collaboration schemes that is now in progress and planned.

Open research data entail opportunities, but are also a major challenge. Considerable resources will be needed to ensure data is stored in a way that lives up to the principles for accessibility and reproducibility. Measures are also needed for improved data handling and development of principles for which data to save. The process towards open research data must be driven in a way that is economically defensible and promotes the quality of research.

Safeguarding of personal integrity is central for the credibility and legitimacy of research. Given this, it important that the development of Swedish legislation is done in such a way that research can use existing data in an optimal way, and that systematic build-up of research data is made possible. It is also important that the adaptation of Swedish legislation and legal practice to the European General Data Protection Regulation (GDPR) is made based on consideration for and knowledge about the needs of research.

1. 1 Introduction

Through its Council for Research Infrastructures (RFI), the Swedish Research Council has overall responsibility for Sweden's national research infrastructure and for Swedish participation in international research infrastructure. The aim is to give the Swedish research community the best possible prerequisites for conducting advanced research, and thereby contribute to the Swedish Research Council's mandate to facilitate research of the highest scientific quality and contribute to Sweden's ambition to be one of the very most advanced knowledge nations. This Guide is the Swedish Research Council's roadmap for Sweden's long-term need for research infrastructure. The purpose of the Guide is to indicate needs, challenges and opportunities relating to research infrastructure, and to propose recommendations aimed at strengthening Swedish research.

> Research infrastructure of national interest is intended to provide resources that enable research for several research teams and different projects within one or several research fields. Examples of these research infrastructures are major research facilities, laboratory environments, experimental workshops, complex digital research systems and databases, but also experts and networks of experts.

The 2018 Guide to Infrastructure is a further development and update of the guide published in 2014. As from 2015, a new model for funding and prioritising research has been implemented, see below. The new model has also had consequences for the layout of the 2018 version of the Guide to Infrastructure. Contrary to the previous Guide, the 2018 Guide does not have any concrete proposals for prioritising specific infrastructures. Concrete proposals can instead be found in the Guide Appendix. Likewise, systematic descriptions of individual infrastructures have been removed from the text of the Guide, and can instead be found on the Swedish Research Council's website. The 2018 Guide thereby focuses on general needs and development trends. When individual infrastructures are mentioned, it is usually in order to exemplify such needs and trends. Despite these changes, much can be recognised from the 2014 Guide, and although development in many areas is rapid, fundamental needs and major challenges still often remain. In 2018, the Swedish Research Council is allocating a total of almost 1.9 billion SEK to infrastructure. A considerable proportion, 483 million SEK, relates to investment in the construction of the European Spallation Source ESS. Just over 600 million SEK is used to fund international infrastructures. Of these, the European particle physics facility CERN is the largest, and the Swedish Research Council's overall expenditure on membership fee and experiments in 2018 is almost 300 million SEK. Other international undertakings, which in 2018 covers 36 separate infrastructures, amounts to just over 300 million SEK.

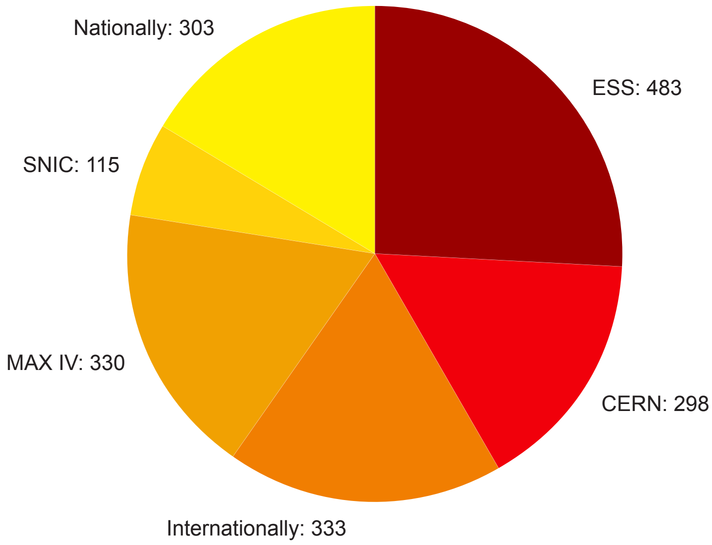
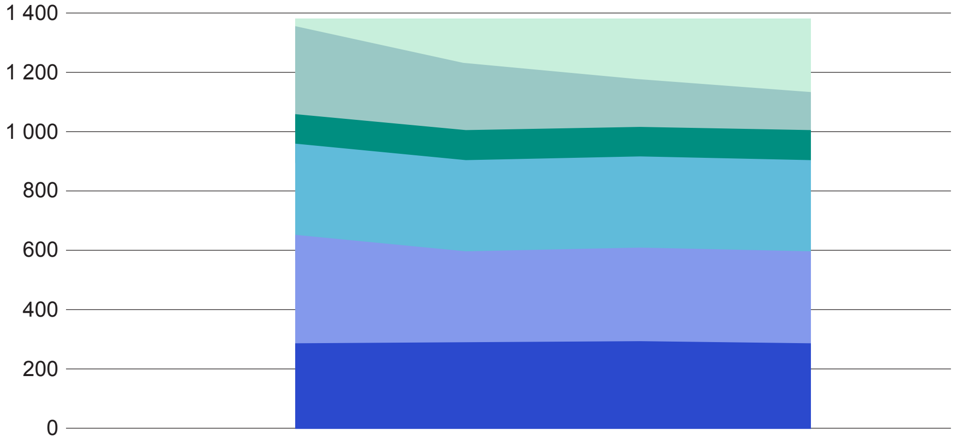


Figure 1. Swedish Research Council funding of research infrastructure 2018 (million SEK)

The Swedish synchrotron light facility MAX IV is the Swedish Research Council's individually largest national undertaking, and in 2018 300 million SEK is being invested in the facility. The Swedish Research Council allocates just over 100 million SEK to SNIC, which provides resources for data processing, data storage and user support. The Swedish Research Council's investment in other national infrastructure in 2019 amounts to around 300 million SEK.

> Even if the Swedish Research Council chooses to terminate all undertakings that are possible to terminate and refrains from new investments, the funds released during the period 2019–2022 will still not be sufficient to cover known cost increases. To meet the needs of the research community for infrastructure, the Swedish Research Council will therefore require increased financial resources to invest in research infrastructure, besides efficiency measures and prioritisation.

Figure 2 shows the budget forecast for the period 2019–2022. Please note that the continuing investments in ESS are not included in the figure. Over the period, funds are released as grants awarded earlier end, and in 2020, the Swedish Research Council can allocate just under 150 million SEK. Figure 2 also shows that the greater part of the funds released is attributable to national infrastructure, and a smaller part from international undertakings. These funds can be used to make new investments in research infrastructure, or to award renewed grants to research infrastructure that has previously received grants. *This means that in each grant decision, the Swedish Research Council must weigh up the benefit of a long-term engagement against the need to renew Sweden's research infrastructure*. Figure 2 also shows that the greater part of the funds the Swedish Research Council allocates to research infrastructure is bound up in long-term undertakings. At the same time, the cost of infrastructure is increasing. In the 2014 Guide, the Swedish Research Council estimated that just the expenditure on the increased need for e-infrastructure for calculation and storage of data up until 2020 needed to double to 200 million SEK. As the development within this area has continued to accelerate, and the requirements on open access to data have increased, most indicators are that this is a clear underestimate of the real needs. The cost of operating MAX IV will increase, and in 2023 an annual amount of just over 70 million SEK needs to be added to manage the operation of the facility. At the same time, we know that many of the international infrastructures are regulated through agreements that tend over time to generate increased costs. This means that the funds released will be less than known cost increases. To meet the need for infrastructure, the Swedish Research Council will therefore require increased financial resources to invest in research infrastructure, besides efficiency measures and prioritisation.



	2019	2020	2021	2022
Funding to allocate	29	149	202	249
Nationally	293	225	160	124
SNIC	100	100	100	100
MAX IV	310	310	310	310
Internationally	359	301	311	305
CERN	290	294	296	289

Figure 2. Budget forecast for the Swedish Research Council's funding of research infrastructure, excluding investment in ESS, for 2019–2022 (million SEK)

The Swedish Research Council thus makes considerable investments and has overall strategic responsibility for ensuring that Swedish research has access to advanced research infrastructure. At the same time, there are a number of other actors who contribute to fulfilling the needs for infrastructure. Swedish universities and higher education institutions (HEIs) play a central role, and have both strategic and financial responsibilities. In most cases, it is also the HEIs that have operational responsibility for national research infrastructures. The HEIs own the equipment and are responsible for employees and premises in conjunction with operation. 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) is an important part of this. Vinnova is engaged in several of the major infrastructure investments in Sweden, and plays an important role in making research infrastructure accessible to Swedish industry. Other research funding bodies are also very important for research infrastructure. The Knut and Alice Wallenberg Foundation (KAW) have made and are making important investments within a number of areas. The Riksbanken Jubileumsfond (RJ) also contributes with specific investments in infrastructure. For the area of medicine, healthcare and the comprehensive registers of healthcare play a central role, and a number of infrastructures are also funded and organised within SciLifeLab. Several public agencies also contribute with infrastructure for research. Statistics Sweden (SCB), the National Board of Health and Welfare (SoS) and other agencies are responsible for the registers that give researchers unique prerequisites for carrying out register-based research. Other examples of agencies that contribute with infrastructure for research are the Swedish National Space Agency, the Swedish Energy Agency and the Swedish Polar Research Secretariat, whose areas of responsibility border and to some extent overlap those of the Swedish Research Council. It is necessary to both find forms for constructive collaboration and to make clear demarcations between different actors in order to provide Swedish research with the best possible infrastructure.

How to read the Guide

The 2018 Guide to Infrastructure is organised as follows: The Guide starts with a number of overall recommendations, where the Swedish Research Council identifies development trends that drive the need for research infrastructure and indicates urgent areas for development of Swedish national research infrastructure. Chapter 2 describes the Research Council's definition of research infrastructure of national interest and a model for financing the same. Chapter 3 contains an overarching discussion on the development within research infrastructure and the challenges of the future. To some extent, this chapter is a summary of the four area chapters that follow, but it is also an attempt at linking together common challenges and questions that affect all areas. Four area chapters follow, three of which are organised according to the area responsibility of RFI's advisory groups, plus one separate chapter relating to e-infrastructure. A Guide Appendix is published in parallel with the Guide. The Guide Appendix contains a summary of the result of the 2017 needs inventory, and a list of the infrastructures supported by the Swedish Research Council. These are described in more detail on the Swedish Research Council's website. The Guide Appendix is updated every two years in conjunction with the needs inventory, while an update of the Guide itself is done every four years.

1.1 Strategic prioritisations and recommendations for the period 2019–2023

Below follow a number of overarching measures and recommendations relating to research infrastructure. In the four following area reviews, more specific recommendations are highlighted.

Increase Swedish investments in research infrastructure. The trend towards ever more advanced, long-term and resource-intensive research infrastructures is clear within nearly all research fields. This applies to both pure basic research and to more applied and industry-proximate research. This in turn means that the cost of research is increasing. The Swedish Research Council considers that this development should be met through a combination of:

– Increased financial resources for investment in research infrastructure.
– Greater efficiency through better coordination and use of existing infrastructure.
– Clearer prioritisation of investments in research infrastructure.

The Swedish Research Council has the ambition to take leading responsibility for the development, which requires an injection of financial resources, continued improvement of the processes for strategic prioritisation and broad collaboration with both public and private actors in the Swedish research system.

Intensify the coordination of research and research infrastructure. The needs of research shall govern investment in research infrastructure. At the same time, investment in research infrastructure entails strategic direction of research, as the infrastructures in themselves create prerequisites for the development of research. In many areas, there is an intimate connection between technical and methodological breakthroughs and crucial advances in research. The long-term work of coordinating investments in infrastructure and investments in research and education must therefore be further intensified. The Swedish Research Council's internal work of integrating the research-funding scientific councils and committees in prioritising infrastructure will therefore continue. In addition, the strategic collaboration between HEIs and other funding bodies needs to be further reinforced.

Clarify the allocation of responsibility for research infrastructures. The Swedish Research Council together with Swedish HEIs have taken considerable steps to clarify the allocation of roles and responsibilities for research infrastructures. This work will continue and be developed. At the same time, there is a need to further improve the coordination between governmental funding bodies' investments in research infrastructure. Besides the research funding bodies Formas, Forte and Vinnova, these include other public agencies of great importance to Swedish research, such as Statistics Sweden, the National Board of Health and Welfare, the Swedish Energy Agency and the Swedish National Space Agency.

Improve the information and strengthen the user support for open access and maximum use of existing infrastructures. Research infrastructures of national interest shall be openly accessible to researchers and other users. When access is limited, prioritisation shall be primarily on the basis of scientific excellence. Well-designed user guides and educational inputs are crucial for ensuring the infrastructures have impact in the research community and attract industry and other users. Swedish HEIs and research infrastructures should collaborate actively to inform about existing resources and design guidance and training materials to guarantee maximum use, engage new user groups and meet future competence requirements. Consideration for gender equality and equality of treatment must permeate this work.

Offer personnel at research infrastructures competence development and clear career paths. It is important to stimulate researchers to become engage in the build-up of infrastructure, and to assist with expert advice and technical support. This requires educational input, both at the country's HEIs and at the infrastructures in question. The persons who work at the infrastructures shall be offered good working conditions, competence development and various career paths. It is important that merits from build-up, development and operation of research infrastructures are upgraded and recognised when appointing personnel. The discussion on the merits and career paths of researchers need to be held in a coordinated way, both at Swedish HEIs and among research funding bodies.

Reinforce the engagement of Swedish researchers and Swedish industry in instrument and technology development. Both national and international infrastructure projects provide opportunities for Swedish researchers and Swedish industry to collaborate in instrument and technology development, both in terms of the construction of the instrument itself, and in the development of analysis tools and supporting software. In this, Swedish technology is at the leading edge in many respects, and active participation by industry needs to be encouraged and supported. A clear funding model for development work and supplies to research infrastructures should be organised. To achieve this, collaboration is needed, involving industry, research funding bodies, the ministries involved and HEIs.

Fulfil the major investments made into MAX IV and ESS. The major investments made into MAX IV and ESS are unique for a country the size of Sweden, and provide opportunities to promote Swedish research and strengthen Sweden's position as an advanced research nation. In conjunction with MAX IV moving from the construction phase to becoming operational, long-term sustainable funding of the operation at the facility must be safeguarded. At the same time, Sweden must fulfil the undertaking to host ESS in the best way possible, and prepare the Swedish research community for the facility becoming operational. It is very important that funds continue to be contributed to manage these undertakings without hazarding other necessary investments in research and research infrastructure.

Inject resources to fill the rapidly increasing need for calculation, analysis, storage, transfer and accessibility of data. The need for advanced e-infrastructure for research is growing in both a national and an international perspective. Developing the digital tools is necessary to guarantee the quality of research and to prevent any lack of access to e-infrastructure from developing into a bottleneck for considerable parts of the research system. Investment in computer resources for calculation and storage needs to increase, as does the capacity in networks for digital communication. Major investments in advanced user support and training need to permeate the entire research system and include general competence enhancement and increased access to e-expertise at the HEIs. National actors, such as the Swedish Research Council and Swedish higher education institutions, need to continue developing funding models for e-infrastructure. Sweden should also play an active part in many of the international collaborations that are now developing.

Intensify the work of creating prerequisites for open access to research data. Open data entail opportunities, but also major challenges for the research system. A central criterion is that the process is managed in a way that is economically defensible and that best promotes the quality of research. Considerable resources will be needed to ensure data is stored in a way that lives up to the principles for accessibility and reproducibility. Besides resources for storage and transfer of large data amounts, measures are needed for improved data handling and development of principles for which data to save. The work towards open data must be carried on in collaboration between HEIs, research funding bodies and the research infrastructures.

Develop and clarify the legal prerequisites for handling personal data within research. Safeguarding of personal integrity is central for the credibility and legitimacy of research. Given this, it important that the development of Swedish legislation is done in such a way that research can use existing data in an optimal way, and that systematic build-up of research data is made possible. It is also important that the remaining adaptation of Swedish legislation and legal practice to the European General Data Protection Regulation is based on knowledge about the needs of research. It is central that the experiences of researchers are utilised and that the HEIs take active part in ensuring this is the case. The Swedish Research Council also plays an important role as adviser to the Government.

2. Overarching definitions, goals and principles for funding research infrastructure

2.1 Definition of research infrastructure of national interest

The implementation of advanced research demands ever increasing access to resources that are built up systematically over a longer period of time, and that normally exceed the needs of individual teams of researchers. Examples of these resources are major research facilities, laboratory environments, experimental workshops, complex digital research systems and databases, but also experts and networks of experts. By creating this type of research resources, we provide the prerequisites for long-term research within entire research fields, which means that we describe them as research infrastructures.

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

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

In addition to the definition, the Swedish Research Council applies a number of criteria intended to clarify and demarcate the type of infrastructure funded by the Council for Research Infrastructures (RFI). RFI funds research infrastructure that:

- Enables research of the highest scientific quality, which thereby contributes to the development of society.
- Is openly accessible primarily to researchers, but also to industry and other relevant actors operating in Sweden. When access is limited, shall be prioritised primarily on the basis of scientific excellence.
- Is of broad national interest, which in most cases means that the research infrastructure is used by several research teams and researchers from several research organisations, and that RFI's funding creates national added value.
- Has long-term planning for the scientific activities.
- Has long-term planning for management and control, funding, competence accumulation and development.

Given the definition of research infrastructure of national interest, the criteria entail that there are important infrastructures that fall outside RFI's demarcation. The considerable local infrastructure that is necessary for a very large part of the research carried out is not included. Here, responsibility rests with HEIs and other research funding bodies. This means that the Swedish Research Council regards itself as one of several actors with responsibility for providing Swedish research with the infrastructure necessary to carry out research of the highest quality, and to ensure that Sweden will remain an advancing research national also in the future.

Making research infrastructure openly accessible also includes open access to data, depending on the circumstances. Making infrastructure accessible to users active in Sweden shall be regarded as a minimum requirement. The Swedish Research Council is positive towards research infrastructure being used by researchers and other actors who are not operating in Sweden. Being openly accessible also includes a gender equality perspective being applied to the operation, which means giving women and men the same opportunities to use the research infrastructure. As part of the Swedish Research Council's gender work, demands will be placed on reporting back and, in some cases, demands for measures relating to gender equality.

The Swedish Research Council funds Swedish participation in several international research infrastructures. The definition of infrastructure and associated criteria also covers international infrastructures. This means that Swedish participation in such infrastructures supported by the Swedish Research Council is required to show, among other things, a well-established and broad national interest.

2.2 Goals and principles for funding research infrastructure of national interest

The Swedish Research Council's overall goal is to work to provide Swedish research with access to the research infrastructure required to carry out research of the highest standard. To achieve this, a combination of long-term investments and necessary renewal is necessary. We also need balance and coordination between investments in research and research infrastructure. The ambition of the funding model for research infrastructure that the Swedish Research Council started to implement in 2015 is to achieve exactly this. At the same time, investments in infrastructure entail direction of the research, as research tends to gravitate towards the major infrastructures once these are in place. This means that investment in research infrastructure has consequences for research strategy.

2.2.1 Needs inventory and targeted call

The Swedish Research Council's model for funding infrastructure, summarily described in the figure below, follows a two-year cycle starting with a needs inventory and ending with a targeted call. Starting in 2015, the needs inventory is carried out every two years. Researchers, HEIs and public authorities with research mandates can notify needs for infrastructure of national interest to the Swedish Research Council. Via a review process – which besides RFI and RFI's advisory groups also includes the Swedish Research Council's scientific councils, the Committee for Educational Sciences and, via URFI, the Swedish universities – areas are identified where research is assessed as having a great need for new or expanded infrastructure. The result is presented in the "Guide Appendix", where the needs for future research infrastructure are summarised.

The results of the needs inventory form the basis of a targeted call. However, all areas identified in the Guide Appendix are not covered by the call. RFI decides on the areas to be included in the call on the basis of strategic consideration of the scientific benefit to Swedish research, an assessment of how well-developed and realistic the planning of the identified infrastructure is, and a budgetary assessment. As infrastructure of national interest requires national mobilisation and coordination, a coordinated application is normally expected for each area covered by the call. This, in turn, means that each application is assessed in particular on the basis of its ability to meet an already identified need for infrastructure.

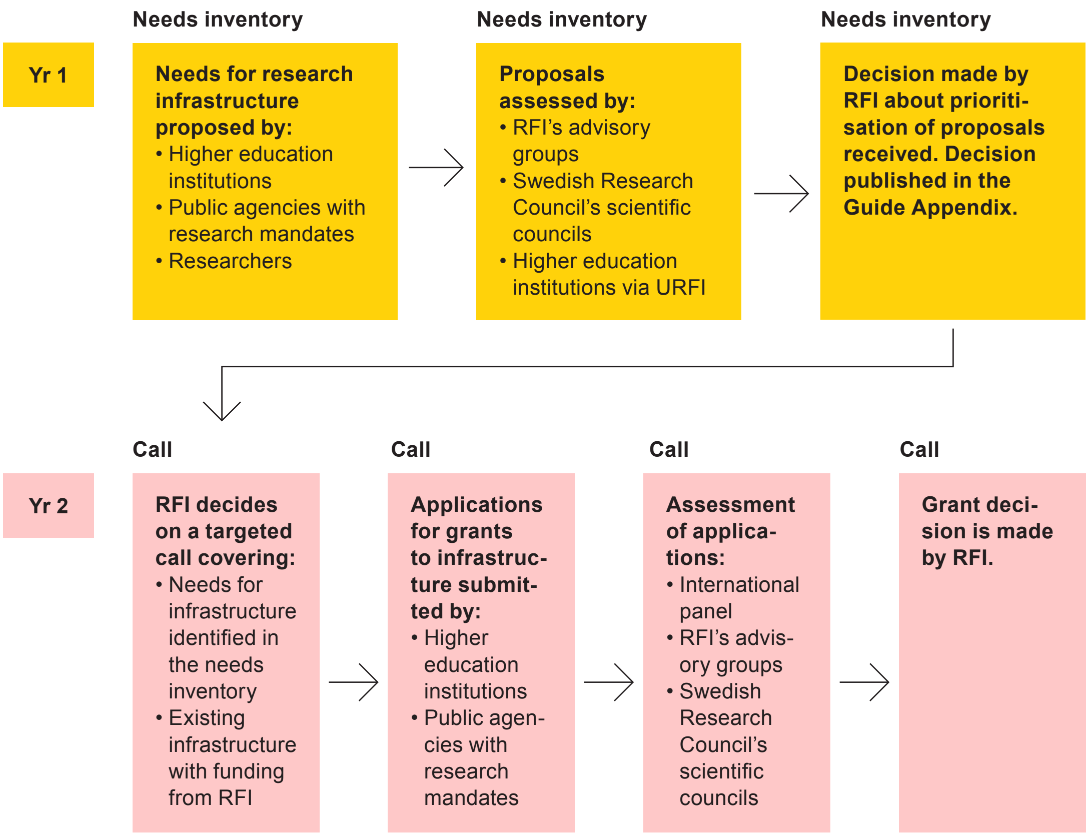


Figure 3. Swedish Research Council's model for prioritising and funding research infrastructure

In conjunction with funds being made available in the call for new infrastructure investments, existing infrastructures financed via RFI are also offered the opportunity to apply for renewed funding. Besides reporting on future activities, these infrastructures are also requested to provide a report on the activities that have been carried out. The application thus also serves as an evaluation.[1] By using the same review process to evaluate older infrastructures that need continued funding and infrastructures within new or associated areas, prerequisites are created for a process that balances long-term stability against necessary renewal.

2.2.2 Funding and operation of national infrastructures

Research infrastructures require long-term undertakings that cover the whole of their planned lifecycle: construction, operation and finally decommissioning. A clear commitment from the organisation, usually an HEI, that is the host and owner of the infrastructure is therefore necessary. In order to guarantee this, only HEIs and public authorities with research mandates can apply for funds from the Swedish Research Council for national research infrastructures. To safeguard national establishment, it is often a requirement that several HEIs back the application and form a consortium.

To fund national infrastructure, 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 increased costs of research

1 The Swedish Research Council also carries out follow-up during ongoing grant periods when this is considered necessary.

infrastructure and at the same time strengthen the commitment from the HEIs. This creates better prerequisites for long-term stable funding and operation of research infrastructures. The funding formats for infrastructure should be reviewed and evaluated continuously. The funding models vary for different types of infrastructure. For example, the system of user fees varies between different types of infrastructure.

2.2.3 International infrastructure

International collaboration on research infrastructure is becoming ever more important, and Sweden participates in and contributes financially to a number of international infrastructures of widely varying character, both in terms of science and organisation format. In a couple of cases, the neutron spallation facility ESS and the space radar facility EISCAT3D, Sweden is the host nation. Sweden participates actively in European and international forums for strategies and planning of infrastructure. One such body is the EU's European Strategy Forum on Research Infrastructures (ESFRI), which contributes to mapping and prioritising of pan-European infrastructure. Since 2002, ESFRI has regularly identified urgent European infrastructure projects in recurrent roadmaps. In September 2018, ESFRI presented an updated roadmap, and the next update is planned for the end of 2021. It is very important that Sweden participates actively in international collaboration, not least within the EU and its framework programmes.

In cases where Sweden is considering participating in new international infrastructures, the Swedish Research Council strives to ensure this is done after a review according to the model described above. This means that the need for a new international commitment shall be clearly defined in the needs inventory. The decision to allocate funds shall be made following a call, and be part of the overall prioritisation of both national and international infrastructure. For international infrastructure too, stability has to be balanced against the demand for renewal. RFI has therefore started a systematic evaluation of Sweden's scientific benefit from participation in international infrastructures.

2.2.4 One model does not fit all

There are considerable differences between different research infrastructures in terms of activities, stakeholders, funding and, not least, costs. To manage this, the Swedish Research Council has in some cases chosen to diverge from the model for prioritising and funding described above. This applies in particular for the very largest national infrastructures, currently MAX IV and SNIC. The funding decisions for these have been made based on considerable investigations and a process involving other research funding bodies and a large number of HEIs. The Swedish Research Council will have to make this type of divergence in the future too, in order to handle large and organisationally complex infrastructures.

2.3 Open access to research data

The discussion about open data has been going on for a long time, both nationally and within the EU. In Sweden, the Swedish Research Council has received an assignment to work towards open data. At EU level, the European Open Science Cloud (EOSC) is being discussed, which has resulted in a declaration that Sweden has signed. A prerequisite for open data is functioning and coherent e-infrastructure for storage, reuse, access and analysis of data. At the same time, open data are an important prerequisite for "data-driven research". Major inputs are also needed to make existing data accessible, which includes careful documentation of how data have been generated and the information the data contain, which is often referred to as metadata. Standardised metadata are, in turn, a prerequisite for research data living up to the principle of FAIR data, that is to say data that are:

- Findable – easy to find
- Accessible – openly accessible without charge or other restrictions
- Interoperable – comply with widely used standards and data formats
- Reusable – available to be used and reused

Open data and the FAIR principle entail opportunities, but are also major challenges for the research system. Considerable resources will be needed to ensure data are stored in a way that lives up to the principles. The major new investment now being made in the national data service SND, which is based on collaboration between almost 30 Swedish HEIs, is one of the steps towards open data. Another example is the Swedish Research Council's register-based research assignment. At the same time, thorough discussion is needed of what data are to be saved and made available. Much data are time-specific, such as data on climate, political values or the link between diet and health, and can therefore not be reproduced. It is essential that this type of data are saved. Other data are generated in experiments and can in principle be reproduced, given that the experiment is well-documented. In this case, saving data is not as much a given, and a balance must be struck between the benefit of saving data and the resources required to do so.

The fact that data are open and managed according to the FAIR principle should not be interpreted as an absence of restrictions. The principle for EOSC is that access to data shall be *"as open as possible, as closed as necessary"*. For research into medicine and health and social sciences in particular, data on individuals play a crucial role. These are data collected by researchers where private individuals provide the information, data from registers, patient data, biobanks, genome sequencing and quality registers. In these cases, technical solutions to protect data and the integrity of individuals are needed. One example of this is SNIC-SENS, which manages gene sequencing data from NGI. Due to the access to registers and the opportunity of using personal identity numbers to monitor individuals, Sweden offers unique opportunities for research. Respect for the integrity of individuals and research that is conducted according to applicable legislation and ethical guidelines are both given. The General Data Protection Regulation (GDPR) entails stronger protection of the integrity of individuals, at the same time as fulfilling the needs of research. It is important that the adaptation of Swedish legislation is done in such a way that research can use existing data in an optimal way, and that systematic build-up of databases is made possible. Here, it is important to emphasise that research is ever more dependent on longitudinal data, where individuals are monitored over long periods. This type of database is typically of a kind that falls under 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 requirement to make data available for peer review on scientific publication. To safeguard the quality of research, this issue needs further consideration in the future. Data available on the internet also raise ethical issues in relation to personal integrity, as the data persons make available via various media cannot be used as research data without problems. This is an area that is developing very rapidly, and continuous discussion is needed about the prerequisites for and ethical attitude of research.

2.4 Business, public sector and other users

Swedish industry can benefit in several ways from the research carried out at our research infrastructures. The researcher-initiated research carried out at the infrastructures generates new knowledge, which both in the short and the long term is crucial for Sweden's power of innovation and ability to meet major societal challenges. Industry and other stakeholders are also in many cases users of research infrastructures, which is something that the Swedish Research Council is working for explicitly, and one of the criteria for funding is that open access shall apply also to industry and other relevant actors. In some cases, industry has its own capacity to utilise advanced infrastructures, but industry's use is often carried out in collaboration with academic users in joint projects. To promote the use of advanced research infrastructure by industry and other stakeholders, collaboration between academia and industry should be further reinforced. Research infrastructures are also important for the development of the public sector; not least to create a knowledge basis for the healthcare and education sectors, democratic processes and reforms of the public sector as a whole.

Research infrastructure being constructed to generate new knowledge is a given, which in turn means that the scientific opportunities dictate what is funded. To reach the scientific goals, new and advanced leading-edge technology often has to be developed. The development of advanced research infrastructure is therefore in itself a driver of knowledge and technology, and here infrastructure can play a central role in driving competence accumulation. Improved opportunities for companies to deliver components to research infrastructure is therefore an important aspect of future investments. For major international engagements in particular, this requires a long-term and coherent strategy, where Sweden sets goals right from the start for deliveries that Swedish companies can contribute. To realise such a strategy, it is also necessary to have funding instruments that can handle deliveries, often "in-kind" contributions, to infrastructure, which in turn requires collaboration between research and business policies.

3. Development within the infrastructure area and the challenges of the future

Access to research infrastructure at national and international level is becoming ever more important in an increasing number of scientific fields, and the following chapter summarises overarching tendencies in relation to Sweden's need of research infrastructure. The starting point is the needs that are driven by basic and researcher-initiated research. At the same time, it should be emphasised that many research infrastructures play an important role for both the business sector and the public sector as a whole. Openness to users outside academia is, as has been pointed out above, one of the criteria set by the Swedish Research Council for infrastructure of national interest. Infrastructures are also important components for building up Sweden's ability to meet the major challenges of our time. Research of relevance to societal challenges related to climate changes, sustainable and safe societal development, public health, food production, switch-over to sustainable energy, democracy, labour market, etc. also require advanced infrastructures.

3.1 Infrastructure for understanding human beings, cultures and societies

The need for research infrastructures is increasing on a broad front within social sciences and humanities. Knowledge about societies today and throughout history, and of the life chances, prerequisites and values of individuals and cultures, outcomes of political reforms and analyses of behavioural changes provide both understanding of and the premises for social and economic development. Research is dependent on data about individuals and the contexts that they live and work in. Individual data may differ in character and cover everything from smaller qualitative investigations to major register-based studies of large groups or entire populations.

It is possible to discern a number of overarching trends that apply to both research within humanities and social sciences and within public health and epidemiology. One trend is that research requires increased access to longitudinal data, where information from the same persons is collected, in many cases over a large number of years. In this way, researchers can observe changes at both individual and group level, which is important for analysing connections and tracing phenomena over time. It also enables studies of outcomes in the longer term, and outcomes that require a long exposure time, which is important in research into working life and health, and research into family dynamics, for example. Sweden and the other Nordic countries are in a unique position, as data on individuals in many cases can be gathered from existing public registers and historical databases that in some cases stretch back as far as the 17th century. Register data are limited in content, however, and many questions require data to be collected for specific research purposes. The possibility of combining data from registers with data collected for specific research purposes gives Swedish research outstanding opportunities within both social sciences and medicine, and contributes to making it interesting and relevant in an international perspective. The collection of longitudinal data on individuals requires a long-term view and a stable organisation, however, which was why the Swedish Research Council made a major and coherent investment in 2017 to coordinate databases within medicine and society. The Swedish Research Council is today funding the infrastructures CORS, aimed at implementing and coordinating major surveys, NEAR, which takes an overall view of databases concerning ageing, and REWHARD, for databases concerning work and living conditions. The investment in register-based research and the build-up of the search and metadata tool RUT, which the Swedish Research Council is conducting as part of its Government mandate in order to make register-based data more accessible forms another important part of the context. In addition, there is the Swedish National Data Service (SND), whose function for making research data accessible has developed since 2017, with the help of the Swedish Research Council and in collaboration with a large number of HEIs, to taking clear national responsibility for making research data accessible. Enabling collection of data on individuals from several countries for comparative studies is another important trend, linked to the need to understand the effect of the country-specific context. Here Sweden's participation is important, as the country is a forerunner in many respects relating to labour markets and working life, gender equality and family policies, and therefore interesting to study, both by itself and in comparison with other countries.

The need to contextualise individual data is expected to grow, in order to enable analysis of more complex questions. 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, neighbourhoods, regions and countries. Context data may also concern exposure to poor working conditions, air pollution or other environmental components. In many cases, contextualisation requires some kind of geographic coding – because this increases the opportunities, due to the use of geographic information systems (GIS). In all cases, systematic 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.

Technology and methodology development are occurring within both social sciences and humanities entailing that different types of data can be analysed simultaneously. For example, numerical data from surveys can be combined analytically with large-scale non-numerical data amounts, based on texts, artefacts, images and sound. This makes it possible to carry out new types of analyses, on a scale and with a precision that have previously not been seen as possible. Examples of this are when machine learning is used to combine information from survey data and satellite images in order to provide a better understanding of living conditions in low income countries. One part of the development is the opportunity for data visualisation in order to analyse, understand and communicate research results, which impacts on humanities, social sciences and also public health sciences. At the same time, this is a process that makes great demands on data quality and standardised formats.

In parallel, information from the internet is playing an ever more important role; not least the opportunity for individuals to actively share information with research, or take part in surveys where respondents are both recruited and answer questions digitally. The information that individuals share spontaneously via social media and other platforms also gives rise to new research opportunities. The possibility of combining information from various types of data sources in new and innovative ways gives researchers new opportunities to address new scientific questions and societal challenges relating to subjects such as the view of democracy and values. This type of data also makes it possible to better understand how everything from views, values and behaviour to contagious diseases are disseminated.

In order to enable researchers within humanities, social sciences and public health sciences to fully utilise the opportunities that research is facing, continued investment in research infrastructure within humanities and social sciences is needed. Today, we are just seeing the beginning of this development, and the in vestments made within the language technology infrastructure CLARIN to develop tools for language analysis is one example of what is being done to support research. At the same time, investment from both research funding bodies and HEIs are needed to build up competence structures that provide researchers within humanities and social sciences knowledge about and access to new methodology advances and the prerequisites for developing digital methods and tools for their areas of research. Besides technical and competence-related challenges, the development raises a number of legal and ethical questions that must be addressed.

3.2 Life sciences, medicine and health

The population's state of health is going through changes that are fundamentally driven by demographic and lifestyle changes. Healthcare is also at the beginning of a development away from a general therapy model to a precision model, where therapy interventions are increasingly tailored to the prerequisites of the individual. This development is largely dependent on access to large data amounts, and to the opportunity to link patient data to genetic and molecular data generated within basic research. In order to develop methods for preventive measures, diagnostics, treatment and rehabilitation that are increasingly individualised, capacity to use complex data and methods is needed, as is bridge-building between different research disciplines. Collection, maintenance and accessibility of individual data and the possibility of combining data is becoming ever more important. The initiatives that today exist both nationally and internationally relating to biobanks (BIS) and register-based research (RUT), and accessibility of research data driven by SND need to be developed and consolidated. Bioinformation needs to be linked to other types of data within health and medical care, not least their quality registers, which in turn need to be improved, in terms of quality, coverage and accessibility to research, and also need to include primary care to a greater degree. The opportunities that exist today of using modern technology to collect health and behaviour data from individuals must be evaluated and developed as necessary. Enabling linkage of data from differing sources in a way that protects integrity is of central importance. There is great potential for better use and combination of data on social circumstances, behaviour, biomedical characteristics and health outcomes. To drive this development forward, collaboration is needed between those who carry out research, both private and public, research funding bodies and health and medical care.

Research is contributing ever faster to the understanding of fundamental biological and physiological processes, which in turn forms the basis for the development of medicines and clinical therapy. The use of various "omics" methods – genomics, proteomics, metabolomics – is increasing exponentially. Continued investment is needed here, in areas such as genome sequencing (NGI), but also opportunities to further develop platforms for metabolomics and proteomics, for example. Medical imaging is expected to become an ever more important tool, and within high-resolution microscopy, these resources are today coordinated nationally by the research infrastructure NMI. Via platforms for protein production and characterisation of proteins, it will also be possible to use synchrotrons, such as MAX IV, and neutron sources, such as ESS, for structural studies of proteins of medical relevance, for example.

The Swedish Research Council also sees a need for continuing competence accrual within bioinformatics and analysis of large data amounts. NBIS is an example of research infrastructure that offers support within bioinformatics to individual research projects, and enables researchers to use complex data and new technologies in their research. The indications are that this type of support for the research process will play a greater role in the future. One example of this is visualisation, and not just within life sciences, but within subjects stretching from humanities to particle physics.

3.3 Materials and the constituents of life

Many aspects of our everyday lives are affected by the characteristics of materials; their hardness, malleability, conductivity, magnetism, transparency or resistance to corrosion. Life itself, with its cells and molecules, is also an advanced form of material. The study of materials in this wide sense is therefore central within a number of research areas, such as 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.

Finding new and innovative materials is crucial for achieving an environmentally sustainable society. The consumables of the future must be based on a life-cycle that requires less energy, is less based on finite resources, and that can be reused or be destroyed in an environmentally friendly and sustainable way. Multi-functional materials with combined characteristics, such as magnetic, catalytic and electric, are a research area that is important for the development of high-technology products. The development of new materials is also necessary in order to produce, transport, store and convert energy in sustainable energy systems. Following very rapid biochemical processes in real time, for example how plants convert sunlight into energy using photosynthesis, will probably become possible. The opportunities that open up for designing nanomaterials will be central for areas such as energy, the environment and medicine and health. Within life sciences and medical research, several methods are playing an ever-increasing role in understanding biological processes in detail. Some of these are structural definition at molecular and atomic level, 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.

To meet the needs of research, investment is needed in advanced infrastructure, such as synchrotrons, 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 party to investments in the European XFEL, the world's most advanced free electron laser. In the area of structural biology, infrastructure for NMR spectroscopy (Swedish NMR Centre) and Cryo-EM microscopy have been built up within SciLifeLab with considerable support from KAW and others. These facilities enable studies of structures and dynamics in 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.

The use of this type of facility also requires access to further infrastructure in the form of laboratories and cleanrooms to prepare samples and carry out preparatory studies. In many cases, these resources will be of a local character. In other cases, facilities such as advanced cleanrooms are needed. These are coordinated nationally by Myfab, which is in itself important for producing and characterising materials. In many cases, considerable e-infrastructure for data storage and analysis is needed in conjunction with carrying out the experiments and taking care of the results. There are major challenges at all stages at all stages of the research process, and avoiding bottlenecks in the system is an important aspect when prioritising infrastructure investments.

The establishment of the synchrotron MAX IV and the neutron facility ESS in Lund entails major undertakings for Sweden as a research nation. At the same time, they give Sweden the chance to establish Lund as a global centre for research using synchrotron and neutron technologies. To realise the potential of MAX IV, long-term funding of maintenance and operation and further investments into beam lines will be required. The Swedish user base should be broadened and increased to include new fields, and also involve industry. MAX IV should aim to be world-leading within a number of profile areas that use the unique features of the synchrotron, but responding to broad needs of the Swedish research community is equally important. However, the facility cannot fulfil all the synchrotron needs of Swedish researchers. The Swedish Research Council has therefore started to develop a strategy, where the development of MAX IV is weighed against continued Swedish engagements in the X-ray facilities ESRF, European XFEL and Petra III.

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 facilities, such as ILL in France and ISIS in the United Kingdom has increased. 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. Sweden should also work to ensure Swedish engagement in the upcoming instrumentation of ESS.

The fact that MAX IV and ESS are co-located at Brunnshög outside Lund creates opportunities for the development of a dynamic research environment that includes both academia and industry. The engagement in the facilities, both grants to and use of, must be a national concern, however. To ensure this happens, a coordinated national strategy is needed, covering the entire chain from the physical infrastructure around the facilities to build-up and optimal use of competences and human resources throughout the country.

3.4 The universe's smallest components

Researchers in nuclear, hadron and particle physics are in many cases entirely dependent on access to large-scale research facilities. 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) to HL-LHC. Sweden is also participating in the experiments ATLAS and ALICE, which are also being upgraded and adapted to HL-LHC. At CERN, Sweden is also engaged in the ISOLDE facility for hadron and nuclear physics. In a related field, there is also Swedish engagement in the nuclear physics facility FAIR, where research using anti-protons and ions will be conducted.

Greater energy and intensity, together with improved measuring methods, open the door to observations of unknown particles outside the known standard model. In order to achieve increases in energy beyond HL-LHC, the possibility of implementing a further upgrade to LHC is being investigated, as well as the construction of an entirely new particle collider in the future. Related projects are being studied simultaneously in Japan, China and USA. Swedish researchers are also involved in a discussion on the possibility of building experiment stations at ESS for research in the field of particle and hadron physics. Other research areas concern dark matter and observations within the neutrino sector, for example. The development in the area is driven by a combination of scientific questions and technological development. To create long-term prerequisites for Swedish research, a coherent strategy is needed for prioritising Swedish engagement in the relevant research infrastructure, as well as prerequisites for technology development in conjunction with these. Producing such a strategy over the next few years is an important task for the Swedish Research Council and the research community as a whole.

3.5 Space

Sweden has long been engaged in national and international investments in large-scale infrastructure within astronomy and astroparticle physics. As a member of the European Southern Observatory ESO, Sweden contributes to the operation and build-up of telescopes in northern Chile, such as the radio telescope ALMA, the optical telescope VLT, and the future optical telescope E-ELT. The Onsala observatory is a national facility for radio astronomy and a Swedish node for international collaboration. Another national facility is the Swedish solar telescope on La Palma. Within astroparticle physics, Sweden participates in the operation of the IceCube observatory at the South Pole. Sweden also has to take a position on its cooperation in the construction of the radio telescope Square Kilometre Array (SKA) and the planned European solar telescope EST, which when in operation are expected to change the prerequisites for global research in their respective fields.

The engagement in international infrastructures is a prerequisite for Swedish research relating to astronomy and questions about the structure, development and origin of the universe. The same infrastructures also constitute tools for studies of fundamental physics, such as gravity waves, gravitation theory, astroparticle physics, neutrinos and dark matter. Here there is a link to the particle physics research carried out at facilities such as CERN.

The research does not just relate to outer space. Space physics addresses questions that relate to Earth's closer environment. Studying the Sun is important in order to understand climate and, not least important, the risk of disruption of technical systems for communication and electricity supply. The investment that is now being made into the international space radar facility EISCAT3D, located in Sweden, will strengthen research relating to near-Earth systems and the interplay between the atmosphere and space.

The latest discoveries within gravity waves are an example of collaboration between different astronomy infrastructures and points to the importance of access to a broad range of national and international complementary infrastructures. Other examples relate to environment and climate research, where data from space, atmosphere, geosphere and hydrosphere can be combined to address complex research questions. Given this, well-considered and long-term prioritisation of Sweden's engagement in the international collaborations is required. Increased national cooperation will also be required between public agencies such as the Swedish National Space Agency, which is responsible for space-based infrastructure, and the Swedish Research Council.

3.6 The Earth's climate and environment

Research within climate, environmental and geosciences is crucial for societal development and for understanding and influencing the prerequisites for life in the world around us. Understanding of the entire climate system and how it is changes is reached through calculation-heavy simulations to capture complex processes. Research into climate and environment also requires detailed and long-term observations of air, land and water. Sweden offers great variation in terms of environment types and climate zones, which is both an asset and a challenge for research. Via our investment in ICOS, measurements of greenhouse gas emissions are made across the whole country, which are in turn linked to similar data from other countries. The Swedish Research Council also supports coordinated field stations via SITES, which enable detailed measurements of land and water conditions around the country and contribute valuable knowledge about environment and climate issues.

Enabling further geographically detailed information is a future challenge, which requires observations and experiments in more locations across the country. To achieve this, continued development of mobile measurements and observations of the marine environment will be needed. As neither climate, environment or geology are controlled by politically determined borders, we will be highly dependent on international collaboration, coordinated investment in infrastructure and common standards for collecting, managing and accessibility of data.

Through the Swedish Research Council's international memberships and national investments in geoscience infrastructure, Swedish researchers are given access to advanced platforms for sampling and analysis. In the future, we will also need an international platform for coordinating data and models for the national and international observation platforms that contribute to understanding of geological process of importance for geo risks and access to natural resources.

Research within environment and climate is partly based on analyses of a very large number of samples, often collected over a long time. Sample banks for substances such as water, soil and relevant biological materials enables future analysis of samples that have already been collected and which due to continuous environmental changes are unique and impossible to replicate.

3.7 Technology and energy

Technological sciences are a field that covers both basic and applied research. The field is in turn made up from many different research fields. A common feature of all is that they strive to implement basic research and to predict process outcomes and functions of products. Researchers use infrastructures such as synchrotron light and neutron scattering facilities, which are central within many other research fields. Research infrastructures aimed directly at technological sciences are often dedicated to a specific area, and often of a regional or local character. Often these also consist of pilot or testing facilities, where research is an integrated part of the facility itself. One such example is Astra Zero near Borås, where the main purpose is to enable testing, development and research into future products and systems for road safety. To safeguard the prerequisites for technological sciences in Sweden, opportunities for coordination should be inventoried and the allocation of responsibilities for funding must be clarified.

Safeguarding 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 energy. Development of renewable energy sources, such as solar energy, wind power and bioenergy, is an important aspect. The same applies to research aimed to increasing efficiency and improving traditional energy sources, such as hydro power and nuclear power. A lot of energy research is dependent on advanced research infrastructures to understand and develop materials with specific characteristics, and to understand the environmental consequences of energy production. Specific trial and demonstration facilities for developing and testing new technology is needed for a lot of energy research. This means that 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.

3.8 E-infrastructure

E-infrastructure refers to resources for storage, transfer, calculation and analysis of digital data. The concept also encompasses the competences and organisations that are necessary to ensure research is able to utilise existing resources and existing data. The need for e-infrastructure is increasing rapidly within practically all areas of research; not just in traditionally data-intensive natural sciences, such as physics and astronomy, but increasingly also within medicine, humanities and social sciences. Advanced research infrastructures within a number of areas in themselves drive this development, as they tend to produce ever larger and ever more complex amounts of data. At the same time, the development means that data can be combined and analysed in every more composite ways. This change is permeating entire fields of research, and entails a comprehensive evolution of how research is conducted and what subjects we can research. The opportunity to conduct "data-driven research" is an important aspect of the change, but it should be underlined that hypothesis-driven research is also impacted fundamentally by new opportunities. The driver behind this development is ever more advanced computer architecture, new applications based on machine learning, artificial intelligence, visualisation and services for discovering, combining, handling, making accessible, using, storing and reusing research data. In the not too distant future, we will see applications of quantum technologies with the potential to open up entirely new opportunities within the "e" area.

Because e-infrastructure is playing an increasingly important role in research, there is a risk of it becoming a considerable bottleneck. Increased resources will be needed to store, transfer and analyse large and complex amounts of data. For example, it is only meaningful to conduct an experiment or genome sequencing if data can be stored and analysed. To make this possible, continued investments in e-infrastructure hardware is needed. Continuous development of programs and applications is also necessary, not least to meet increased demands for visualisation, which in itself is an area of research where Sweden has a strong presence.

Competence is central for maintaining and using advanced e-infrastructure. This applies specifically for the competence that is necessary for building and operating the e-infrastructures themselves. It applies equally to building up the research competence that is needed to utilise the opportunities that are now opening up within an increasing number of research fields, in particular those fields where digital development is offering radically new ways of conducting research. Today, NBIS is offering advanced user support within bioinformatics. Similar needs are now emerging in other areas. Being able to harness the potential of digital development is a formidable challenge, not just for leading-edge research, but for the whole of the Swedish educational and research system.

The e-infrastructure area has long been international. The Swedish HEI data network SUNET and its Nordic and European equivalents NORDUnet and GÉANT link together the European HEIs and research institutions, and guarantee that we are linked up with the rest of the world. WLCG is an internationally distributed system for handling the data amounts generated at CERN. SNIC has the task of meeting Swedish researchers' needs for e-resources and collaborates within the Nordic countries via NeIC and beyond with PRACE within Europe to guarantee availability of the most advanced calculating resources to Swedish researchers. All indications are that international collaboration on e-infrastructure will increase in importance. This is shown not least by the major investment now being made in Euro-HPC, a European collaboration that Sweden will participate in.

Sweden needs to play an active role on the international arena, both to ensure that researchers active in Sweden have the best possible conditions, and to continue to develop Swedish competence within the e-infrastructure area. At the same time, the national e-infrastructure must develop and be organised in the best possible way, not least because the national resources form the foundation for international collaboration. The Swedish Research Council has started work on a national compass for e-infrastructure, which is expected to form the basis for future development of the area.

4. Infrastructure for humanities, social sciences, life sciences, and medicine and health

Research infrastructures within this area cover a broad spectrum and include everything from language databases, historical archive material, and surveys to characterisations of protein structures, which in turn reflects the width of the research carried out. At the same time, several of the infrastructures covered by this heading are relevant for several different research areas. The historical demographic data organised within the framework for SwedPop is not just of importance to historical research, but also to social scientists who want to understand long-term social changes, and to researchers within public health and medicine, who are studying the hereditary features of diseases. As the border between social sciences and medical research is partly being dissolved, researchers within these fields will increasingly be dependent on the same research infrastructures. Social science data from surveys and registers form the basis for understanding the development of living conditions, the labour market careers of individuals, the importance of education for continued life chances, etc. They are also central for understanding the link between social conditions and the health of individuals, and therefore also of importance for medical research. 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.

Sweden is already towards the leading edge in terms of research infrastructure within the areas in question. Despite this, there is potential for further improvement aimed at reinforcing Swedish research. This applies not least to improving the opportunities for researchers to use register data and biobank data, but also by making available through digitising and making accessible a cultural heritage that, from an international perspective, is relatively intact.

4.1 Key issues

The needs for advanced infrastructure for humanities, social sciences, medicine and health and for life sciences are increasing quickly, and on a broad front. Sweden has a long tradition within linguistic research and of developing language technology tools. Archaeology uses methods and tools from natural science disciplines, which are now developing rapidly and result in considerably better knowledge about pre-history development and its chronology, and about the interaction between humans, nature and climate. Within the field of history, databases have been built up that exploit the opportunities offered by digitisation of Sweden's historical population registers. In these areas, investments and improved national and international coordination will further reinforce research.

At the same time, several of the other areas within humanities need to build up national and international infrastructures for coherent solutions to produce and make accessible digitised material for research purposes. Ongoing initiatives to reinforce research via improved language databases and systematic digitisation of cultural heritage are important elements of this. These initiatives should be followed by continued coordination aimed at long-term investments in national research infrastructures.

Access to large-scale data amounts from the internet, digitisation of existing data sources and the rapid development of new machine learning methods for data analysis will probably have a major impact on research within all fields; not least humanities and social sciences. Non-numerical data quantities based on texts, images and sound will be possible to analyse on a scale and with a precision that was previously only possible for numerical data. Improved techniques and methods for digital visualisation of data provides new opportunities to analyse, understand and present data. The opportunities to combine different types of data mean new opportunities for research. For example, GIS data linked to individual data can improve the opportunities to study the link between individual factors and the social and environmental context the persons live in.

An important prerequisite for developing Swedish research is the opportunity to utilise public authority registers. Sweden's register data is based on centuries-old traditions, and their strength lies in them often including the entire population, and offering systematically collected data with low drop-out rates. The latter is important not least in the light of the problems with failing response frequencies that affect many surveys. Through interdisciplinary collaboration and an expanded e-infrastructure for using register-based data, Swedish research can make considerable progress. The potential increases further when data from registers is combined with other data sources. For example, by linking data about schooling from the database UGU, which contains data collected from school pupils, with register data, entirely new knowledge about the importance of the educational system for the life chances of individuals can be gained. Unique opportunities for gaining new knowledge can also be found through combining individual data collected in longitudinal studies, for example the life circumstances survey LNU, register data and context data for analysis of causes and consequences of societal change. Integration of register data with data from biobanks and the quality registers of healthcare create new opportunities to conduct medical research.

However, established systems for making data searchable and accessible, as well as technical and practical solutions for guaranteeing personal integrity are needed in order to use the register. The work that is now ongoing within the Swedish Research Council's register-based research mandate and the establishment of the search tool RUT, coordination of biobanks via BIS and SND's work on making research data accessible are important components in this context. Improved international collaboration, perhaps primarily but not exclusively with our Nordic neighbours, will create further potential for register-based research.

Strengthening and improving the opportunities for research using registers and databases entails a challenge in terms of access to research infrastructures that offer common standards, coordinated technical method and tool development, and capacity for storage and analysis of large data amounts. The greatest challenge relates to competence provision, however. Considerable resources and new competence will be needed within statistics, bioinformatics and analysis of large data amounts if

Swedish research is to benefit from the opportunities offered by digitisation.

Research within life sciences aims to create increased understanding of how all living organisms function, interact and affect their environments. Basic research uses various model organisms and also genetics, genomics, proteomics and a large number of measuring methods integrated with calculation biology in order to map how organisms function at system and molecular level. Complex biological processes can today be studied, thanks to technology developments taking place in parallel with basic scientific research. The development is making research ever more dependent on multidisciplinary collaboration and access to biological material. The research results find their use primarily within medical diagnostics, prevention and therapy, but also within plant research and biotechnology. The results are in many cases also applicable in interaction with researchers from different disciplines other than medicine and biology, for example technology, chemistry, physics, materials science and pharmacology. Living conditions and environmental aspects are also important components.

Continued development of research infrastructure is necessary in order to meet the demands of the future. Technology platforms for research and questions relating to DNA, RNA and proteins, which have been built up within SciLifeLab, for example, with support from the Swedish Research Council, KAW and the universities, must be further developed and continuously modernised. To create long-term and national development, collaboration between these and other actors will be necessary. Infrastructure within life sciences often consists of distributed resources with nodes in several different locations, based on different technologies and resources. Examples of such infrastructures are NBIS for bioinformatics, NGI for DNA and RNA sequencing, and BIS for the Swedish biobanks. But infrastructure in the form of larger facilities for studying structures and molecular interactions will also be important for driving the development forwards. For example, new advanced microscopy, MAX IV and ESS are expected to provide entirely new opportunities.

The European infrastructure collaboration within life sciences, in particular those proposed by ESFRI, are and will probably become ever more dominant in the formulation of calls within the next framework programme, Horizon Europe. In order for Sweden to participate in a good way in this development, national infrastructures have to be consolidated and integrated in the European investments in an open process that fulfils the needs of research.

A long-term successful strategy for life sciences must be based on strong basic research in interaction with well-developed clinical research anchored in healthcare and in the pharmaceutical industry. The development towards more individually adapted health and medical care will require ever closer collaboration with basic research and method development, as the need will increase for techniques such as advanced diagnostics. Healthcare is currently at the beginning of a development away from general care models and towards healthcare that is ever more adapted to the needs and prerequisites of the individual. A prerequisite for individual-based healthcare is developing more precise medical and clinical therapy models. This requires research that can identify the type of care that is the most effective for any given patient, based on combined analysis of genetic, social, environmental and lifestyle data. In concrete terms, this means that the research underlying an ever more individualised healthcare is data-driven and dependent on access to considerable population-based databases. Coordination of biobanks that are currently operated by BIS, access to Sweden's comprehensive register-based data and quality registers, support for bioinformatics provided by NBIS play a central role here. At European level, BBMRI-ERIC is driving forward the coordination of biobanks, and ELIXIR is offering a European structure for bioinformatics. The ability to use information from social media and various technologies, such as health apps, opens up new opportunities to improve understanding of how individuals' behaviour and exposure to both social and environmental factors impact on health and the prerequisites for healthcare. Just as within many other areas, the development means that the needs for storage and analysis of large data amounts are increasing.

4.2 Areas that need development, changes to funding or other measures

4.2.1 Databases and register data

Access to longitudinal individual-based databases, where individuals are followed up during a number of years within the framework for surveys that are repeated regularly during long periods is becoming ever more important for both social sciences and medical research. The collection of data on individuals from a number of countries enables research into subjects such as the importance of societal institutions for the economic and social behaviour of human beings, inter-personal relationships, health and integration. To satisfy the need for longitudinal individual-based databases, purposefulness, long-term prioritisation and coordination of both resources and competence are needed. The investment in databases made by the Swedish Research Council in 2017 is an important step in this direction. At that time, investments were made into three new infrastructures responsible for operating and developing databases. Within CORS, several international surveys are run, such as ESS, SHARE and ISSP. The Swedish part of the international election study CSES, Comparative Study of Electoral Systems, is also carried out within the framework for CORS. REWHARD coordinates and operates major longitudinal studies of working life and living conditions, among them the Swedish Level of Living Survey (LNU) and SLOSH, which concerns health conditions on the Swedish labour market. A large number of surveys relevant to research into ageing, such as SNACK, H70 and the Betula project, are coordinated by NEAR. The Swedish Research Council is looking forward to continued development towards coordination and long-term prioritisation of broadly defined databases within social sciences and medicine.

Improved opportunities to use register data for research should be a continued priority. Through the work carried on by the Swedish Research Council within the register-based research project and the development of the RUT tool, progress has been made towards simplifying the use of registers for research purposes. RUT contains meta-data, that is to say descriptions of the content of registers and research databases, and offers support and help to researchers who wish to use register data. The project should continue in order to further intensify the collaboration that is taking place between different register-keeping public agencies and representatives of research. This is important, not least to find a joint solution for public agencies to give access to register data to researchers. Within the healthcare area, better use of systematic data on medicine use within healthcare and data from the quality registers are important development areas. To achieve comprehensive documentation for research into human health problems, a discussion should also be held on whether it is possible to find a national solution for making data from primary care accessible. This would promote research within the area and better describe the needs of various target groups, what interventions are made within primary care and what the consequences of these are.

In order to create strong research within life sciences, access is needed to both the infrastructures of health and medical care (for example medical history systems, treatment units, research and quality registers), and to more pure research infrastructure (such as biobanks, research environments with relevant subject-specific competence and logistics/technology). To utilise data from health and medical care in an effective way, these infrastructures need to be coordinated nationally.

Improved opportunities to use registers and combine data from various sources must take place in a way that guarantees the integrity of individual persons. Implementation of the European General Data Protection Regulation, GDPR, and the development of technical solutions that fulfil both individuals' right to integrity and the needs of research are of crucial importance.

4.2.2 Aggregated and contextual data

Besides individual-based databases, research requires access to contextual data, that is to say data about institutional circumstances, legislation, finances, organisation of welfare policy, etc. When it comes to research into the prerequisites for democracy in various countries, this type of data is utterly central. But this is the case within many, or rather most, research areas where the research question relates to the behaviour and prerequisites of individuals. It should be underlined that contextual information is not just central for social sciences, but also for research into subjects such as epidemiology and history. When it comes to context databases, Sweden has for many years been internationally prominent, and coordination and long-term prioritising are important steps in the continued development of the area.

4.2.3 Digitised cultural heritage and laboratory archaeology

What is often called digital humanities is a rapidly growing field where infrastructures can be developed. Archaeology with laboratory analysis is an area that generates large amount of data. Currently, national infrastructure is lacking for unified and coherent handling, archiving and publication of research data on both scientific and artistic basis within humanities. In an international perspective, Sweden has a relatively intact and accessible cultural heritage, as well as the technical and competence prerequisites for digitising data and making it accessible. The resources to do this are, however, too few and too small, and furthermore insufficiently coordinated, which means that Sweden has lagged behind other comparable countries in this area. Individual infrastructures in the area lack critical mass, and a joint resource is needed to develop research nationally. Existing "humanities laboratories" should be considered as part of such a national infrastructure for research into this type of material.

4.2.4 Reality lab

A technical research infrastructure for health research, with experimental but close-to-reality studies with humans can be used to evaluate and develop innovative solutions, and to optimise functions in everyday life (for example using virtual reality). This type of research infrastructure can also extent our knowledge about interactions between persons and the environment in a multitude of disciplines, over and above that of medicine, and at the same time improve our use of resources through sharing expensive equipment, technologies and leading-edge knowledge.

4.2.5 Biological/medical imaging

The Swedish Research Council has invested considerable resources in medical, primarily macroscopic, and biological imaging, and is currently supporting the national microscopy infrastructure for advanced, high-resolution microscopy (NMI). Continued coordination and national prioritising of biological/medical imaging is of great importance for both basic and clinical research. At European level, the area is coordinated within EuroBioimaging-ERIC, and the Swedish Research Council will decide in 2019 on possible Swedish membership.

4.2.6 Large-scale molecular studies

There is a need for national infrastructure for protein production and characterisation of protein products. The development in genomics has cleared the way for collecting several types of biological data on a large scale. The use of various "omics" methods, such as genomics, proteomics and metabolomics, is increasing rapidly. Clinical use of large-scale techniques, which is still at an early stage, will probably increase, which in turn places increased demands on collaboration between healthcare and researchers. There are already platforms for sequencing using clinical methods to map hereditary diseases (the Clinical Genomics nodes at SciLifeLab), and because knowledge about the genetic predisposition of various diseases is increasing, this will become more and more useful, in particular for producing information for preventive care. This also applies to other "omics" techniques, which can identify metabolites and other types of bio-markers for diseases, for example. This makes it possible to tailor therapy for diseases, and even to start treatment to prevent or delay the onset of diseases.

4.2.7 Biobanks

The national biobank infrastructure BIS, which was established in 2018, includes all universities with a medical faculty and associated university hospital principals (county councils and regions), and the goal is to improve the access to samples and associated data for researchers in academia, health and medical care and industry. Biobank samples are used both in healthcare and treatment and also in medical research. In order for biobank samples to be used optimally, harmonised collection, documentation, storage and withdrawal of samples is required. Continued development of BIS and the collaboration that takes place at European level within the framework for BBMRI-ERIC is therefore necessary. Thanks to the access to register data, Sweden has a unique opportunity to use existing personal identity number-based registers within medical/public health and social science research, and to combine this data with data from biobanks.

4.2.8 Bioinformatics

Just as in many other areas, life sciences are producing ever greater and ever more complex data quantities. Great demands are placed on tools for analysing and storing data. As these data are in many cases potentially sensitive data from individuals, there is also a requirement that the data is handled securely. To meet this requirement, SNIC has developed "SNIC-sens" to analyse and store sensitive data. At the same time, there is also a need to reinforce competence within bioinformatics and analysis of large data quantities. Here, the bioinformatics infrastructure NBIS has been organised within the framework for SciLifeLab, funded by the Swedish Research Council and KAW among others. NBIS offers researchers support in the analysis process, including standards for data handling, access to data, software and help with analysis and storage of data. The need for this type of research infrastructure is expected to increase. One challenge is the linkage and integration of different types of data: linking patient data with genetic or molecular data from basic research in order to develop diagnosis, prevention and therapy within the field of individual-adapted medicine. Here there is a clear link to infrastructure in the form of databases and registers for public health and social sciences, and e-infrastructure (e-science). There must also be a transfer of competence within bioinformatics, statistics and mathematics that is combined with understanding of basic questions within life sciences and clinical research.

The area of bioinformatics is on the borderline between basic research and applied research; between research and industry. A further issue is how industry's use of bioinformatics to develop the next generation of medicines and health and medical care shall be developed. Here there is a need for collaboration between different research funding bodies, such as the Swedish Research Council, Formas and Vinnova, and industry, to enable research infrastructures to benefit many.

4.2.9 Secure labs

Diseases caused by infection are a common cause of morbidity around the world, and are the second most common cause of death after coronary disease. To study the microbes that cause infection – bacteria, virus, parasites, fungi, worms, etc. – laboratories are needed with security classifications for risk class BSL2, BSL3 or the uncommon highest security class BSL4. Class BSL2 is also needed for research into organs, certain cells and tissues. Sweden is currently investing primarily in infrastructure in BSL1, the lowest security classification, but we are lacking dedicated equipment that can be put into laboratories with higher security classifications. Therefore, national collaboration and investment is needed in experimental equipment for these security-classed environments, such as equipment for visualisation/microscopy, live cell imaging, PET, magnetic resonance imaging camera, sorting with flow cytometry, etc.

4.2.10 Laboratory animals

Experiments on animals enable studies of fundamental disease mechanisms and the effects and side effects of new medicines. They are necessary for understanding complex diseases in both humans and animals, for developing new and more effective disease treatment and for improving livestock production. Despite progress in the development of alternative testing methods, there is currently no alternative that can replace experiments on animals, and the use of animal models within biological and medical research is an important but also very costly and complicated operation. Research is today demanding the facilities used for animal experiments are of very high quality. At the same time, it is necessary to have requirements for animal protection and ethics, which is reflected in the comprehensive regulatory framework that covers the research. Overall, this means that we need both increased investment and better coordination in order to fulfil Swedish research needs. This requires dialogue and active participation by the various actors in Sweden, primarily Swedish HEIs, which currently have equipment and competence of national interest in the area.

4.3 Recommendations

- Support for initiatives aimed at developing compatible data systems within register-based research should continue. Simplifying access by the research community to register data is urgent for a number of research fields. Ongoing measures to reinforce Swedish register-based research should be fulfilled, including initiatives aimed at facilitating Nordic register-based research and international comparisons, as well as continued investigation of the legal aspects and adaptation to GDPR.
- Infrastructure investment to facilitate comprehensive data collection and data processing will be needed in the future in order to enable researchers to fully utilise the opportunities provided by large-scale collection and digitisation of data.
- The prerequisites for infrastructure for humanities, where data and results can be made searchable, shareable and reusable, both nationally and internationally, should be clarified. These needs within humanities could possibly be satisfied within the framework for existing national infrastructures, but may also require new resources.
- The coordination and consolidation of individual-based databases within social sciences and medicine that has begun should be followed up and further developed. Experiences from this work should form the basis for similar measures within other areas, such as digitisation and making cultural heritage accessible, as well as context databases within social sciences.
- As part of improving the opportunity to use registers for research, the prerequisites for making primary care data more accessible to research should be investigated in consultation with healthcare principals.
- The development towards a clear structure, where various national actors collect, handle and distribute biological samples and data, needs to continue. Another important part relates to inputs that enable the development of tools for storage, calculation and analysis of data from the life sciences and medicine areas.
- The needs of research within the "omics" field are developing rapidly, which places demands on development of the capacity, technology and method development of existing platforms. Clinical use of large-scale techniques will increase, which places demands on increased capacity and on development of platforms with special requirements for patient and data security. A clear trend is miniaturisation, automation and the development towards "omics" analysis of individual cells. To meet these demands, investment in both technical equipment and expertise is needed.
- Ensure that infrastructure for protein production and characterisation is available.
- There is an increasing need to develop techniques and systems for storage, making accessible and analysis of image information. The need is clear in a number of areas covering everything from humanities and social sciences to medical and biological imaging.

- Research is facing a situation where the access to and opportunity to produce ever more complex data are increasing. Phenomena can be investigated with higher resolution, and both phenomena and individuals can be studied longitudinally. Data in the form of text, sound and image can be analysed for research purposes using new technology. Data from different sources can be combined in new ways. All this offers new opportunities for research, but in order to utilise these, improved competence supply is required. This places large demands on higher education institutions in terms of education and recruitment. At the same time, investment in research infrastructure must be designed in a way that promotes competence accumulation and transfer of competence between different research fields.
- To meet the increased requirements set for laboratory animals, relating to both quality and animal welfare, increased investment and better national coordination are needed.

5. Observatories and other measurement platforms for astronomy, climate, environmental and geosciences

Sweden carries out advanced research within astronomy, climate, environmental and geosciences. These research disciplines are necessary to meet future societal challenges and enables new technical solutions, innovations and progress within basic research. Climate, environmental and geosciences are crucial for societal development and for understanding and influencing the prerequisites for life in the world around us. Astronomy and astroparticle physics help us understand the structure, development and origins of the universe. Space physics are central to explaining how the Sun and the Earth interact, and what effects this might have on technical systems and societal functions, for example.

5.1 Key issues

It is important to have access to a broad range of complementary national and international research infrastructures for research within astronomy, climate, environmental and geosciences. For example, astronomy needs access to data from the entire electromagnetic wavelength area, but is also dependent on studies of particles and gravity waves. Many central research questions within space physics and astronomy also require a combination of ground and space-based observations. Within climate, environmental and geosciences, we need continued investment in long time series, at the same time as there is a need for mobility and flexibility for advanced measurements in differing environments where the natural complexity is considered, and to utilise Sweden's large variation in environment types and climate zones. In addition, increased opportunities to carry out large-scale experiments in each environment studied are needed, to identify and quantify causal relationships in a very complex reality.

All fields touched upon in this chapter need long-term investment in infrastructures that generate long measurement series adapted for research. Long time series of research data with sufficient resolution in both time and space are important to enable determination of when changes occur, and to develop and verify models for complex processes. Investments that reinforce Sweden's ability to generate, preserve and refine long measurement series for research within each field are therefore central, which means an ongoing need for continuous access to infrastructures with the relevant measurement capacity over a long period – in many cases over several decades.

Method and technology development are central for world-leading research and increased innovation potential. Many of the major scientific breakthroughs are enabled through the development of new methods and techniques at research infrastructures, and earlier investments, where such development has been a prioritised and integrated part, emerge as good examples. In the future, mobile, autonomous and adaptable techniques for in-situ studies should also be encouraged.

There is an increasing need to enable combination of information from different types of research infrastructure, and sometimes this is a requirement for in-depth understanding of complex processes. Examples of this are combinations of space and ground-based measurements for modelling global greenhouse gas balances. Improved infrastructure coordination does not just benefit Swedish research, but also provides better prerequisites for work with many societal challenges, such as the global sustainability goals. Improved organisation, less competition between organisations and increased resources for user support and data handling would offer greater opportunities for research and the impact of research.

It is also desirable for Sweden to take part in the international investments that are striving towards greater sensitivity and increased resolution (i.e. better focus in order to see details and opportunities to reach shorter length and time scales), which is needed for paradigm shifts within fields such as astronomy, space physics and astroparticle physics.

5.2 Areas that need development, changes to funding or other measures

The fact that research within all areas is becoming more data-intensive creates a need for infrastructures for data handling, data storage and data-intensive calculations that are available to all research fields. The need for HPC resources for advanced modelling of climate models, for example, will continue to increase.

5.2.1 Astronomy and astroparticle physics

Long-term access to research infrastructures with high resolution and sensitivity continues to be important. Observation-based activities within astronomy and astroparticle physics is entirely dependent on Swedish researchers' access to major international infrastructures. Continued membership of the European astronomy organisation ESO is important to ensure Sweden can continue to conduct first-class research within the field. Access to facilities outside ESO, such as within radio astronomy and solar physics, is also central. Sweden holds a prominent position within these areas, and has a tradition of strong technology development. ESFRI's roadmap mentions the international radio astronomy infrastructure SKA and ESO's upcoming optical telescope E-ELT as developed *landmark* projects. The projects are operated through studies of subjects such as the early universe (cosmology), galaxy development and super-heavy black holes, new discoveries of exo-planets and their bio-markers. The facilities can also be used for studying gravity waves.

Together with the current radio telescope ALMA, SKA will probably be the most important instrument within radio astronomy in the future. Within optical astronomy, E-ELT will dominate with the support of ESO's other telescopes, such as VLT. The planned European solar telescope EST is an ESFRI project, which in the long term is expected to replace the Swedish solar telescope SST. These new facilities are important for Swedish researchers, and participation is therefore urgent. Within astroparticle physics, major progress has been made at IceCube within neutrino astronomy, which has justified a possible expansion of this infrastructure. Sweden has played a central role in the IceCube project from the start. National nodes within radio astronomy, optical astronomy and solar physics will continue to be important in the future, and should be focused towards primarily supporting, operating and to some extent supplementing the major international facilities.

5.2.2 Space physics

Studies of the space environment around the Earth and their link to the Earth's atmosphere are important in order to safeguard communication systems, electricity distribution and satellites, but also to understand climate change and its effects. The research includes observations of northern lights, space weather, meteors and space junk. The ongoing upgrade of the radar facility ESICAT to EISCAT3D will provide new opportunities for studies of near space and the upper atmosphere, in particular cloud formation and turbulence. To utilise these opportunities in an optimal way, support should be provided to the international consortium formation and increased coordination with other existing infrastructures.

5.2.3 Geosciences

Observation systems for long-term local, regional or global measurements are necessary for understanding the Earth's dynamics. This is done through ground-based international networks for studying the composition of the Earth, but are also used for researching and monitoring earthquake zones and volcanoes. These are supplemented by satellite platforms, such as within ESA's Copernicus programme. EPOS is an initiative for coordinating, optimising and giving researchers access to data from all observation networks across the continent. Swedish participation in a future EPOS-ERIC should therefore be considered.

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. The Swedish Research Council is a member of the international boring programmes IODP and ICDP to give Swedish researchers access to the most advanced tools for sampling below the seabed and on land. Through the boring platform Riksriggen, Swedish research also has access to the most cost-effective platform for boring on land.

Analysis instruments with high precision and resolution, such as Nordsim/Vega and beam lines at MAX IV are urgently needed to enable research into the development of the Earth and solar system, as the key to these large-scale processes is often found in the structure and the chemical composition of individual grains of minerals. These analyses are also needed to understand the hydrological cycle, soil characteristics and the development of life.

5.2.4 Climate and environment

Sweden is very varied in terms of environmental conditions on land and along our long coastline. This provides outstanding opportunities to conduct research in many climate zones and habitat types, and to carry out integrated studies of land, ground and water environments and the atmosphere. Continued development of and coordination between national and international infrastructures for this type of research, such as the national field stations organised within SITES for studying ecosystems and ICOS and ACTRIS for measuring carbon dioxide and aerosols, would be very beneficial for generating comparable data series and knowledge development across ecosystem and discipline borders.

Sweden's high-quality marine research infrastructures in the form of ships, unmanned vessels, research stations and stationary measurement buoys need to be coordinated for simpler and more effective use. This would be of benefit for Swedish research within marine sciences, meteorology, limnology, geology, resource management and environmental monitoring. Coordination of the stationary marine platforms and development of the coast-proximate marine data collection with inspiration from SITES should be considered, as well as membership of EMBRC-ERIC, a European coordination infrastructure for marine biology and ecology. The capacity that the icebreaker Oden gives to Swedish polar research is important and needs to be safeguarded.

Better understanding of how systems respond to outside influence, such as climate changes, is one of our greatest challenges. This is conditional upon measurements and experiments that are carried out on site and include the complexity of the systems, but can simultaneously be replicated and conducted over sufficiently long timescales. For this reason, we need to establish mobile and flexible measuring systems and experiment environments that can be linked to existing infrastructures. Investment in environmental and climate databases continues to be important. As a complement to these databases, we also need sample banks to give quick answers to questions such as how, when and why changes have occurred, and to provide knowledge of time series when new methods become available. Here there is a need to investigate the prerequisites for a coordinated and comprehensive Swedish sample bank operation for environmental samples.

5.3 Recommendations

- Long-term support for research infrastructure within climate and environment, geosciences, space and atmospheric physics and astronomy should be safeguarded. Many phenomena within these fields need to be studied over a long time in order to be understood. The timescales vary, but the need for long time series is a common factor.
- Regular, substantial and long-term investment in development of state-of-the-art measuring methods, models and technologies for infrastructures should be implemented within astronomy and climate, environmental and geosciences.
- The construction of the international space radar facility EISCAT3D, which Sweden is hosting, has begun. To optimise the scientific benefit of EISCAT3D, a strategic plan should be developed for complementary observations and for how new user groups can utilise the infrastructure and its opportunities.
- To retain Sweden's strong position within radio astronomy, solar physics and astroparticle physics, Swedish participation in international investments and collaborations is recommended. Participation in international large-scale infrastructures is a prerequisite for carrying out first-class Swedish research in these areas.
- Access to and the development of mobile, flexible and autonomous platforms for both measurements and experiments should be ensured. This would enable on-site studies of complex systems in order to understand processes and causal relationships within climate, environmental and geosciences.
- Improved coordination of existing marine infrastructures, such as research stations, research ships and other research platforms should be striven for.

Small increases in resources here can lead to major scientific gains that contribute to important societal goals, such as the global sustainability goal.

- An investigation into the needs of research for long-term storage of environmental samples should be conducted. The investigation should include an overview of the sample banks that exist, what new additions are needed, and how the desired coordination and accessibility shall be achieved.

6. High-technology laboratories for physics, chemistry, materials sciences, engineering and life sciences

Today, Sweden has a strong research presence within physics, chemistry, materials sciences, engineering and life sciences. These fields cover a broad spectrum, from basic research to applied research, and address current societal challenges within energy, environment and health. In this way, research is laying the foundation for both future innovations and for meeting the UN's global goals for sustainable development.

The broad spectrum of research within physics, chemistry and engineering is reflected in these issues stretching from the searching for new particles at sub-atomic level to explaining the composition of the universe, via research into energy systems based on fusion and studies of the functioning of complex components on site, such as batteries being charged/discharged. 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 forests. Development of facilities for fundamental atomic and particle physics usually also requires considerable technology development, which can later be of benefit in a broader societal context.

The infrastructure of national interest that exists today often fulfils needs within many scientific fields. One example is the infrastructure for neutron scattering, where Sweden as the host of ESS will play an important role, which has users that span the entire materials spectrum – it will be possible to study everything from particle physics to life sciences. The infrastructures within this area are currently characterised primarily by large-scale facilities with a broad user base. A number of the infrastructures are international, and the national ones also have users from other countries.

6.1 Key issues

Today's national and international infrastructures for research into chemistry, applied physics, materials sciences, engineering and life sciences includes X-ray and neutron technologies and access to cleanrooms. A general trend is that research is ever more needs-oriented, addresses the global challenges and that this is often done in cooperation with industry and public operations.

There is currently rapid development of facilities for X-ray technology, through the Swedish synchrotron MAX IV, the European free electron laser European XFEL, which has just become operational, the European synchrotron light facility ESRF, which is beginning an upgrading phase, and the Swedish beam line at the

German facility PETRA III, which will be completed shortly. Access to all facilities that have complementary characteristics (such as ultra-fast processes at the European XFEL, imaging with nanometre-sized beams at MAX IV and high penetration with high energy at ESRF and PETRA III) is needed to meet diverse needs from a broad spectrum of users and research questions.

The neutron landscape is also undergoing rapid change. At the same time as ESS in Lund is under construction, several older facilities will be closing. Despite the capacity increase that ESS entails, the overall effect of this will probably lead to increased competition for beam time. In this context, it should however be noted that Sweden's use of neutron scattering facilities has doubled in the last five years; primarily due to growth of the user community. This will, it is true, involve higher costs for Sweden, but is still positive, as it means Swedish research will be better equipped ahead of ESS becoming operational.

Within nanotechnology, the Swedish cleanroom network Myfab plays a crucial role by offering instruments and expertise for producing and characterising new materials, structures and components. The current trend is towards ever smaller structures and increasing complexity. International work is also ongoing to establish a EuroNanoLab, with Myfab as partner.

Within particle physics, the focus is on understanding how the standard model shall be expanded to explain features such as dark matter and the relationship between matter and anti-matter. For research into high energy, the greatest challenges are increasing the energy and improving the measuring precision when searching for new particles. Sweden is a member of the European particle physics facility CERN and there supports the experiments ALICE and ATLAS, and is also engaged in the upgrade of the current accelerator LHC to High-Luminosity LHC (HL-LHC), which will begin in 2024. Full use of LHC is of high priority in Europe, and the upgrade to HL-LHC is part of ESFRI's roadmap. The research community is now working on upgrading the European strategy for particle physics, which is expected to be completed in 2020.

The starting point for a future programme for particle physics, beyond LHC, is that we need both more powerful hadron colliders in order to achieve the highest energies, and also lepton colliders powerful enough to create, and study with high precision, the heaviest particles in the standard model. To this end, there are plans for further upgrades to LHC and new colliders at CERN, as well as at other facilities. Any expansion of the standard model does not just have to lead to new phenomena at high energy, but may also include new, difficult-to-discover phenomena at lower energies. There is therefore a continued need to conduct parallel and complementary search programmes at lower energies within fields such as neutrino physics and detection of dark matter.

Sweden is today a member of the ISOLDE facility at CERN for studying atomic nuclei. In the future, the European nuclear physics facility FAIR, and the experiments built up there, are expected to constitute the most advanced facility for hadron and nuclear physics. FAIR will offer a broad research programme including detailed studies of strong nuclear power and the characteristics of matter under extreme temperature, density and pressure conditions. The facility will therefore be of central importance for Swedish researchers in these areas. Sweden is a member of FAIR, and Swedish groups are involved in the planning and completion of detector systems for these experiments. The first experiments at FAIR are expected to start in 2025, and the entire facility is expected to be completed around 2030.

Safeguarding an environmentally sustainable energy supply is one of the most important issues of our time, which is reflected not least in the rapid development of the area. Research in the area relates to the entire chain, from supply, transformation and distribution to use of energy. Development of renewable energy sources, such as solar energy, wind power and bioenergy, is an important aspect. The same applies to research aimed to increasing efficiency and improving traditional energy sources, such as hydro power and nuclear power. Within fusion energy, the European and Swedish focus is on the construction of future operation of ITER, which is an experimental reactor for indicating fusion as a possibility for future electricity production. ITER is expected to be fully operational by 2035 at the earliest. Today, Swedish researchers are active at the European facility JET, both in preparation for ITER but also for current research projects. Within nuclear fission research, the development of the next generation of reactors, such as Generation IV and accelerator-driven systems, requires new materials and diagnostics. A lot of energy research is dependent on advanced research infrastructures to understand and develop materials with specific characteristics. Specific trial and demonstration facilities for developing and testing new technology are also central.

A general trend is that new experiments generate large amounts of data (increased detector coverage, sampling frequency, etc.). Data handling is therefore becoming increasingly complex, and requires access to computer resources that are normally not available to individual user groups. Making sure that Swedish users have access to relevant computer resources, either via the facilities themselves or through other national infrastructures, will be crucial.

6.2 Areas that need development, changes to funding or other measures

6.2.1 Chemistry, applied physics, materials sciences, engineering and life sciences

Realising the potential of MAX IV is a matter of national importance. To do this, further investment in beam lines will be necessary, as will long-term support for the operation of the facility, which must be at a level that enables the facility to give researchers and other users the support needed during the preparation and implementation of experiments and, not least, the analysis of the results. The Swedish user base should be broadened and increased to include new fields and applied sciences, and also involve industry. This can be done through information, education and support to groups that are less familiar with the opportunities offered by these facilities. It is also important that MAX IV focuses on a number of profile areas, where it is world-leading. The stakeholders in MAX IV will need to agree on a long-term scientific strategy for developing the facility.

MAX IV cannot cover all the needs in terms of experiments using X-ray light by Swedish researchers, as all techniques will not be available there. Swedish engagement in a number of international facilities with complementary techniques, primarily ESRF, PETRA III and European XFEL, will therefore be needed. The use of the major X-ray facilities ESRF, European XFEL and PETRA III, where Sweden is a member, must be evaluated against the background of the major investment made in MAX IV.

On the neutron side too, there is a need for further development of the Swedish user community and engagement in the instrumentation at ESS. Sweden is expected to cover around 10 per cent of the operating costs of ESS. Given this fact, the long-term goals should be that the Swedish use of ESS also amounts to around 10 per cent. This is considerably more than Sweden's use of the current facilities. Because of this, several initiatives have been taken to further stimulate the growth of the user community. As a result of the increased interest in ESS, we are already seeing increased Swedish use of facilities for neutron scattering. There is, however, still a need to further develop the user community ahead of ESS becoming operational, and access to experiment time must be safeguarded. This means that the Swedish engagement in ILL should increase further, at the same time as the Swedish engagement in the British neutron facility ISIS is retained. The contract with ILL will be renewed in 2018, and should then be adapted to the increased Swedish use.

The responsibility for ensuring there is suitable infrastructure to support data analysis and handling of large data amounts at facilities for X-ray and neutron techniques (in particular MAX IV, European XFEL and later ESS) has currently not been clarified. The extra cost of large data amount has to be included when new infrastructures are planned, including new beam lines/experiment stations. A new model for coordinating the development of the physical infrastructure and e-scientific infrastructure (and funding of the same) needs to be developed.

Currently, major national and international research projects towards quantum computers and quantum communication are being launched, and it is important that research within these strategically important areas is given access to relevant infrastructure, and also that access to and development of instrumentation can be safeguarded in the long term, which will require development and some renewal of Myfab. The rapid development within quantum technology leads to new needs for instrumentation within nanotechnology provided by Myfab.

In parallel with the methods offered by the large-scale facilities, there are a number of other experimental methods that also provide crucial information. These are usually available at all research-intensive higher education institutions, and constitute important local infrastructure. But, the most advanced instruments, in areas such as electron microscopy or NMR, are today very expensive. A key issue is what role a national infrastructure within these technologies could play, and if so, how it should be designed, at the same time as the HEIs have continued responsibility for meeting the local needs.

Within engineering, there is also the problem that the need for infrastructure borders on/overlaps the need for facilities of pilot type, with research and development within materials, processes, methods and techniques as 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) are often involved, which means that the funding of the facilities risks falling between chairs.

As different components of the energy system are part of a complex interplay, better cooperation between different research fields and actors is worth striving for. To meet the needs within fusion research before ITER becomes operational, it is a priority that the European research facility JET remains in operation at least until 2020. It is also necessary to concretise how the transfer from JET to ITER shall be optimised. In the same way, it is important for user groups within fission research that access is secured to international facilities, such as Jules-Horowitz, ASTRID and MYRRHA, where radiation and local chemical environments can be combined, and thereby pave the way for the next generation of reactors.

6.2.2 Particle, hadron and nuclear physics

Within the research frontier of high energy, the emphasis in the immediate future should be on full utilisation of LHC, including detector upgrades ahead of HL-LHC, At the same time, it will be necessary to develop new technique for future accelerators, detectors and their data infrastructure. Planning has reached furthest for a possible new electron-positron collider, such as ILC, which enables precision measurement of the characteristics of the Higgs particle. Here, Swedish researchers are already involved. For projects that lie further into the future, it is important to conduct research and development and to implement design studies even now, as the time scales for this type of project are incredibly long.

When it comes to experiments with high intensity particle beams, for example for neutrino studies, and low background-experiments, for example to detect dark matter, the Swedish Research Council currently does not support any infrastructure, but researchers can still participate in experiments, research and development and construction through international agreements. This allows access to research in important areas, such as neutrino physics and detection of dark matter, and should be considered as long as it is not done at the expense of LHC, HL-LHC and experiments at future colliders within the research frontier of high energy. A key issue is which facilities/experiments Sweden can and should support, apart from the HL-LHC upgrade.

The potential for using ESS for particle physics is also interesting, and might broaden Sweden's user base for ESS. The opportunity to support Swedish initiatives, in those cases where they have high scientific relevance, should be investigated.

For Swedish hadron and nuclear physics research, there is a need for access to existing facilities during the development phase of FAIR, in particular to test instrumentation (such as AGATA and CALIFA). This has become even more topical due to the delay in FAIR. There is a need for a strategic plan for nuclear physics, in order to clarify exactly which needs FAIR will be fulfilling, and to what extent complementary operations will be needed; i.e. a key question is which facilities Sweden should be a member of in the long term.

6.3 Recommendations

- Ensure that Sweden has a broad and strong user base at the start-up of ESS, and that Swedish research teams are involved in the first experiments. Access to the current facilities (ILL and ISIS) at a level up to the Swedish operational grant to ESS should therefore be achieved in the longer term. Measures should also be taken to involve Swedish user groups in a selection of the first eight instruments at ESS, so that they become part of the first experiments carried out. This work should also include any Swedish engagement in particle physics at ESS.
- Develop and long-term strategic plan (scientific and financial) for MAX IV to ensure the investment made in the facility is fully utilised. Review the organisation format for MAX IV and clarify the Swedish Research Council's role as main funding body. Strategies for Swedish engagement in other existing X-ray facilities where Sweden is a member, and future facilities, should form part of this work.
- Develop a strategic plan for infrastructures for fusion and fission research, with a clear division of responsibility between different funding bodies and

operators. A key point is to renew the Swedish participation in the coordinate EU-based fusion research area in the upcoming framework programme Horizon Europe in order to safeguard current activities until ITER become operational.

- Support the use of LHC, including the HL-LHC upgrade of the accelerator, detectors and data infrastructure. For future projects, research and development of new technologies for accelerators, detectors and their data infrastructure should be encouraged. New funding forms for long-term work with instrumentation and technology development should be considered. The development of infrastructures within the research frontiers for high intensity and low background, for example within neutrino physics and detection of dark matter, should also be monitored.
- Work towards ensuring a long-term strategy for nuclear physics is developed jointly by the user community, HEIs and the Swedish Research Council. The strategy shall aim to make Swedish researchers ready to benefit from FAIR when the facility becomes operational.
- Define clearly the roles for and allocation of responsibilities between HEIs and national funding bodies in the borderline between national infrastructure and networks of local infrastructures ("distributed infrastructures"). Criteria in the form of added value and prerequisites for research of the highest scientific quality, user base and accessibility should be defined in order to steer the development.
- Define clearly the roles and responsibilities of stakeholders (HEIs, governmental funding bodies and the business sector) within engineering and energy research in order to improve the coordination of participation and funding of national research infrastructures.

7. E-infrastructure

Methods and tools for e-science are becoming ever more important within nearly all fields of scientific research, both in Sweden and worldwide. E-infrastructure is therefore becoming an increasingly important part of everyday life for researchers. Traditionally, the needs for calculation by high-performance computers, accessible via SNIC, have dominated the use of e-infrastructure, with strong research within fields such as materials sciences and fluid mechanics. Growing needs are driven by new technologies and infrastructures that generate considerable data amounts within successful research areas, such as life sciences and image analysis.

7.1 Key issues

The development in research fields with great needs for e-infrastructure is rapid, and it is taking place in an international context. The report "Swedish Science Cases for e-Infrastructure" describes how the quality at both the foundation and leading edge of Swedish research can be maintained and strengthened through investments in e-infrastructure. Continuous support in the form of large-scale computing resources for calculation, storage, networking, etc. needs to be ensured. Long-term extra investment in advanced user support is also needed, including career paths within e-infrastructure and educational input at all levels within the HEI sector. The potential is great for Swedish research to maintain a very prominent place within established areas within advanced calculation. Within these areas, the challenge consists of the transition to new computer architecture and scalability, for example "exascale computing". The potential is if possible even greater within new research areas, where entirely new insights and ground-breaking progress can be achieved by using advanced e-tools.

The clearest ongoing change, which is permeating the entire research field, is the increased needs for data storage and tools for analysing large data amounts, known as "data-driven research". Many of today's research infrastructures generate great e-infrastructure needs in the form of storage of high-resolution observations, where national and international access to data for analysis, image processing and visualisation is necessary. The research areas that have traditionally needed much calculation, such as simulations within fluid mechanics, plasma physics, electromagnetism, climate, materials physics and quantum chemistry, have rapidly growing needs for storage and analysis, as new research questions are studied using a finer-meshed calculation net. Increasing interest in studying the development of dynamic systems is also noted, and entails significantly greater storage needs and new methods for analysis. Other infrastructures generate smaller data amounts, but the needs to organise data, combine different types of data, develop metadata and reinforce the incentive to make data accessible are of the greatest importance. The increasing interest from researchers in areas where e-science is a relatively new tool, such as medicine, social sciences and humanities, mean there is an increased need for support functions, competence development and education.

The needs for infrastructure within data-driven research are very varied, and issues discussed at several levels both nationally and internationally related to accessibility, ownership and also ethical and legal aspects, not least in relation to the EU's new General Data Protection Regulation, GDPR. It is important to have opportunities within e-infrastructures to test and use technical solutions for handling and making calculations based on sensitive data. Support and inspiration can be obtained within the framework of EOSC (European Open Science Cloud), for example, for the best ways of supporting Swedish research.

E-infrastructure is changing rapidly, which might lead to uncertainty about what constitutes research, and what researchers can expect e-infrastructures to provide, in the form of hardware, software and support. A considerable portion of the software and service development is taking place within research teams, and a mechanism for transferring some, more general software and services to the infrastructure would be appealing. It should also be possible for part of the development to take place within the infrastructure.

A considerable increase in resources and services within the e-infrastructure area is necessary to ensure effective use of many existing and planned infrastructures, such as MAX IV, SND and EISCAT3D. This places demands on how the Swedish e-landscape should be organised and funded.

Gains from coordination on a national scale are enabled through advanced support and services from organisations such as SND, SNIC and SUNET, which places demands on both funding and management[2]. Responsibility for archiving data rests with higher education institutions, which in reality means that it is delegated to the researchers. What needs archiving, how to store data in the long term, and procedures for this are, however, currently very unclear to many researchers.

7.2 Areas that need development, changes to funding or other measures

In the general digitisation of society, research plays a specific role. It is naturally a source of new knowledge, but also a signpost for how advanced IT may be used in practice. The introduction of the internet and its predecessors in Sweden is just one example of how the needs of research have shown the way. To ensure future success, intensified measures will be needed for linking together different research fields with the most advanced IT and communication research. Within the next few years, this will apply in particular to the development of the internet ("next generation internet"), new advanced computer architecture for high-performance calculation, new applications for research tools, such as machine learning and artificial intelligence, and visualisation and services for handling, discovering, making accessible, using and preserving (open) research data.

One of the effects of digitisation is to make the research process more efficient, and to enable more intensive and larger national and international collaborations focusing on research data. International research infrastructures based on federated data resources is a clear trend that has already led to the restructuring of many

2 An inquiry into these issues is in progress on behalf of URFI and RFI at the Swedish Research Council.

natural science fields, and is now also opening up entirely new opportunities within humanities and social sciences. Interoperable data within and between research fields is based on international, and preferably global, agreements on issues such as data format and working methods. Swedish participation in this work is very important in order to satisfy the priorities of Swedish research. Coordination at global and European level of the work to develop guidelines, etc. is already taking place, for example via the OECD's various project teams within "open science", and initiatives such as EOSC, with the ambitious goal of coordinating and making accessible national and European resources for open research data. Coordination of this work at Nordic level is recommended, to achieve better impact of specific prioritisations at European and global level.

Within the next decade, we can also expect the first concrete implementations of the next quantum revolution, with quantum communication, quantum computers and quantum simulators. It is very important to analyse and prepare Swedish e-infrastructure early for the changes in coding structure that are necessary when computer architecture changes, and for the opportunities for new, ground-breaking research this may entail.

Data within different research fields have differing characteristics, and the way in which they are generated and analysed creates differing infrastructure needs. For research fields that are expanding strongly in terms of use of e-infrastructure, such as humanities, social sciences and to some extent medicine and life sciences, it is common for research to be based on databases, registers or genetic information, where EU directives apply, for example GDPR. This places new demands on the e-infrastructure, both in terms of hardware and software, but primarily in the form of strict procedures for handling, use, operation and even discontinuation of the infrastructure. When developing these e-infrastructures, user friendliness for researchers should be considered when safeguarding the legal aspects relating to how data can be made available, shared and used.

Within astronomy, environmental, climate and geosciences, the need for structured storage in databases is great. Considerable advances in the understanding of space, our planet and its development can be achieved by combining data from different sources, such as instruments on the ground and in space, and from physical, biological and chemical observations. This places demand on the construction of databases, so that using data from many sources for purposes such as understanding processes through modelling, data assimilation and climate modelling can be done efficiently. Coordination and knowledge transfer from already organised areas, and active participation in Nordic (for example NeIC – Nordic e-Infrastructure Collaboration), European and global initiatives is crucial for success.

Sub-atomic physics, in particular particle physics, is an area that has emerged through data-driven research. Particle accelerators are data generators, where researchers can study phenomena, including rare ones, with very high precision thanks to efficient handling of very large data amounts. Facilities such as MAX IV ad ESS have the capacity to produce several petabyte of data every year, and the future HL-LHC accelerator at CERN will achieve the exabyte scale already in 2024. To use these infrastructures in an optimal way, it is of the greatest importance that users of these facilities have access to adequate infrastructure for calculation and data handling that is integrated with national e-infrastructure.

Several research fields generate data that are stored as files and not in standardised database formats. Here, specially adapted software that also means the data is available for use in large international research teams is needed. This applies to areas such as experimental physics, flow calculations, climate modelling and materials physics, and also leads to e-infrastructure challenges, such as very large and long-term storage opportunities (including tape storage), high-capacity networks, etc. Participation in internationally coordinated projects sometimes also places demands on undertaking periods of great calculation needs years in advance, which is something that the current allocation systems cannot handle.

Several major research fields have growing needs for large-scale data processing. Developments needs supporting to fulfil needs that entail data analysis with high flow rates, including hardware architecture and software solutions. The development of these technologies is in progress internationally, and Sweden has the potential to play a leading role when it comes to developing software models, tools and services. The large data amounts produced and stored enable data to be used within new areas and in new combinations. Algorithms and analysis methods are also disseminated to other fields and gain new applications, and today we are for example see AI methods being spread to several cross-border research fields. Several investments are currently being made within AI; not least by KAW through their investment in Wallenberg AI, Autonomous Systems and Software Program (WASP). The development means that the needs for data storage, networks, analysis tools, visualisation and opportunities for advanced calculation are increasing rapidly and expansively within a number of research fields, business and society as a whole. As data-driven research is dependent on the quality of the data the researchers can access, greater demands are also placed on cyber security and quality audits of data.

In summary, the Swedish Research Council sees a great need for increased funding of e-infrastructure, which should be prioritised in order for Swedish research to maintain high quality internationally. Access to research, education and competence, both width and depth (use and development) within e-science is assessed as being insufficient, and should be strengthened. A strong increase in capacity needs to be prioritised to satisfy the needs that exist, both within research and within society as a whole. Such a capacity increase must include distributed solutions where capacities are shared between countries.

7.3 Recommendations

- Safeguard sufficient access to networks, storage, computer resources, advanced user support, e-science tools and databases. A considerable increase in resources within the e-infrastructure area is necessary to meet the accelerating needs within Swedish research. It is important to guarantee access to strong national supercomputer resources to continue developing calculation-intensive research, and to widen the areas of responsibility of e-infrastructures in order to capture new e-research methods. Parts of software development and advanced user support should be included in the infrastructures.
- The systems for accessing e-infrastructure need to be reviewed, to make it possible to plan with a sufficient time horizon for more flexible allocation of resources, to enable participation in internationally coordinated projects.
- To fulfil calculation needs that go beyond what is possible to supply in Sweden, it is important that Sweden continues its engagement in the European collaboration PRACE and collaborates in Euro-HPC, so that we are part of developing the EU's strategy for HPC in Europe and gain full benefit from the investments made at EU level.

- Sweden should monitor and engage in the development of international coordination initiatives, such as NeIC and EOSC.
- Data-driven research is developing rapidly and expanding to new research areas, which means that the following aspects need to be considered:
- E-infrastructures need to be organised so that they are able to give the right support to research environments with varying experience, from well-established ones to new users.
- Competence-enhancing inputs are needed, both for experts within the infrastructure environments and in the research teams.
- The opportunities for cost-effective storage of data for research environments, for both analysis and long-term storage, need to be clarified and communicated.
- The legal and technical aspects of open data, in particular sensitive data (such as personal data), need to be handled to enable ground-breaking research.
- Access to data needs to become more efficient by using internationally agreed meta-data and standardisation of databases.
- Increased coordination and interaction are needed between existing research infrastructures that are data-producers in order to create coordination and efficiency gains and to enable research with larger data sets.
- The ongoing acceleration in the development of e-methods is placing new demands on education within first, second and third cycles within higher education institutions. Existing programmes within all scientific fields need to be modernised, and entirely new programmes created with emphasis on new e-science methods in order to meet the future needs of research.

Appendix 1. Acronyms

ACTRIS	Aerosols, Clouds and Trace gases Research Infrastructure Network
AI	Artificial Intelligence
ALMA	Atacama Large Millimeter Array
ASTRID	Aarhus Storage Ring in Denmark
BBMRI ERIC	Biobanking and Molecular Resource Infrastructure
BIS	Biobank Sweden
CERN	European Organisation for Nuclear Research
CESSDA	Consortium of European Social Science Data Archives
CLARIN	Common Language Resources and Technology Infrastructure
CORS	Comperative Research Centre Sweden
EBI	European Bioinformatics Institute
ECORD	European Consortium for Ocean Drilling
E-ELT	European Extremely Large Telescope
EISCAT	European Incoherent Scatter Facility
ELIXIR	European infrastructure for bioinformatics
EMBL	The European Molecular Biology Laboratory
EMBRC	European Marine Biological Resources Center
EOSC	European Open Science Cloud
EPOS	European Plate Observing System
ERIC	European Research Infrastructure Consortium

ESFRI	European Strategy Forum on Research Infrastructure
ESO	European Southern Observatory
ESRF	European Synchrotron Radiation Facility
ESS	European Spallation Source
ESS	European Social Survey
EURO-HPC	European collaboration within e-infrastructure
FAIR	Facility for Antiproton and Ion Research
FAIR	Principle for data management – Findable Accessible Interoperable Reusable
GBIF	Global Biodiversity information facility
GDPR	General Data Protection Regulation
GEANT	Project within e-infrastructure financed by the EU
GIS	Geographical Information System
HPC	High-Performance Computing
ICDP	International Continental Drilling Program
IceCube	South Pole Neutrino Observatory
ICOS	Integrated Carbon Observatory System
ILL	Institute Laue Langevin
In-situ	On site/in position
IODP	International Ocean Discovery Program
ISF	Institute for solar physics
ISIS	British neutron source
ISOLDE	Facility for nuclear- och hadron physics
ISSP	International Social Survey Programme
ITER	Experiment reactor for fusion research

JET	The Joint European Torus (European facility for fusion research)
KAW	Knut och Alice Wallenbergs foundation
LHC	Large Hadron Collider LifeWatch e-infrastructure for bio diversity data
LNU	Survey about living conditions
MAX (IV)	Microtron Accelerator for X-rays
Myfab	Network for microfabrication laboratory
MYRRHA	Multi-purpose hybric reactor for high tech applications
NBIS	Infrastructure within lifeScience for bioinformatics
NEAR	The National E-infrastructure for Aging Research
NeIC	Nordic cooperation within e-infrastructure
NGI	National Genomics Infrastructure
NMR	Nuclear Magnetic Resonance
Nordsim	Nordic Secondary Ion Mass Spectrometer
NORDUnet	Nordic computer network for universities
PETRA	Synchrotron light source in Germany
PRACE	Partnership for advanced computing in Europe
REWHARD	Relations, Work and Health across the life-course – A Research Data infrastructure
RFI	Swedish Council for Research Infrastracture
RJ	Riksbankens jubileumsfond
RUT	Register Utiliser Tool
SCB	Statistics Sweden
SciLifeLab	Science for Life Laboratory
SHARE	Survey of Health Ageing and Retirement in Europe
SITES	Swedish Infrastructure for Ecosystem Science

SKA	Square Kilometer Array
SLOSH	The Swedish Longitudinal Occupational Survey of Health
SND	Swedish National Data Service
SNIC	Swedish National Infrastructure for Computing
SoS	Swedish National Board of Health and Welfare
SUNET	Swedish network for data communication
SwedPop	Infrastructure for historical demographical data
UGU	Database about educational data
URFI	Universities Reference Group for Research Infrastructure
VEGA	Microanalytical laboratory
VLT	Very Large Telescope
WLCG	System for data management at CERN
XFEL	X-ray Free Electron Laser Facility

The Swedish Research Council's Guide to Research Infrastructure is a plan for how Swedish researchers within academia, public sector and industry are to access the most sophisticated research infrastructure in Sweden and other countries.

Research infrastructure refers to central or distributed research facilities, databases or large-scale resources for calculation, analysis and modelling.

The Guide to Research Infrastructure is the Swedish Research Council's guidebook to Sweden's long-term need for national and international research infrastructure. It provides documentation for discussions about funding future infrastructures within the Swedish Research Council, but also in consultation with other research funding bodies nationally and internationally.

The Swedish Research Council published the first edition of the Guide in 2006. It has been supplemented with updated editions in 2008, 2011 and 2014.

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The Swedish Research Council has a leading role in developing Swedish research of the highest scientific quality, thereby contributing to the development of society. Besides research funding, the agency advises the government on researchrelated issues and participates actively in the discussions to create understanding of the long-term benefits of research.