Norwegian Roadmap for Research Infrastructure 2023

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Technology and Science

Information and communication technology

Digitalisation is a comprehensive process of change involving the transition from traditional information processing methods to digital technologies and tools. Information and communication technology (ICT) is a key driver for this, across disciplines and sectors. ICT is a generic term for technologies that make it possible to collect, store, process, share, communicate, visualize, us and collaborate on data and information in electronic form.

Generic data- and e-infrastructure

In order to support increasingly data-driven research, the need for robust and generic data and e-infrastructure and good servic for data management is increasing. Research data is a valuable resource that must be stored, analysed, archived, shared, made available and preserved long-term in a secure and efficient manner.

Data and services everywhere

Many disciplines need generic data and e-infrastructures for e.g. high-performance computing, data storage, archiving and long-term preservation of data and associated services such as authentication and authorization, tools for efficient workflow and software for simulation and analysis of data. This includes digital registers and databases for storing large amounts of data, so-called 'big data', and computational resources for complex calculations, so-called High Performance Computing (HPC). HPC is a important tool for meeting major scientific and societal challenges, including marine research, climate research and health research. Data infrastructures are particularly important for research that requires complex calculations and generates large amounts of data through simulation and analysis.

Technology development in high-performance computing and big data is happening at a rapid pace, and new user groups with different and specific needs are constantly emerging. It is therefore of great importance that the infrastructure being developed i able to meet these needs and support research effectively. It is also important to have interacting data infrastructures, and to establish infrastructures along the entire digital value chain.

A safe information society

Sensitive data that cannot or should not be shared openly, for legal, ethical or security reasons, must also be collectable, managed, analysed and archived in a secure and good manner. For this, one needs data infrastructure, services and tools that ensure that data collection and management takes place in accordance with applicable legislation and ethical guidelines and prevents unauthorized access and misuse.

Groundbreaking ICT research and development

The new Long-term plan for research and higher education describes ICT as a transformative driving force that provides the bas for new business models and applications in all areas of society. ICT spans a wide field of technology areas including computer science, informatics, information systems, artificial intelligence and machine learning, network and software technology, sensor technology and the Internet of Things, human-computer interaction, network and security, cryptography and cyber security. Research and research-based innovation in artificial intelligence and quantum technology are particularly highlighted in the Long term plan, but there are also a number of other disciplines within ICT research that are relevant in an infrastructure context. The various disciplines may need capacity for generic infrastructures for high-performance computing, storage, etc., but there may also be a need for infrastructures related to the specialist areas.

ICT is not just a field in itself. ICT is the technical basis for a comprehensive innovation system, linked to most societal challenge The internet and digital technologies are transforming not only industries, but also work processes and tasks and the dynamics organizations and labor markets. The digitalisation wave is a driver for Industry 4.0 perspectives, the green shift, restructuring in the private and public sectors and value creation in important areas for society. Norway has good prerequisites for succeeding through the digital transformation. However, this requires that we succeed in competence building, research activities and priorities, strategic investments in national infrastructures, innovations and solutions in the ICT field.

The infrastructure landscape today and in the future

Generic data- and e-infrastructure

For a complete picture of data- and e-infrastructures, it is necessary to also look to the other sub-areas of the roadmap. The INFRASTRUKTUR-portfolio contains a large number of relevant projects that have been developed for the needs of one or more disciplines and technology areas. Part 3 provides an overview of the cross-cutting research infrastructures that can be used in a number of disciplines and areas.

Within all sub-areas of the roadmap, there is a need for continued investment in national high-performance computing capacity. Sigma2 is a generic data infrastructure with great significance for a number of disciplines, within high-performance computing and data storage. Managing and sharing sensitive data and enabling analyses on it is a challenge and a need in many fields of research, including health and social sciences. In order for researchers to do this, one needs a secure and reliable data infrastructure with services that comply with relevant legislation and research ethics guidelines.

It is important that Norway take part in international cooperation to ensure that Norwegian research groups and infrastructures operate and are established in accordance with international standards and principles for good data management, -administration and curation. In this regard, Norway should continue to play an active role in the cooperation on EOSC, EuroHPC JU and ESFRI landmarks such as the Partnership for Advanced Computing in Europe (PRACE).

Infrastructure for groundbreaking ICT research and development

Research and development in ICT requires a wide range of research infrastructures along the entire digital value chain, from data collection to analysis and user interfaces. This includes, among other things, experimental infrastructures for communication networks, sensor and circuit technology, analysis tools and high-performance computing platforms, and solutions to improve the user experience in various technological systems.

The eX3 research infrastructures offer an experimental heterogeneous high-performance computing facility for experimentation with exascale computing and NorNet offers a large-scale, real-world Internet testbed, where increased performance and robustness in the network is a key research challenge. ReRaNP provides opportunities to validate and demonstrate new methods and systems for radio communication. Increased speed, development and realization of truly massive MIMO systems and advanced wireless sensor networks are key research challenges. NAIC will establish the most powerful infrastructure for artificial intelligence in Norway and find the best technology solutions for this.

For most new technologies, basic and applied research on ICT is a necessary part, and in the future it will be important to have infrastructures that enable ICT research that is strategically important for Norway.

There are good opportunities for increased international cooperation in several areas within ICT. For example, quantum computing (QC) is a field where cross-border collaboration can provide significant added value.

Material-, process technology and basic natural sciences

The Long-term plan emphasises the importance of long-term basic research for building new knowledge we need to handle challenges and crises. Basic natural sciences are wide-ranging, but here we have described some particularly equipment-demanding subject areas. Basic research is also important for the development of new advanced technology. Research on new advanced and industrial technologies contributes to new applications and new production methods that will be crucial for the implementation of the green transition.

Space-, particle- and nuclear physics

Basic research in space- and astrophysics/astronomy, particle physics and nuclear physics helps to increase understanding of various fundamental phenomena that contribute to building knowledge and competence and developing technology that is also important in many other areas.

Space research contributes important knowledge, among other things, to understanding climate systems, ocean currents and the movements of the earth's crust. Norway's participation in the European Space Agency (ESA) and the EU Space Programme facilitates strong research communities and international cooperation within the breadth of space-related research and technology development. Norway has long traditions when it comes to space exploration, including northern lights- and solar research. In order to maintain Norwegian research communities, for example in the fields of Earth observation, operational meteorology and ice, climate and environmental applications, access to advanced research infrastructure is necessary, both nationally and through international cooperation.

CERN is one of the world's largest and most respected centres for research. Here, the smallest building blocks of the universe are revealed using particle collisions at extremely high energies. Norway has been a member since its inception in the 1950s and participates in several of the experiments. Participation in this work is important for the scientific development of Norwegian research communities in the field of particle physics. The infrastructure itself is located in Geneva, but much of the work on developing new detectors takes place in Norway.

In both space-related research and particle physics, very large amounts of data are generated, which necessitates data infrastructures that can handle it. However, it also contributes to expertise in handling and using large amounts of data, which is demand in several areas.

Norway has long traditions also within nuclear research. The need for knowledge and expertise in basic nuclear physics and nuclear chemistry is made clear in the Long-term plan. Although Norway do not have electricity production based on nuclear power today, there are several countries nearby that have nuclear power plants and plans for new ones. It is necessary that Norway's expertise in nuclear safety and preparedness is maintained and further developed. Norway also has significant activity radiopharmaceuticals.

Nanotechnology and advanced materials

The Long-term plan emphasises the importance of research in nanotechnology and materials technology, and the importance o investments in research infrastructures in these areas.

Nanotechnology encompasses the study of phenomena occurring at the nanoscale and how we can control and manipulate these phenomena. Technology can thus contribute to innovations in most areas of society. This also applies to microtechnolog and advanced materials. Nano-, micro- and materials technology are technologies used to develop and manufacture advanced materials and systems with specific and controllable properties. This contributes to increased competitiveness within topics suc as energy and the environment, oceans, food and health, with the goal of avoiding creating undesirable effects on health, the environment and society.

Within this field, there is often a close link between public R&D environments and companies. For example, new advanced materials are important in the development of various types of sensors, solar cell technology and new batteries. Advanced biomaterials are important in the development of new medical products and more sustainable packaging.

Production and process technology

There is a need for advanced production processes and process technology, which can contribute to reduced resource use an a low carbon footprint. The Long-term plan refers to vulnerable value chains that highlight the need for advanced production processes that can also contribute to reduced emissions and increased reuse. Reference is also made to the need for basic research in disciplines necessary for the development of enabling and industrial technologies for more sustainable production.

The Government's roadmap The green industrial initiative points out that there can be much to be gained for business and industry by increasing research efforts, strengthening links between different sectors and improving the interaction between research and innovation. For the latter, the importance of knowledge sharing between actors within research and industry is pointed out. The business sector in Norway uses advanced production processes, but there is a potential to exploit the opportunities inherent in new technologies and data to an even greater extent.

The infrastructure landscape today and in the future

Many national and international research infrastructures have been established within technology and basic natural sciences wi funding from INFRASTRUKTUR. These are listed in Part 3.

Within space research, particle physics and materials research, Norway participate in major international infrastructure collaborations. This includes EISCAT_3D, CERN, European Synchrotron Radiation Facility (ESRF) and European Spallation Source (ESS). ESS is still under construction in Lund, Sweden, and is scheduled for completion in 2027/2028. National and international infrastructure for calculating large amounts of data (Sigma2-NRIS and Norwegian participation in Euro HPC and NeIC-Tier-1) is very important, because research in these areas generates large amounts of data. Norway also participates in the Swiss-Norwegian Beamline (SNBL), which serves as an important home laboratory for the use of synchrotrons and provides an increased benefit from membership of the ESRF.

Within space research, there are also several important infrastructures that have been developed and made available to Norwegian researchers with support from sources other than the INFRASTRUCTURE scheme. An example of the latter is satell data from ESA and the EU's space programmes, where Norwegian participation helps to ensure relevance to Norwegian needs. The launch base, which is currently under construction on Andøya, is another example.

Through INFRASTRUKTUR, investments have been made in several national infrastructures, including cleanroom facilities for nano- and microtechnology and various national infrastructures for materials characterization, as well as cyclotron laboratory fo nuclear research. In order to exploit the European Spallation Source (ESS), expertise in neutron research is needed, and we hav invested in NcNeutron as a national infrastructure for this. NcNeutron was moved to the Paul Scherrer Institute (PSI) in Switzerland after the JEEP II reactor at the Institute for Energy Technology (IFE) was shut down in 2019, but is still available to Norwegian research communities.

Within production and process technology, several national research infrastructures have also been established, for example within commodity and metal production.

In the years ahead, there will be a need to maintain and further develop existing research infrastructures, both national and international. Modern, advanced equipment for material characterization will be important, and will also have high relevance for a number of other disciplines and technology areas.

Norwegian researchers currently have access to several international research infrastructures adapted for basic scientific research. Access to these should be maintained and further developed. Among other things, new upgrades of CERN are planne There will also be a great need for infrastructures for the use and utilisation of data, for example for the development of new production methods and computing resources for large amounts of data.

Energy and the energy systems of the future

The Long-term plan emphasises the need for research that contributes to the green transition and low emissions, and further develops the energy industry to be profitable also in the future. Energy efficiency is an important part of the transition to a sustainable low-emission society. Energi21 and OG21 are the national strategies for research, development, demonstration and commercialisation of energy and petroleum technology, respectively.

Energy research encompasses a number of different disciplines and technologies such as geophysics, nano- and materials technology and digital technology. The emergence of new energy industries requires an interdisciplinary approach with contributions from, for example, climate and environmental research, the social sciences and the humanities.

New industries such as offshore wind, hydrogen and carbon capture and storage and seabed minerals can build on further development of expertise and technology from the established energy industries.

Hydrogen, carbon capture, utilization and storage

A number of research needs remain along the entire value chain of hydrogen and hydrogen carriers. This research entails a nee for adapted research infrastructure, as pointed out by, among other things, the Energi21 strategy. The OG21 strategy also points out that hydrogen as part of the decarbonisation of petroleum value chains can also contribute to securing the future market fo natural gas.

Carbon capture, utilisation and storage (CCUS) is central to the green transition, and is highlighted in, among other things, the EU's green growth strategy. Especially within carbon capture and storage (CCS), there is great potential for international cooperation. The OG21 strategy16 points out, among other things, the importance of making natural gas greener, and CCS is central in this context.

Environmentally friendly energy

Research on renewable energy and low emissions is intended to support long-term, sustainable development of the energy system, contribute to the transition to a zero-emission society and promote a competitive Norwegian business sector.

The Energi21 strategy points out that the European power system of the future will increasingly consist of intermittent and renewable power production. To ensure flexibility in the integration of intermittent and distributed energy sources in the power system, there is a need for further research into hydropower and the consequences of variable operation of hydropower plants, as well as research infrastructures where conditions relevant to the future power grid can be tested. According to Energi21, digitalisation will provide a more precise decision basis and a more solid basis for good analyses of investments and choice of operational strategies.

There is a major investment in offshore wind power at home and abroad. The white paper Energy for work – long-term value creation from Norwegian energy resources refers to different knowledge needs associated with bottom-fixed wind turbines compared to floating turbines. In general, for ocean-based power production, based e.g. on petroleum, wind, sun, wave and tidal there is also a need for knowledge to ensure coexistence with other ocean-based industries and social acceptance, as well as understand the consequences for the environment and climate.

In Europe, there is a strong focus on sustainable battery production and an increased degree of self-sufficiency. There is a neec for a broad approach in the energy transition, and for increased capacity build-up both solar and battery technology are importa The International Energy Agency (IEA) has developed a scenario for reaching the 1.5°C target and thus net zero emissions in the energy sector in 2050. This requires the development of new and advanced battery technologies. In the IEA scenario, solar energy accounts for about one-fifth of the global power supply, and this requires continued investment in research and technology development in solar cell technology.

The Long-term plan also identifies bioenergy as an important factor in an effective and just transition to a sustainable low-emission society, for a society with increased circularity and a sustainable bioeconomy. Energi21 also points out that bioenergy will play an important role in the transformation of a number of sectors.

Research on environment-friendly energy is also central to the transformation of the transport sector, which includes maritime and land-based transport and aviation by contributing to knowledge, expertise and innovation for future sustainable zero- or low emission transport solutions. In addition to the transition to zero-emission solutions, it will be important to make all transport mor energy efficient.

There is also a great need for energy conversion in buildings and industry, both for more energy-efficient solutions and for solutions based on zero-emission energy carriers. In the construction sector, this is particularly about reduced heat loss from buildings and reduced energy consumption for ventilation and lighting. In the manufacturing sector, there is a particular focus on switching to more energy-efficient processes and replacing fossil energy raw materials. This applies both to processes that require heat and to processes that require energy raw materials as a reducing agent.

Petroleum

Petroleum research and technology development is important to ensure continued value creation from the sector, to develop th sector in a sustainable direction and to help ensure that expertise and solutions from the sector can be used in new industries. T achieve this, new technology will be developed and adopted that provides more cost- and energy-efficient extraction of petroleum, better knowledge about the subsurface and lower greenhouse gas emissions.

Several petroleum fields on the Norwegian Continental Shelf are in a mature phase. There is therefore a continued need for cos and energy-efficient methods of production, as well as safe, cost- and energy-efficient methods for permanent plugging and abandonment of wells (P&A). Moreover, there is also a continued need for research and technology development related to oil spill preparedness, which will also be of great value for the maritime sector.

Within the petroleum sector, there is also a need for continued utilisation and further development of infrastructure to meet existing and future needs. There is a strong focus on energy efficiency and emission reductions. Here, autonomy, automation, robotics and artificial intelligence can play an important role together with workflow and interaction across disciplines, in additio to more efficient processes and energy recovery.

The infrastructure landscape today and in the future

Investments have been made in a number of national infrastructures within the above-mentioned research fields. Research centres that have been launched also help to ensure good coordination and utilisation of research infrastructure and to good lin with industry.

The research infrastructures that have received funding from INFRASTRUKTUR are listed in part 3. This includes infrastructures within wind power, solar cell technology, bioenergy, energy systems, energy use in buildings and industry, drilling and well technology and multiphase flow. Investments have also been made in research infrastructures that support research and development of technology to produce hydrogen from renewable energy, the use of hydrogen in the transport sector, and for transport and storage of hydrogen.

Research infrastructure for CO2 handling is largely integrated into the ESFRI project ECCSEL, which is led by NTNU. ECCSEL is European project that brings together R&D infrastructures from several countries. The infrastructure has received funding from t Research Council on several occasions. In addition to ECCSEL, there are several major piloting facilities. The most important are the technology centre at Mongstad (TCM), Aker Solutions test unit for CO2-catch, SINTEF's pilot for CO2-catch and field laboratories for storage in Svelvik and Longyearbyen.

Looking to Europe, there are also several infrastructures among ESFRI Landmarks that may be relevant for parts of the Norwegian energy sector, e.g. in ocean-based power generation or solar energy. However, the European research infrastructur landscape is deficient for several parts of the energy field, including petroleum.

In addition to specialised infrastructures, equipment in several other areas is important for energy research. This applies in particular to nano- and materials technology, which are used in large parts of the energy research field, and which are central to solar energy research and research on battery and fuel cells. Infrastructures in the area of bioresources are also used in bioenergy research, and within ocean-based power production infrastructures within maritime technology (towing tank and oce basin) are of great importance. Climate and environmental infrastructures, as well as generic infrastructures for high-performanc computing and other computer infrastructure are also very important for the breadth of the energy field.

In the years ahead, there will be a need for both upgrading and renewal of existing infrastructures. There is also a need for completely new research infrastructures. Generally for new infrastructures in the energy area, digitalisation, security, circular value chains and reuse are becoming increasingly important. These are factors that must be given great weight.

The sustainable energy systems of the future require the development of new and advanced technologies, for example within energy storage. There is a need for access to research infrastructures that include necessary test facilities and facilitate resear on the reuse and recycling of materials.

In order to realise the value chains for hydrogen (blue and green) and hydrogen carriers, there is a need for a targeted and coordinated effort to ensure that research infrastructures exist along the entire value chain. There is a need for research activiti based on real volumes and the complexity of the value chain. It is important to look at the development of infrastructure in Norw in the context of the establishment of research infrastructure in the EU.

Within ocean-based power production, a number of needs for increased efforts have been promoted. There will be a need for th development of marine technical, electrotechnical and material technology laboratories. Test centres for floating structures may be relevant to offshore petroleum, offshore wind (including mooring methods) and floating solar power (FPV). There is also a ne to develop technology for shipping and assembly of floating offshore wind, and for maintenance and repairs. There is also a nee for sensors and more measurement data to be able to design even better models that are used, among other things, to optimize wind and solar power facilities.

There is a growing need for high-performance computing, data storage and sharing, as well as data security and digital technologies.

Earth science, oceans, climate and environment

The area of geoscience, oceans, climate and environment comprises research and technology development that will contribute increased knowledge about the earth system, climate and environmental change, geohazards such as earthquakes, landslides, volcanic eruptions and tsunamis, including the risks and harmful effects to society. Projects within this sub-area shall also contribute to safe, environmentally friendly and sustainable exploration, extraction and utilisation of georesources, such as meta raw materials, energy and industrial minerals, construction raw materials and groundwater. The area also includes research and technology development that contributes to more sustainable solutions and adaptation to climate change. Of particular importance to Norway is the management of oceans, coastal and polar areas.

The Long-term plan describes a number of objectives and priorities relevant to geoscience, oceans, climate and the environmer

Climate and environment

Climate and environmental research includes research on terrestrial and marine environments, all components of the coupled climate system, research in the social sciences and humanities related to climate challenges and societal, business and geopolitical issues.

Norway has research groups that for decades have contributed to UN climate reports and participated in the World Climate Research Programme. Climate research will provide the necessary new knowledge about the climate system, the evolution of climate in the past, present and future, as well as the effects of climate change on nature and society – as a basis for adaptatior measures. In an emergency preparedness and climate perspective, it will be of added value to link natural and social science models to see the impact of different scenarios or the effect of different measures. In addition, climate research will contribute tc new knowledge about policy instruments and policies for emission reductions.

Studies of the carbon cycle and biogeochemical processes provide important knowledge about the coupling between the ocean land (biosphere) and atmosphere and how these interact and affect the Earth's climate. Knowledge about the carbon cycle is ke to seeing whether Norway and Europe are achieving their emission targets. It is important that the time series established in this area are continued.

Environmental research covers both terrestrial and marine environments. The research shall increase knowledge about key environmental challenges and provide the public administration, business and industry and society at large with a better basis fo making decisions for a green transition. Loss of biodiversity and the spread of pollutants and alien species, as well as deterioration of water quality, are key global challenges. Moreover, the various threats and causal relationships are often closely intertwined. The greatest threats to biodiversity are land-use change, exploitation, climate change, pollution and the spread of alien species. Monitoring biodiversity, ecosystem change and environmental pollution requires an interdisciplinary approach anc cooperation with/contributions from other areas, especially health and bioresources, but also social sciences and energy.

Norwegian research groups have contributed significantly to the global knowledge summaries under the IPBES within biodiversi ecosystems and ecosystem services. Research efforts in the field of biodiversity include a societal perspective, i.e. research on society as the cause of the nature crisis, but also potential solutions to the crisis with research-based action alternatives for policy development.

A number of hazardous substances are now banned in industry and production, and stricter requirements for industry have reduced pollution through point emissions. At the same time, more and more chemical compounds are being used in society, many of which have negative or unknown effects on ecosystems. Diffuse emissions of hazardous substances are considered tc be the most important source of proliferation today, and greater research efforts in this area are required to map the origin, spre and isolated and interacting effects of established and new pollutants

Several basic biosciences are based on research on ecosystem services and nature recycling. Rapid advances in genetic sequencing and ICT, including big data analysis of genetic sequences and mass digitization, can be adapted to provide more automated systems regarding genomics, species, and ecosystem analysis7.

Environmental data are important for achieving national climate and environmental goals. It is important to have good coordinati of the collection and analysis of different types of environmental data, and a breadth of infrastructures that together cover the aquatic, terrestrial and atmospheric. The focus on autonomous vehicles, both at sea and in the air, has been important for Norwegian research communities. This is important for the collection of high-resolution data in time and space and for reducing the environmental footprint associated with data collection.

The sea and coastal areas

Clean and resource-rich marine and coastal areas are a prerequisite for long-term sustainable marine value creation. More and more knowledge is needed about the structure and function of marine ecosystems, and how they are affected as a result of climate change, ocean acidification, pollution and plastics in the oceans, and other anthropogenic factors. Norwegian research must promote sustainable value creation based on marine resources, and improve management of ecosystems and resources i Norway's sea areas.

Our goal is for Norway to continue to be a world-leading maritime nation, and for Norwegian ocean industries to deliver the mos innovative, sustainable and environmentally friendly solutions for the future. Maritime technology is of great importance for safe and sustainable value creation in all ocean industries. The Long-term plan promotes a goal of climate and environmentally frienc maritime transport, and reference is made to the recommendations from the Maritim21 strategy. It states, among other things, th in order to succeed in taking a leading position in the green shift, it must be facilitated for the maritime industry and research communities to be early adopters with regard to research, development, demonstration and commercialisation of technologies and sustainable solutions. Priority strategy areas are Maritime 4.0, which involves digitalisation of the maritime industry, low- anc zero-emission technologies and solutions, as well as green and safe maritime transport.

Within marine research, there is a need for continuous coastal and ocean monitoring. This will have great significance for ocear based industries and for environmental and climate research. There is also a constant need for test facilities for ocean technologies, including subsea technology that may be important for marine minerals and seismic.

Polar

According to the Research Council of Norway's policy for Norwegian polar research, an overarching goal for Norwegian polar research is that Norway shall be a leading polar research nation and that polar research shall safeguard Norway's special responsibility for developing knowledge as a basis for policy, administration and business activity in the Arctic and Antarctic. An overriding consideration for Norway is to maintain the Arctic as a peaceful and stable region based on international cooperatior and respect for principles of international law, and to strengthen Svalbard as a research platform.

Norway's ocean interests in the north and south have been emphasised from a political perspective, and exploitation of its resources must be sustainable and safeguard natural values. In the polar regions, we need more knowledge about the effects o hazardous substances, ocean acidification and reduced ice cover in combination with increasing human activity.

There is a need for better earth system models and increased national modelling capacity to link weather and climate. Good access to data is needed, such as ocean observations in Antarctica and long time series, especially from the Arctic. Autonomou and/or mobile observation systems can play an important role here. There is also a need to link different observation systems tc ensure multiple uses across disciplines and technology areas.

The infrastructure landscape today and in the future

A lot of infrastructure has been invested in this area – both through the INFRASTRUKTUR scheme and other sources of fundinç Infrastructures that have received funding from INFRASTRUKTUR are listed in Part 3.

Norway has well-developed land-based research platforms, ice-breaking research vessels and various fixed and mobile marine observation systems. Norway also has research infrastructure at the year-round stations in Antarctica (Troll) and on Svalbard, and there are good logistics for collecting environmental, climate and biological data in polar areas and our adjacent sea areas.

To ensure good analyses of samples, there are several laboratories for environmental chemical (e.g. contaminants, air and wate quality), biological (e.g. DNA analyses) and physical/chemical analyses (e.g. sediments and isotopes) using quality-assured analysis and calibration tools.

Norway has particularly advanced earth system models used by the Intergovernmental Panel on Climate Change (IPCC) that connect all parts of the Earth system. Development of the model requires large data storage and computing capacity and acces to high-performance computing facilities. Norwegian research groups are important contributors to many internationally coordinated databases and manage many valuable and long time series.

Through INFRASTRUKTUR, the Research Council of Norway has provided funding for several phases of the upgrade work of th

Marine Technology Centre in Trondheim. This infrastructure has been very important for maritime technology development relevant to all ocean-based industries. The upgrade work will be useful now that construction of the new ocean technology laboratory is under way, which is financed directly through a grant from the Storting (the Norwegian Parliament). The Ocean Technology Laboratory is referred to in the Long-term plan as the Ocean Space Centre, and includes a number of laboratories and pools. This also includes a fjord laboratory spread over three different locations.

There is a high degree of international cooperation in the areas of geoscience, oceans, climate and the environment, including cooperation on research infrastructure and sharing and reuse of research data. In the time ahead, it will be necessary to upgrad and further develop existing infrastructure and continue international cooperation on infrastructure.

Norway has a responsibility to establish and maintain historical archives and long-term observations of relevance to climate anc environment on Norwegian land, sea and polar areas. This entails continuation of unique, long time series, renewal of the observation systems, maintenance and availability of data, in addition to equipment for collecting and analysing new data.

There is a need for technology development that enables increased use of autonomous and mobile observation systems, electronic sensors and instrumentation and simulation tools etc., that include the use of artificial intelligence and digital twins.

There will be a need for new analytical tools, laboratories and measurement technology – among other things to be able to dete new pollutants and contaminants and understand their biological effects. In biological and ecological research, it is important to adopt new DNA techniques, improve systems for storing and securing information in natural history collections, conduct in-situ ecological experiments and establish archives/databases for biological material and environmental samples.

Well-integrated observation systems that utilise new technology, remote sensing and earth observations from ships, satellites, aircraft and drones, in Norwegian coastal and marine areas and linked to geohazards on land are important. These allow for dynamic data acquisition and adaptive spatial resolution, and research of high quality and importance. There are publicly availab and highly detailed data sources in this area. Nevertheless, there is a need for a breadth of infrastructures that together cover ar coordinate data for aquatic, terrestrial and atmospheric observations, and that enable short- and long-term climate modelling.

There is a need to link observation systems (based on e.g. land-ocean observations, molecular biological monitoring, as well as chemical and physical measurements) to ensure multiple use and data sharing across disciplines and technology areas. There i a great international need for development and harmonisation of existing observation systems in the Arctic and Antarctic. Improved coordination and joint access to various research services and international coordination of regional and global observation systems in Svalbard and in surrounding waters will be important Norwegian contributions to a pan-Arctic integrated observation system.

Climate research is dependent on large computing capacity to be able to perform complex calculations in a short time, and ther is therefore a need for access to infrastructure for large calculations (high-performance computing and supercomputers).

There is a need for infrastructure for data management, analysis and modelling for research on various issues. This includes research on biodiversity and all parts of the ecosystem, carbon cycles and ocean acidification, marine resources, etc., as well a digitalisation and virtual access to natural history collections. There is a need for better cooperation with existing infrastructures for analysis and management of data in other sub-areas, e.g. bioinformatics and modelling of ecosystems in a climate perspecti For the development of smart, sustainable and carbon-neutral cities, open platforms and databases for climate and energy modelling and urban effects are important.

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