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The role and added value of large-scale research facilities

Final report

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Contents

Figures

Summary

The Taskforce to Promote Large-Scale Research Facilities and the Dutch Ministry of Education, Culture and Science requested Technopolis to carry out a study of the literature regarding the role and added value of large-scale research facilities, with the emphasis being on their value to society. This comprises their scientific added value but definitely also their socio-economic impact (and potential impact). Besides the literature study, a Web survey was also carried out of all the large-scale research facilities in the Netherlands at the request of the Rathenau Institute. The aim of the survey was specifically to assemble more empirical data on the various aspects of the added value of large-scale research facilities. This study will therefore deal in detail with the value to society of such facilities. Little scientific literature is as yet available on this topic. The study does, however, offer a large number of examples, and the survey data provides substantiation in some respects. The study must therefore be seen not so much as a synthesis of the existing literature but rather as being in the nature of an exploratory investigation. We will give a brief summary of the main elements below.

Conclusions regarding added value from the scientific point of view

Large-scale research facilities are crucial to the advancement of science in all scientific fields. It is only with large-scale, unique research facilities that one can make material visible or carry out pioneering experiments. By linking facilities to a large infrastructure network, researchers can bring about an exponential increase in the number of observations and experiments that are carried out. The network generates far more research results than could ever be done by all the individual groups together.

Large-scale research facilities are not only of crucial importance for acquiring new knowledge but have also contributed to a more efficient way of working in the world of science. Large-scale infrastructures are sometimes necessary in order to achieve the set scientific goals within a given time. Large-scale research facilities are also often a focal point for multidisciplinary research. Research is becoming increasingly multidisciplinary and transdisciplinary, for one thing because scientific and social problems are often so complex that it is not possible to provide an answer from merely a single scientific perspective. Combining a number of different disciplines and parties often brings about an increase in scale and creates a need for large-scale research facilities. Such facilities also have a positive effect on the reputation of research groups, research organisations, and sometimes even whole research fields. Researchers who use large-scale research facilities can carry out state-of-the-art research, which then has the effect of boosting their reputation. Conversely, large-scale research facilities also often attract the best researchers and research groups.

The role and added value of large-scale research facilities need to be considered against the background of the scaling up and concentration of research. The development of large-scale research facilities and technologies has made a major contribution to this. Such facilities ensure, on the one hand, that the research is centralised around unique instruments and, on the other, they ensure increases of scale by combining and integrating complex, linked research facilities. The use of large-scale research facilities in all its forms also brings about innovation in the way science is managed. The management of these facilities can often not be fitted into the local structure of governance, meaning that new management systems must be devised. In addition, existing funding structures are also frequently not appropriate for large-scale facilities. Many European countries are facing the challenge of finding both new sources of funding and new funding arrangements.

Creation of networks and human capital

The scientific literature shows that building up "social capital" is an important mechanism for large-scale research facilities to have an impact on science, the economy, and society in general. "Social capital" generally refers to the benefits that arise from social networks – both formal and informal – and to the shared values and mutual trust that people develop on that basis. In the case of large-scale research facilities, one is dealing both with networks of scientists amongst themselves and with networks comprising both scientists and non-scientists, for example representatives of businesses, government bodies, and civil-society organisations. Social capital plays a crucial role in bringing about the ultimate impact of these facilities on science, the economy, and society in general. The social capital that is built up facilitates and catalyses learning processes and knowledge-sharing by the parties concerned.

The literature also reveals that social networks play a major role in building up human capital. We can conclude indirectly from this that large-scale research facilities are important in building up human capital (via social capital). There is not as yet any scientific data, however, to support the assertion that unique research facilities are a major force in attracting the best and most talented researchers. Nevertheless, the literature does show that a good research infrastructure is indeed one of the factors that determine researcher mobility. Various assessments do show that large-scale research facilities can play a major role in capacity building. A lot of facilities play a role in training young researchers and technical personnel. Large-scale facilities can also promote capacity building, in the first place by providing access, enabling researchers in countries where the facilities are of less high quality to still carry out state-of-the-art research. Secondly, international consortia generate a whole range of learning effects that can serve to improve the infrastructure in those countries.

The economic value of large-scale research facilities

The economic value of large-scale research facilities can be linked in the first instance to the economic activities that take place in the context of developing them – building, construction – and the procurement of related goods and services. Studies show that a major proportion of the investment involved benefits the local (and/or national) economy. Establishing a large-scale facility in a country is therefore beneficial for the local and national economy. The use of such facilities also creates jobs. A distinction needs to be made, however, between temporary effects and long-term effects. The temporary effects involve jobs created as a result of the construction and development of a large-scale research facility. The longer-term effects involve, on the one hand, the jobs that are created for the personnel who work at the facility – both scientists and research staff – and, on the other, the jobs created for suppliers of materials and services for the facility. Jobs may also be created due to "second-order effects". These include such things as the extra jobs created as a result of expenditure by the personnel and users of the facility – for example on homes, consumer goods, hotels, etc. – or by the boost given to further development of the region or of a technology cluster. Economic added value can also be created by the spin-offs that are set up around a large-scale research facility. These are based on the knowledge generated with the aid of the facility or knowledge generated in developing and running it.

Large-scale facilities also contribute to economic innovation. They can generate knowledge that a business cannot generate for itself or acquire via its existing network. Studies show that industrial users in fact make relatively little use of large-scale research facilities. These facilities are largely accessed via or in collaboration with public knowledge institutions. It is not only the use of large-scale research institutions that can drive innovation in the commercial sector but definitely also their construction and development. In the course of constructing and developing the facility, it is often necessary to come up with new technical solutions. Suppliers cannot provide these "off the shelf" but must develop new and innovative products. Large-scale research facilities therefore act as "launching customers" for innovative products and services provided by the commercial sector.

Added value for society

The primary purpose of research facilities is to carry out scientific research. Nevertheless, many of them have a social mission, in the sense that the research performed using the facilities is not an end in itself but is intended to contribute to producing solutions to problems facing society. Large-scale research facilities add value because the necessary data can only be acquired via a large-scale infrastructure or because it can be collected far more efficiently. Large-scale research facilities can also have added value for society without pursuing an explicitly social mission. They can contribute to various types of social innovation, by which we mean various new products, services, and concepts that find their way into the public domain. Large-scale research facilities also play an important role in scientific communication and scientific education. They often appeal to people's imagination, and are therefore frequently used to introduce the public to science in general and research in the relevant discipline in particular. Finally, some large-scale research facilities owe their very existence to the contributions made by the public, patients, or other stakeholders. This leads to a special kind of commitment and obliges the facilities to provide information and render an account of themselves to those stakeholders.

A framework with several dimensions that needs to be worked out in greater detail

The above considerations show that the role and added value of research facilities is extremely varied. The impact of large-scale research facilities extends into a number of domains, and they have both direct and indirect effects. The various impacts that such facilities can have are also time-dependent. In some cases, they generate their effects within the short term, but it sometimes takes years before their impact becomes apparent (and quantifiable). The framework outlined above consequently has several dimensions. More detailed investigation will be necessary to make the framework presented in this study more specific and to fill in the details. Many of the elements involved will also need to be substantiated more effectively from an empirical perspective. In line with this, further consideration will also need to be given to a framework for evaluating and monitoring large-scale research facilities.

1. Introduction

1.1 Background

Large-scale research facilities have been high on the innovation agenda in recent years, both nationally and internationally. In the Netherlands, this topic was first raised by the Innovation Platform. In its report *Knowledge Ambition and Research Infrastructure* [*Kennisambitie en researchinfrastructuur*] (2005), the Platform once more referred explicitly to the importance of large-scale research facilities for science and innovation. The Platform recommended that a national roadmap be developed and that more systematic funding be provided.[1] The topic had already been placed on the European agenda, and in 2002 the *European Strategy Forum on Research Infrastructures* (ESFRI) had been set up. In 2004, the Competitiveness Council – partly at the initiative of the Netherlands – requested ESFRI to draw up an initial European agenda in the form of a roadmap for large-scale research facilities. The ESFRI roadmap was published in late 2006, with an update appearing in December 2008. A new update is foreseen for early in 2011. The Netherlands has taken the matter further. The Strategic Agenda for Higher Education, Research, and Science Policy (2007) emphasises the importance of an "excellent research climate" and the role in that context of large-scale research facilities.[2] In mid-2007, the Minister of Education, Culture and Science also set up the National Roadmap for Large-Scale Research Facilities Committee. The committee's assignment was to draw up the country's roadmap; this was published in late 2008.[3] It presents 25 large-scale research facilities that are of major importance for the vitality and innovativeness of the Dutch scientific system. Following on from the committee to draw up a national roadmap, the Taskforce to Promote Large-Scale Research Facilities was set up early in 2010 with the task of promoting implementation of the roadmap and if necessary advising the Minister on alternative methods of funding.[4] With a view to this, the Taskforce held a large-scale conference – *Closing the Deal* – on 2 December 2010 at which the country's ambitions regarding large-scale research facilities were presented to the general public. The government has also provided an extra budget to fund such facilities: in response to the report by the Innovation Platform, the then Cabinet provided a one-off incentive of M€ 100 at the end of 2005. That amount has been used to create five large-scale facilities in various scientific fields. Regular funding for large-scale research facilities has also been added to the budget of the Netherlands Organisation for Scientific Research (NWO) in the form of an amount that will increase to a regular sum of M€ 20 from 2011.[5]

1.2 Definition of large-scale research facilities

Scientists make use of a very large number of research facilities, but by no means all of them are on a large scale. The question is therefore when a research facility can be considered to be one on such a scale. In the report *Groot in 2008* [*Big in 2008*], the Rathenau Institute went into the definition of large-scale research facilities in greater detail. The report specifies seven relevant features:

- Feature 1: The initial investment and any modernisation and replacement investment goes beyond the capacity of an individual faculty, institution, or funding programme.

[1] Innovation Platform, Kennisambitie & researchinfrastructuur. Investeren in grootschalige kennis-infrastructuur (The Hague 2005).
[2] Ministry of Education, Culture and Science, Strategische Agenda voor het Hoger Onderwijs-, Onderzoek- en Wetenschapsbeleid (The Hague 2007).
[3] Nederlandse Roadmap voor grootschalige onderzoeksfaciliteiten, October 2008.
[4] Instellingsbesluit Commissie Taskforce Stimulering Grootschalige Onderzoeksfaciliteiten, February 2010.
[5] Kabinetsreactie Nederlandse Roadmap voor grootschalige onderzoeksfaciliteiten, June 2009.

- Feature 2: A large-scale facility has major potential learning effects, networking effects, and cluster effects.
- Feature 3: A large-scale research facility has its own research group and support staff, with the costs being covered largely from the facility's budget. In addition to the researchers, the facility requires specialised technical and scientific staff to run it and to keep it up to date.
- Feature 4: A research facility is institutionally embedded and has its own management model that specifies the roles of the various parties concerned, as well as the regular evaluation, ownership, costs model, and accessibility of the infrastructure. As a rule, that model is monitored by the facility's own management.
- Feature 5: Large-scale research facilities have a national or international orientation – as opposed to a local orientation – and are based on collaboration. If a facility (database, sample set, equipment) is utilised only by a local research group or institute, it does not fall within the definition of a large-scale facility.
- Feature 6: Some large-scale facilities are unique within the Netherlands or in the world. These are facilities of which the country will have no more than one because a second would be too costly or because the number of users is not big enough. One reason for having such a facility may be that it serves a specific public purpose and the Netherlands cannot be dependent – or does not wish to be dependent – on facilities in other countries as regards the type of research concerned.
- Feature 7: Research facilities are accessible to external users, whether or not in return for payment. Large-scale facilities are characterised by the way they attract foreign researchers and users from within the commercial sector.[6]

Large-scale research facilities can take a number of forms. The following types are involved:

- *Single-site facility*: This is a single piece of equipment or unified body of pieces of equipment at a single physical location.
- *Distributed facility*: This is a network of distributed instruments or collections. The separate components do not themselves need to be large, but taken together they constitute a large-scale facility.
- *Mobile facility*: This involves vehicles or vessels specially designed for scientific research (for example ships, aircraft, etc.).
- *Virtual facility*: This is an ICT-based or Internet-based system for scientific research.

In addition to the literature study, a Web survey was also carried out for the purposes of this report, at the request of the Rathenau Institute, of all the large-scale research facilities in the Netherlands. The results were taken into account in producing the report. The survey also collected information about the type of facility. The majority of facilities are single-site facilities (49%), followed by distributed facilities (29%), and virtual facilities (20%). Only one is a mobile facility (2%).[7]

When defining a research facility, the Rathenau Institute distinguishes between capital-bearing (for example buildings and equipment) and non-capital-bearing (people) and between knowledge-bearing (researchers, laboratories, collections, etc.)

[6] E. Horlings and A. Versleijen, *Groot in 2008. Momentopname van grootschalige onderzoeksfaciliteiten in de Nederlandse wetenschap* (The Hague 2008).
[7] Web Survey of Large-Scale Research Facilities, Technopolis Group (2010), N = 41).

and non-knowledge-bearing (support staff, office space, "ordinary" computers, etc.). Large-scale research facilities involve a combination of knowledge-bearing and capital-bearing. On this basis, the Rathenau Institute arrives at the following definition: "A research facility is a complex capital asset within which a number of research instruments can be combined as a unified whole and which, thanks to developments in ICT, can also be geographically distributed or virtual. A research facility also distinguishes itself from other capital assets by its role in the production of knowledge. A research facility is part of the process of scientific research and gives shape to the knowledge produced".[8] The Rathenau Institute emphasises that a large-scale research facility is a "tool for science". This means that the facility is part of the research process or the object of research (the experiment, the field study, etc.). If that is not the case, then we do not speak of a research facility. An archive or a collection of data may be a facility, for example, but a university library is not: it provides researchers with scientific information, but it does not form part of the object of research or the research process. In addition, we would argue that large-scale research facilities are not only tools *for* science but also tools *of* science. By that, we mean that such facilities are not merely instrumental – i.e. are in the service of science – but are also decisive as regards the organisation of science – they constitute the method, organisation, and management of science. (This will be dealt with in greater detail in Section 2.).

1.3 Assignment and approach

The Taskforce to Promote Large-Scale Research Facilities and the Dutch Ministry of Education, Culture and Science requested Technopolis to carry out a study of the literature regarding the role and added value of large-scale research facilities, with the emphasis being on their value to society. This comprises their scientific added value but definitely also their socio-economic impact (and potential impact). The role played by such facilities within the current research landscape is closely related. This aspect also deals in particular with large-scale facilities as tools *of* science (see above), in other words the function of such facilities in science (specifically in "big" science). The purpose of the report is to outline the wide range of value to society and illustrate it with interesting examples. The report has been written with a wide readership in mind. The study involved close collaboration with the Rathenau Institute, which has already brought out a number of publications about large-scale research facilities,[9] and the other offices of the Technopolis Group, which also have considerable knowledge of this material. The results of the study were also used as input for the conference on large-scale research facilities in December 2010. The starting point for the study was the existing literature, both Dutch and foreign. We began by carrying out a quick survey of the existing literature. This made clear that there was very little scientific literature regarding the role and added value of scientific facilities, meaning that we could not fall back on any solid empirical basis. The statements made regarding the value that large-scale research facilities have for society must be viewed in this light, and the necessary caution needs to be exercised as regards the general validity of the conclusions presented. Given the lack of sufficient scientific literature, we deliberately searched for a wide range of case studies and other examples that can illustrate the role and added value of large-scale research facilities. Based on the literature that was available, we then produced an overall categorisation, together with a number of subcategories. As a result, the present study has produced a framework for surveying the value that large-scale research facilities have for society. It clarifies what categories/subcategories there are as regards the added value of such facilities, referring for each category/subcategory to the relevant literature, as well as giving

[8] Ibid.

[9] In addition to *Groot in 2008*, the Rathenau Institute has also published *Investeren in onderzoeksfaciliteiten. Prioritering, financiering, consequenties* (2009). We also made use of the draft of an article reviewing the relevant scientific literature: E, Horlings et al., "The societal footprint of big science. A literature review in support of evidence-based decision making".

various examples to illustrate the value that these facilities have for society. This categorisation constituted the structure followed in writing the final report. It was also decided, in consultation with the Rathenau Institute, to carry out a Web survey among all the large-scale research facilities in the Netherlands.[10] The aim of the survey was specifically to assemble more empirical data on the various aspects of the added value of large-scale research facilities. An explanation of the methodology for the survey is given in Appendix B. The results of the survey were incorporated into the report. The final report was then written on the basis of all the material.

1.4 Guide to this publication

This report is structured as follows. Section 2 deals with the added value from the scientific perspective. Section 3 deals with networking (social capital) and human capital. Economic added value is dealt with in Section 4 and added value for society in Section 5. Section 6 summarises the main conclusions.

[10] The Web survey was funded by the Rathenau Institute.

2. Added value from the scientific perspective

This section focuses on the role of large-scale research facilities in science and the scientific added value of large-scale research. It involves consideration of such questions as: Why are large-scale research facilities necessary? What are the reasons for scaling up research? What are the effects of introducing large-scale research facilities or scaling up research?

2.1 Contribution to the advancement of science

Large-scale research facilities make a major contribution to the advancement of science. We will investigate that contribution in the present section.

2.1.1 Unique facilities as an indispensable tool

Over the course of time, scientific research has undergone upscaling and further concentration.[11] The development of large-scale research facilities and technologies has made a major contribution to this. Such facilities, particularly in the natural sciences, are an important means of conducting research and advancing science. It is only with large-scale technologies that one can carry out pioneering experiments, for example to make the smallest possible components of material visible. Without spacecraft and satellites, we would not know what the Earth looks like from space, and our knowledge of the universe would be extremely limited. A lot of pioneering scientific research could simply not take place without large-scale facilities.

One key feature of such facilities is that constructing and maintaining them costs an enormous amount of money. A single research group or faculty, or even a single university, generally lacks the funds to pay for large-scale research facilities. Such facilities are often on a national scale and also play a role that goes beyond merely local level. In some cases, even a single country cannot provide the necessary funding. It is for this reason that special national or international consortia are set up to construct and develop facilities of this kind. They are to be found only in a few places in the world (or in Europe), and they therefore offer something unique. They provide opportunities for scientific research that are hardly available elsewhere. In the case of physics, for example, large particle accelerators and high magnetic fields are to be found in only a few places in the world.[12] Three quarters of the large-scale research facilities in the Netherlands that were approached via the Web survey say that there are one or more comparable facilities in Europe or elsewhere. Within Europe, the average number of comparable facilities is 7.2, with 16.6 outside Europe.[13] This shows that the large-scale research facilities in the Netherlands fulfil a national role and can also be of great importance to other countries in the region. After all, it is not every European country that has such large-scale facilities at its disposal. It is only with the aid of such facilities that research can be carried out at the limits of what is possible. It follows that large-scale research facilities are indispensable if science is to advance and if we are to explore the boundaries of knowledge. One example is the Large Hadron

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[11] See J. H. Capshew and K. A. Rader, “Big Science: Price to Present”. *Osiris, 7* (*Science after ‘40*), 2–25 (1992), E.J. Hackett, “Introduction to the Special Guest-Edited Issue on Scientific Collaboration”. *Social Studies of Science,* 35(5), 667–672 (2005), J. S. Katz and B.R. Martin, “What is research collaboration?” *Research Policy, 26*, 1–18 (1997), and W. Shrum, J. Genuth, and I. Chompalov, I. *Structures of scientific collaboration* (2007).

[12] There are a number of magnetic field laboratories, but only a limited number of facilities that can maintain very high magnetic fields for long periods of time. See *High Magnetic Fields. Science and Technology*, ed. Fritz Herlach (*Katholieke Universiteit Leuven*, Belgium) and Noboru Miura (University of Tokyo, Japan). Volume 1: *Magnet Technology and Experimental Techniques*: “Introduction with Survey of Magnet Laboratories” (F. Herlach and N. Miura).

[13] Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).

Collider (LHC).[14] The LHC is an extremely large particle accelerator in which subatomic particles collide with one another and fall apart, producing the smallest possible particles of material. That material is then studied with the aid of large-scale detectors. After a few months of testing with the LHC, the string theory can be refined. According to the string theory, "little black holes" are created by high-energy collisions between particles. Up to now, however, they have not been observed during testing in the LHC, and scientists are already prepared to assert that at the energy level achieved during testing, they are not in fact created. The level of collision energy during testing was between 3.5 and 4.5 TeV, but when the LHC is running at full power, the level will increase to 7 TeV. Black holes may then in fact turn up, but the string theory posits that they should also be created at a lower energy level. The theory must therefore be refined and perhaps even revised completely.[15] Scaling up research is not anything new; the United States already began scaling up research in physics in the early the twentieth century. The increasing shortage of energy led to three universities in California – Stanford, Caltech, and Berkeley – engaging in research on the production and distribution of energy.[16] This resulted in 1930 in the setting up of the Lawrence Radiation Laboratory in Berkeley, where the first cyclotron was built. The laboratory quickly developed into a national and international centre for nuclear research, where physicists, chemists, engineers, and biologists collaborated on physics experiments with the aid of radiation. The cross-fertilisation that this led to between research in physics and medicine shows how large-scale research facilities generate scientific innovation, even leading in some cases to entirely new avenues of research.[17] Nowadays, the Lawrence Radiation Laboratory concerns itself not only with research in physics and medicine but also with environmental research and climate change.[18]

A good European example is the European Organisation for Nuclear Research (CERN) in Geneva, where research on elementary particles has been going on since the 1950s with the aid of particle accelerators and detectors.[19] The use of these technologies costs a great deal of money, meaning that collaboration at global level is necessary. CERN is a good example of post-war European collaboration that has promoted scientific integration. Currently, more than 2900 scientists work at CERN; they come from 172 organisations in 37 countries, including the Netherlands.[20] Developments in physics in recent decades have led to research becoming greatly dependent on the availability of large-scale facilities, and in the sub-disciplines of high-energy physics and astrophysics, research without such facilities is virtually inconceivable. Other sub-disciplines, for example research on condensed material, are now also rapidly moving towards the use of large-scale facilities. Large groups of researchers investigating condensed materials now base their research to a great extent on the availability of synchrotron facilities and neutron sources. These facilities are only available at a limited number of locations in the world. The cost of other instruments – for example high magnetic fields and free electron lasers (for example XFEL) – has increased enormously in recent years. The investment for facilities of this type amounts to some M€ 50 or more, with operation costing an average of 15% of that amount. The enormous investment involved means that such instruments now fall into the category of unique facilities. Like physics, aerospace is a field of science that makes use of large-scale research facilities. The United States National Aeronautics and Space Administration (NASA) and its European counterpart, the European Space Agency

[14] See http://public.web.cern.ch/public/en/LHC/LHC-en.html
[15] "LHC maakt geen zwarte gaten", Kennislink, 14 januari 2011.
[16] Galison, P., and B. Hevly, Big science: the growth of large-scale research (1992).
[17] Creager A. N. H., and Santesmases, M. J. "Radiobiology in the Atomic Age: Changing Research Practices and Policies in Comparative Perspective". Journal of the History of Biology, 39(4), 637–647 (2006).
[18] For more information, go to http://www.lbl.gov/
[19] D. Pestre, A. Hermann, J. Krige, U. Mersits, History of CERN, Vol.1., Launching the European Organization for Nuclear Research (1987) and D. Pestre, A. Hermann, J. Krige, U. Mersits, History of CERN, Vol.2., Building and Running the Laboratory (1990).
[20] See http://cdsweb.cern.ch/record/43632

(ESA), send Shuttles into space to carry out all kinds of measurements intended to improve our knowledge of the universe. These organisations have even constructed a permanent laboratory in space, namely the International Space Station (ISS). This carries out experiments in five scientific disciplines: physical sciences, biology and physiology in space, terrestrial observation, astronomy, and product development in space. Research carried out at the ISS has so far led to 214 publications.[21] We are therefore dealing here with unique research facilities that can only be constructed through international collaboration and that produce new results. Disciplines such as physics and aerospace are striking examples of fields of science in which large-scale research facilities play an entirely crucial role. The major importance of those facilities ensures that research is centralised around unique instruments. Such centralisation of research is often considered to be the most important type of large-scale research. There are, however, other types of upscaling of research, involving not centralisation but rather networking.

2.1.2 Increasing the scope of research by linking instruments

In disciplines such as astronomy and biology, it is not just instruments that lead to the scaling up of research but also the development of complex, linked research infrastructures. National or global distributed research centres are linked to one another with the aid of information and communication technologies (ICT).[22] By collaborating within a linked infrastructure, researchers can broaden their horizons enormously. The network enables them to bring about an exponential increase in the number of observations and experiments that are carried out. The network generates far more research results than could ever be done by all the individual groups together. The value of linking up research data is much greater than the sum of the parts. Combining the research results produced by individual groups creates an extra dimension to knowledge generation and produces insights that would not have been possible without collaboration. Linking up the research data produced by a number of different centres has a long history. In astronomy, there is a long tradition of linking up specific observations from different locations.[23] One early example of this kind of upscaling was the observation of the Transit of Venus – in which Venus is seen to pass across the face of the Sun – in 1761 and 1769. In order to optimise observation of this phenomenon, a number of groups of scientists from England, France, and other countries decided to collaborate. Doing so enabled them to combine measurements from locations in various different parts of the world, thus producing a complete picture of the Transit of Venus and generating valuable new knowledge regarding the movement of the planets. That collaboration was also the prelude to the development of an international scientific community of astronomers. Today's astronomers still make great use of complex, widely distributed infrastructures for observations, for example in the framework of the LOFAR project. This originally Dutch project utilises an extremely sensitive radio telescope constructed in the form of the network of thousands of sensors. The numerous small antennas are distributed over a diameter of 100 kilometres within the Netherlands and connected to a supercomputer via an extensive optical fibre network. At least eight stations with antennas are also being constructed in Germany (5), the UK (1), France (1), and Sweden (1); these will be connected to the network in the Netherlands.[24] The LOFAR project is expected to produce numerous new scientific insights. If all goes well, LOFAR will be the first telescope capable of picking up signals from the first stars and galaxies that came into

[21] http://www.nasa.gov/mission_pages/station/research/experiments/Publications.html#PV

[22] P. Glasner "From community to 'collaboratory'? The Human Genome Mapping Project and the changing culture of science". *Science and public policy*, 23(2), 109–116 (1996), N. Vermeulen, *Supersizing Science. On building large-scale research projects in biology* (2009) and W. A. Wulf "The Collaboratory Opportunity", *Science, 261(5123), 854–855* (1993).

[23] R. W. Smith, "The biggest kind of big science: astronomers and the space telescope", in P. Galison and B. Hevly (eds.), *Big science; the growth of large-scale research*, 184–211 (1992).

[24] This information is taken from the LOFAR website: http://www.lofar.org/

being in the early universe after the Big Bang. The project pushes back the boundaries of science, which can lead to revolutionary insights into the origin and development of the universe. The project also generates new knowledge in the field of ICT. In order to construct LOFAR's network of sensors, large-scale ICT research is necessary, for example into how to process unprecedentedly large quantities of data and identify patterns in that data, the possibilities for gaining an interactive understanding of complex multidimensional data sets through visualisation, the efficient linking of distributed calculation capacity, and data storage capacity. Traditional field biology and more modern ecological research also involve complex infrastructures with which to carry out observations on a global scale.[25] Although an individual researcher can of course successfully discover a number of new species of organisms and fauna, or study a local ecosystem, it is impossible for an individual or a small group to acquire a more comprehensive picture of life on earth. Making statements about the diversity of life and how it develops requires collaboration. Large-scale ecology therefore brings together the results of numerous research expeditions at scientific "nodes" such as museums, libraries, and databases. Darwin and his nineteenth-century contemporaries were only able to bring back a limited number of species of fauna from their expeditions and assemble and study them at natural history museums; expeditions today can fill large electronic databases with enormous quantities of information about life on earth. These then often act as the building blocks for modelling ecological processes, thus enabling us to understand how biodiversity increases or decreases. A good example of a highly complex contemporary ecological project is the "Long Term Ecological Research Network" (LTER), which began work in 1980.[26] This is an originally American project which now has a European equivalent. Its aim is to disseminate knowledge of ecology by assembling observations covering not only large parts of the world but also a lengthy period. The project enables a synthesis to be made of various ecological observations, thus generating new insights into population biology, landscape development, changes in the hydrological regime, and the impact of disturbances on the natural environment. The ARGO project is another example. This involves measurements of the water temperature and salinity of the oceans by means of instruments called "Argo profilers", which are buoys or floats that operate independently. Getting a good picture of the world's oceans requires international collaboration. The project involves 23 countries, together providing 3000 profilers. Each country's contribution is coordinated by the Argo Project office.[27]

Another example of the necessary large scale of facilities, this time in the world of medicine is the Biobanking and Biomolecular Resources Research Infrastructure (BBMRI). Scaling up has taken place in medical research through the use of all kinds of new technologies ("high throughput screening") and the realisation that most disorders are caused by an accumulation of factors, both genetic and contextual, all of which contribute a bit to a syndrome arising and progressing. In the study of such multi-factor disorders and the underlying biology, statistical reasons require us to have large numbers of biological samples, often specific to the particular disorder. These are not generally available at a single location, i.e. in a single biobank. Connecting up biobanks makes complementary collections accessible and allows us to conduct statistically reliable research on the disorders concerned. Research projects on a relatively large scale are also currently under development in the humanities and social sciences.[28] These projects are not comparable as regards size and investment to the facilities in the natural sciences but they do represent a considerable increase in scale within their own discipline. As in astronomy and biology, space and time are important dimensions in the humanities and social sciences where scaling up research is concerned. In this case, we are often dealing with comparative historical,

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[25] J. Parker, N. Vermeulen, and B. Penders, (eds.) *Collaboration in the New Life Sciences* (2010).
[26] Ibid.
[27] See www.argo.net
[28] S. Dormans and J. Kok, "An Alternative Approach to Large Historical Databases: Exploring Best Practices with Collaboratories". *Historical Methods*, 43, (3), 97–107 (2010).

psychological, sociological, or ethnographic research. With a view to acquiring greater scientific understanding, individuals or communities are currently being studied for long periods and/or in various places in the world. Where possible, the data produced is then assembled or combined. This method of conducting research is highly complex and it also necessitates substantial investment. One example are the academic variations of the successful British documentary *Seven Up*, in which a number of children were interviewed about their lives every seven years.[29] The long time span of the study – literally covering the subjects' whole lives – means that it teaches us far more about how individuals develop within society than a short-term study. In the Dutch context, the Historical Sample of the Netherlands (HSN) is a representative sample of some 70,000 people born between 1812 and 1922. The HSN database comprises individual life stories, thus constituting a unique tool for research on Dutch history and demography.[30] A comparable project in the United States is the series of National Longitudinal Surveys (NLS), which study the work and other events in the lives of various groups of men and women.[31] A further example is Data Archiving and Networked Services (DANS), an institute run by the Royal Netherlands Academy of Arts and Sciences (KNAW) and the Netherlands Organisation for Scientific Research (NWO), which concerns itself with the storage and provision of access to research data in the humanities and social sciences.[32] For this purpose, DANS has developed its own archiving system (EASY), to which researchers can upload their dataset for permanent storage. Working with national and international partners, DANS also helps researchers access large databases. The institute also carries out a large number of projects to make data accessible to researchers. Two examples are the Hub for Aggregated Social History, in which an infrastructure is being constructed that integrates various information sources, and the Veteran Tapes, a collection of interviews with ex-servicemen (this includes annotation tools). One final example of this kind of large-scale research is the "Tensions of Europe" project. This involves a group of almost 200 scholars from 17 countries recounting the modern history of Europe and European integration on the basis of technological changes.[33] Comparison of the processes of modernisation in the various different countries is producing many new insights. Comparing the role of various technologies in European integration provides a far more comprehensive and precise picture of the connection between the history of technology and European integration processes than research on a smaller scale on the development of a single technology in one or more countries could ever have done.

2.1.3 Large-scale facilities as a vehicle for multidisciplinary research

Large-scale research facilities and the scaling up of research are also considered necessary in order to solve complex questions. The scientific and social problems facing us today are often so complex that it is no easy matter to find answers to them, and we cannot hope to do so if we approach them from only a single specific scientific perspective.[34] This means that we need to mobilise various different types of expertise and combine them in the form of multidisciplinary and/or transdisciplinary research. Multidisciplinary research involves collaboration between a number of scientific disciplines, while transdisciplinary research also involves civil-society parties. Their interaction leads to cross-fertilisation and the development of new knowledge. Combining a number of different disciplines and parties often brings about an increase in scale, and large-scale research facilities form a vehicle or focus for multidisciplinary research. Many of the large-scale facilities in the Netherlands that

[29] Stella Bruzzi, *Seven Up*. London: British Film Institute (2007).
[30] See http://www.iisg.nl/hsn/indexnl.html
[31] See http://www.bls.gov/nls/
[32] See http://www.dans.knaw.nl/
[33] http://www.tensionsofeurope.eu/
[34] J.T. Klein, Interdisciplinarity: History, Theory, and Practice (1990) and J.T. Klein, et al. Transdisciplinarity: Joint Problem Solving among Science, Technology, and Society (2001).

were surveyed indicate that they serve a number of disciplines; this demonstrates their multidisciplinary nature. This feature is greatest in the natural sciences and life sciences, and can be found to a far lesser extent in the humanities, the social sciences, and the behavioural sciences. The large-scale facilities for the sciences involve less overlap with other disciplines.[35]

One example of a transdisciplinary project is the Knowledge for Climate [*Kennis voor Klimaat*] programme, in which researchers collaborate with policymakers and other interested parties to determine the impact of climate change on a given region or city and to develop the necessary policies.[36] A good example of multidisciplinary research is systems biology.[37] Molecular biology focuses on studying the minute building blocks of life while systems biology is primarily concerned with the interactions between these various components. These interactions are made visible in models that can greatly increase our understanding of how life on earth functions. Developing these models requires contributions not only from molecular biologists and biochemists but also from physicists, mathematicians, and information scientists. Collaboration between these various disciplines takes place in new laboratories with advanced techniques for generating data (for example microarrays, DNA sequencing, and mass spectrometry), managing data, and visualising and analysing data (IT and calculation capacity). In the context of systems biology, large-scale research facilities make an important contribution to the necessary collaboration between different disciplines and to the integration of the various research results. Combining different scientific perspectives sometimes even leads to new disciplines with the associated large-scale facilities. Bioinformatics is a good example.[38] Since 2003, all the Dutch bioinformatics groups have been collaborating within the Netherlands Bioinformatics Centre (NBIC).[39] Research is carried out at the centre, but it also has an important function in supporting researchers by assisting them with data storage and data analysis. Together with the SARA computer centre, the NBIC has developed a large-scale ICT infrastructure for that purpose and also set up a number of communities and platforms.

2.1.4 Increasing the efficiency of research

Large-scale research facilities are not only of crucial importance for acquiring new knowledge but have also contributed to a more efficient way of working in the world of science. This type of upscaling is closely related to processes of modernisation in industry, in which Fordism and Taylorism argue in favour of scaling up, division of work, and increased efficiency.[40] Similar phenomena can be observed in large-scale scientific projects. Having large-scale facilities is then not so much necessary in order to achieve scientific results but crucial if the set target is to be achieved within a given period of time. Shortening the time needed to carry out research is not only advantageous from the financial point of view – “time is money” – but can also have major scientific and social advantages. If a research project involves developing a new influenza vaccine, for example, then speed not only means profits for the company producing it but also a better understanding of how to combat the disease and a population that is armed against it. One familiar example is the Human Genome Project, whose aim was to unravel the structure of our DNA.[41] In order to achieve that aim, a decision was taken to engage in extensive international collaboration and to

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35 Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).
36 See http://kennisvoorklimaat.klimaatonderzoeknederland.nl/nl/25222734-Home.html.
37 Special Issue: Systems Biology, Science, 295 (5560) (2002).
38 E. Thacker, The global genome: biotechnology, politics, and culture (2005).
39 http://www.nbic.nl/
40 M. Berman, All that is solid melts into air: the experience of modernity (1983) and K. Kumar, From post-industrial to post-modern society: new theories of the contemporary world (1995).
41 P. Glasner “From community to ‘collaboratory’? The Human Genome Mapping Project and the changing culture of science”. *Science and public policy*, 23(2), 109–116 (1996) and S. Hilgartner, “The Human Genome Project”. In S. Jasanoff (ed.), *Handbook of science and technology studies*, 302–315 (1995).

utilise modern technology (including computer technology). One important reason for this large-scale approach was to shorten the time required for the research (i.e. to get results fast). Although the large-scale approach came in for a great deal of criticism – particularly regarding the industrial aspects of this scientific enterprise, for example division of work and the mechanisation of the research – it soon became apparent that scaling up the research was far more efficient than had been expected. The project was five years ahead of schedule and also remained below the budget that had been allowed for. This project is therefore a good example of how scaling up research may not perhaps make it more interesting but can make it more efficient. The rapid availability of knowledge in the field of genomics led to numerous new developments that are referred to as "post-genomics research". The Census of Marine Life project is another good example of this increase in efficiency.[42] This large-scale international project involves collaboration over the past ten years between scientists from more than 80 countries to survey life in the world's oceans. To quote the project's website: "In one of the largest scientific collaborations ever conducted, more than 2700 Census scientists spent over 9000 days at sea on more than 540 expeditions, plus countless days in labs and archives".[43] This resulted not only in the discovery of more than 6000 new species but also in a new database providing access to the new knowledge regarding the species and their locations. It was possible to create an overview of the current situation of life in the world's oceans within only a relatively short time. This "ecological baseline" is an important starting point for further research on marine life and the future of both the oceans and the Earth. The study shows, for example, that populations of large fish such as tuna are declining not just in coastal waters but also in the deep oceans.[44] Although the scale of this project has numerous advantages – for example worldwide integration of the research results – one can argue that marine biologists would ultimately have discovered these new species even without upscaling; the research would, however, have taken considerably longer. Moreover, conditions in the oceans are subject to change and it was precisely those changes that were the subject of the study. In this case, therefore, the speed argument is indeed scientifically relevant.

2.2 Innovation in the organisation of research

Large-scale research not only has an impact on the development of science but also important implications for how research is organised. Upscaling and the use of large-scale research facilities lead to innovation in how science is organised. It is therefore important to note that large-scale research facilities and the scaling up of research are bringing about fundamental changes in the organisation and management of science. Developing new tools or knowledge infrastructures involves not only constructing new facilities for scientists to use but also developing a new way of carrying out scientific work. "Big Science" generally involves developing a new kind of research practice.

2.2.1 Integration of research

The use of large-scale facilities and the scaling up of research is to a great extent associated with the increased integration of research.[45] This is clearly apparent in various methods of organisation. Centralised large-scale research at large-scale facilities is always highly integrated because the various components of the research are greatly dependent on one another in order to function. The clearest example of this is aerospace, in which the organisation of the launch of a spacecraft is worked out in detail, with every step needing to be implemented with extreme precision and in the

[42] See http://www.coml.org/ and N. Vermeulen, *Supersizing Science. On building large-scale research projects in biology* (2009).

[43] http://origin.coml.org/pressreleases/census2010/PDF/Census-2010_Public_News_Release.pdf

[44] B. Worm et al., "Global patterns of predator diversity in the open oceans", *Science,* 309, 1365–1369 (2006).

[45] W. Shrum, J. Genuth, and I. Chompalov, I. *Structures of scientific collaboration* (2007).

correct order if the overall process is to take place correctly. Connecting instruments within the network also contributes to the integration of research. The enormous developments in ICT in the past century have led to a huge increase in scientific networking.[46] High-quality ICT infrastructures simply make it much easier to connect up research efforts and research results. Molecular biology is a good example of networking, with ICT and an electronic database forming the technical backbone. That was not always the case: unlike research in the field of ecology, analytical and experimental biology was for a long time only a small-scale enterprise, one that took place in relatively independent laboratories. Recent scientific developments in molecular biology and the development of bioinformatics have led to a major change in research practice. Laboratory research is now often closely linked, on a global scale, by means of ICT. The Human Genome Project is a striking example. At first, the project was seen as a revolutionary method of scientific endeavour but the networking that it involves has since become the most normal thing in the world. As an editorial in *Nature* put it in 2001: "Big biology is here to stay".[47] Connecting up various different medical biobanks is also a kind of integration. In order to create a networked structure of biobanks, the competition model – i.e. competition between research groups for funding and reputation – has been replaced by a collaboration model. It is only when countries and research groups collaborate that the desired virtual research into structure can be developed. Such collaboration involves harmonising ethical and legal rules, standardising IT platforms for communication, standardising nomenclature,[48] harmonising access and distribution, and standardising quality assurance procedures for collection and storage. This collaboration creates enormous added value. The United States – itself renowned for its high-quality biomedical research – is following this European development closely and would like to participate in the networks (the United States has in fact approached BBMRI with a view to collaboration).

In the field of history, where archives have always played an important role, developments in ICT are also leading to further integration of research.[49] One example of this, on a national scale, is the creation of a database of the names and careers of more than 100,000 Church of England clergy: the Clergy of the Church of England Database. This publicly accessible database combines information from fifty different archives. Another more international example is the Global Collaboratory on the History of Labour Relations, which provides a worldwide survey of labour relations in particular years (1500, 1650, 1800, 1900, and 2000). The collaboratory involves sixty researchers from all over the world contributing to a central database containing estimates of the number of independent entrepreneurs, employed persons, slaves, etc. per country. The CLIO-INFRA project collects and standardises economic data – BNP, unemployment figures, wage trends, demography, interest rates, etc. – from as many countries as possible. The data is made suitable in this way for scientific research on global economic trends. The purpose of the infrastructure is "*to change the 'rules of the academic game' in such a way that more efficient ways of cooperation are being made possible and the exchange of data is facilitated. These new rules are institutional adaptations in response to the greater possibilities for cooperation and exchange made possible by modern e-technology such as the internet*".[50]

The way in which the use of large-scale research facilities is organised is often closely interwoven with the nature of the scientific activity concerned. In other words, the form and function of the research are closely related and the various different scientific disciplines or specialisations bring with them specific types of organisation.

[46] P. Groenewegen and P. Wouters, "Genomics, ICT and the formation of R&D networks". *New Genetics and Society,* 23(2), 167–185 (2004).
[47] Anonymous, "Post-genomic cultures", *Nature* 409, p. 545 (2001).
[48] Nomenclature: the entire body of scientific rules that are followed when assigning names, and the names themselves.
[49] S. Dormans and J. Kok, "An Alternative Approach to Large Historical Databases: Exploring Best Practices with Collaboratories". *Historical Methods*, 43, (3), 97–107 (2010).
[50] See http://www.clio-infra.eu/index.php/Main_Page.

The organisational method is not, however, solely dependent on the nature of the research or the discipline concerned. The intended result may also determine the extent of integration. When certain drugs are being developed, the various stages in the research process build on one another and the order cannot be altered. When a database is being constructed to which everyone contributes, for example, there is far less integration of the research even though, here too, requirements need to be set as regards standardisation and specialisation.

2.2.2 New types of management

The use of large-scale research facilities in all its forms also brings about innovation in the way science is managed. A new management entity is often set up separately from the traditional management echelons (within research institutes, universities, or national structures). In many cases, an extra management echelon is added to the science.The nature and structure of the management of large-scale facilities and projects differ enormously. Despite this great diversity, the management structure often depends on the specific nature of the science involved. In the case of large-scale centralised facilities, a new organisation is often set up, for example, with its own administrative structure and its own staff. Another type of management involves having only a small permanent staff, with managers and other personnel being seconded to the research facility (on a part-time basis) by universities and research institutes. In the case of networked facilities, management often involves an inter-institutional construction, with one or more institutes being in charge or with representatives of the various research institutes dividing up the management duties between them. One extremely important aspect of large-scale research facilities (and the associated networks) is the increased coordination that takes place between geographically scattered national or international researchers. In the past, communication between scientists at different institutes generally took place via traditional channels such as scientific conferences, publications, and personal contacts. There is much more coordination and alignment around large-scale research facilities. Researchers are more aware of one another's activities and there are regular meetings to discuss proposed studies or results. This is separate to coordination of the use of the facility. Such coordination has clear added value for researchers, as is shown by a study of the impact of large-scale projects in the field of nutrition science. That study showed that a large-scale project produces just as many reliable and credible claims for the effect of nutrition as a large number of small-scale projects with a comparable total size. In that sense, the use of large-scale facilities did not produce anything extra. The main added value of using such facilities, however, was to be found in constructing a joint research agenda. By organising research on a large scale, it was possible to bring together people, expertise and agendas, thus giving direction to the future research agenda. The coordinated efforts also had a positive effect on the "narrative" of nutrition science vis-à-vis the public.[51] In other scientific domains, coordination at national and international level is sometimes even essential for knowledge generation because standardisation is required. Systems biology involves developing models for living processes. Standardisation is of the greatest importance because no effective model can be developed if each research group applies its own standards (for example uses a different temperature for analysis and experimentation). Achieving a good research result therefore requires intensive coordination. Where systems biology is concerned, consideration is now being given to setting up a "European Systems Biology Office" (ESBO) to coordinate arrangements at a European level.[52] Managing large-scale research facilities demands innovation and, precisely for that reason, finding the right structure is often a process of trial and error, not least because so many aspects are involved. One striking illustration of all this is the BBMRI project, in which a number of different biobanks have been linked to

[51] Penders, B., The Diversification of Health. Politics of cooperation in large-scale nutrition science (2010).
[52] http://www.systembiology.net/esfflshort.pdf

one another in a network. Developing the network involves major organisational challenges. To develop an integrated international biobank, it is necessary not only to construct an entirely new organisational structure but also to reach agreement on shared legal frameworks, models for public-private collaboration, policy on intellectual property, and harmonisation of quality control systems. It goes without saying that international coordination of all these aspects is no easy matter.[53]

The BBMRI project has brought another point to light in the context of managing research, namely monitoring and accountability. The project can no longer be assessed according to traditional quality standards (often focussing on scientific quality). The added value of such biomedical, major, virtual, European infrastructures consists of their large critical mass (the number of samples collected), biodiversity, standardisation, good accessibility, transparency, and outreach to stakeholders. “Measuring” and monitoring the added value of the facility requires a new evaluation framework that does justice to these elements.[54] The same applies to other large-scale research facilities. Technopolis worked out an evaluation strategy for BBMRI in 2010 that does justice to the different phases (setting up, expansion, and maintenance) and aspects of a large-scale research facility; the strategy specifically takes account of the socio-economic impact. The European Commission has given evaluation and monitoring of large-scale research facilities a place high on its agenda, for example, in particular the importance of pan-European facilities.[55]

2.2.3 New types of funding

Large-scale research facilities also require new types of research funding. Many European countries have developed a national roadmap and participate in the ESFRI Roadmap. A roadmap is only valuable if sufficient funds are available to pay for the proposed facilities. In a few European countries, funding instruments exist that are linked to the long-term agenda for research facilities, but in many countries that is not the case. Existing funding systems are in most cases not suited to enormous levels of investment or the costs involved in using and maintaining the facility.

Several national budgets are sometimes also combined with a view to funding large-scale research facilities. That is certainly the case with such enormous research facilities as the LHC in Geneva but also with smaller facilities. In some cases, funds are combined in advance so as to create a large-scale research facility, and in some cases what is involved is linking and scaling up existing national facilities. National governments are not always prepared, however, to finance large-scale international facilities, for example because long-term investment and commitment are often required or because governments prefer to invest research funds in a national infrastructure. The study of the BBMRI shows that European funding is essential for setting up the network and organising the infrastructure. In some cases, the solution is to be found in accessing other sources of funds, for example private parties and foundations (such as patient organisations) that finance research, or the EU’s structural funds; the latter already play a crucial role in a few countries.[56] The international Census of Marine Life project, for example, is funded by the Sloan Foundation, which realised the importance of scaling up marine biology and was prepared to finance international coordination of doing so. The Sloan Foundation paid for such coordination, with the research being funded in a number of countries from

[53] See P. Mattson, J. Molas-Gallart, G. Dagher, G. and I. Meijer, “Biobanking in transition: towards professional research infrastructures” (policy commentary for Science (under review), and I. Meijer et al., BBMRI: an evaluation strategy for the socio-economic impact (Technopolis Group, September 2010).

[54] See Technopolis and Interface, Evaluating the Pertinence and Impacts of EU support to Research Infrastructures, Final Report for DG Research and DG INFSO (2006) and I. Meijer et al., BBMRI: an evaluation strategy for the socio-economic impact (Technopolis Group, 2010).

[55] Presentation by Hervé Péro, Head of Unit Research Infrastructures DG Research at the International Conference on Research Infrastructures, Rome, 30 September 2010.

[56] In Spain, for example, the structural funds play a major role; M€ 150 is available for large-scale research facilities.

national sources. This led to a patchwork of local projects linked by an international management structure, a unique solution that some now view as a model for international collaboration.[57] However, government support is generally indispensible for the long-term funding of large-scale research facilities.

2.3 The need for systematic funding

The question of funding for large-scale research facilities is a matter for discussion. One of the aspects under discussion has to do with concern that large-scale facilities and large-scale research projects are being funded at the expense of scientific research on a smaller scale.[58] That concern was expressed by many biologists, for example, regarding the Human Genome Project. Such concern is to some extent justified, although large-scale projects can also free up more money for the relevant research sector.[59] Many countries face the challenge of providing sufficient funds for investment in large-scale research facilities and determining how that investment should be implemented. This involves, on the one hand, deciding on the scale that investment should take. That may involve national facilities versus participating in international consortia, but also creating options for scaling up promising facilities. On the other hand, it is important to bear in mind the balanced distribution of funds between the various types of research. Investment must not be at the expense of scientific endeavour. This often means that additional new sources of funds need to be created, at both national and international (European) level, that take account of differences in scale, flexibility, and long-term investment programmes. There are major differences between countries in how they tackle the financing of large-scale research facilities. In the Netherlands, some of the funding for research facilities is integrated into the lump sum funding for the universities (and is consequently not clearly visible). The NWO also has specific programmes for research facilities and there is occasional investment (to a large extent funded from the proceeds from natural gas). The Netherlands does not, however, have sufficient systematic funding.[60] Some countries – for example Germany, Spain, and Sweden – have reserved additional large sums for investment in large-scale facilities. Others – such as Australia, the United Kingdom, and the United States – do have systematic funding mechanisms. The lack of sufficient systematic funds means that appropriate new funding instruments need to be identified for investment in large-scale research facilities. This is possible by increasing the science budget or by restructuring that budget. Other European countries do, however, have a more systematic budget.

2.4 Effects on the reputation of research

One final important aspect of large-scale research facilities is the effect they have on the reputation of research groups, research organisations, and research fields. The reputation of such facilities is linked to the added value that they represent for scientific progress. Researchers who use large-scale research facilities can carry out state-of-the-art research, which then has the effect of boosting their reputation. Conversely, large-scale research facilities also often attract the best researchers and research groups. Moreover, very large and unique facilities admit only the very best research groups because they simply have to be selective.[61] Another point to note in this connection is that using and participating in large-scale research facilities raises the profile of the researchers and research groups concerned. When using facilities of

[57] D. Cressey, "Out of the blue", *Nature*, 467, 514–515 (2010).

[58] G. Petsko, Big Science, Little Science. *EMBO Reports* 10: 1282 (2009) and N. Vermeulen, J.N. Parker and B. Penders. *Big, Small or Mezzo?: Lessons from Science Studies for the ongoing debate about "Big" versus "Little" Science*. EMBO Reports, 11, 420–423 (2010).

[59] See, for example, the investment by the Dutch government in genomics via the Genomics task force, later Netherlands Genomics Initiative (NGI).

[60] See Rathenau Institute, *Investeren in onderzoeksfaciliteiten. Prioritering, financiering, consequenties (2009) alsmede Innovatieplatform, Kennisambitie & researchinfrastructuur* (2005).

[61] S. Traweek, *Beamtimes and Lifetimes: The World of High Energy Physicists* (1988).

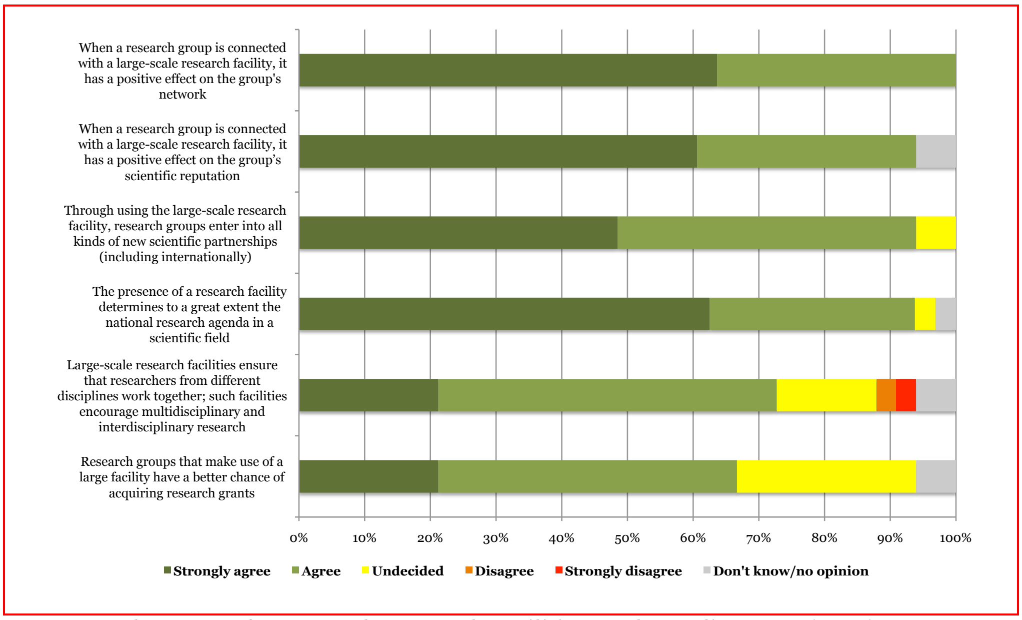
this kind, researchers need to cooperate with other researchers and research groups, and in some cases consult with industrial partners and government. In other words, large-scale research facilities provide researchers with an international platform. As the profile of researchers within international partnerships increases, they are more frequently invited to international conferences, the volume of their publications increases, and that higher profile often also leads to their publications having a greater citation impact. All this leads to a much higher profile (including internationally) and ultimately to a self-reinforcing effect of increasing reputation and scientific reward: the "Matthew effect" as described by the science sociologist Robert Merton.[62] A Dutch example of such a mechanism is the development of Utrecht University's Bijvoet Centre, one of the first institutes in the country to utilise NMR spectroscopy for research on biological material. That position led to the research group forming part of the National Centre for NMR Spectroscopy. Based on their national position, they then began participating in a European network in the context of the third European Framework Programme. This early participation in the European programme led to the group gaining a reputation both nationally and at European level. The group also made use of its international experience to acquire more European funding. The late Dr Rien de Bie, the Centre's research manager, remarked "We were extremely successful, although I still don't entirely understand why, but it would seem that we had already invented 'Eurospeak' at an early stage."[63] The scale of research can have consequences not only for the reputation of researchers and research groups but also for whole disciplines. The work of the historian Jane Maienschien has shown that scientific collaboration is not only prompted by better research results but also aims to improve the reputation of research as a whole. Collaboration between different researchers can lead to greater credibility because all the researchers contribute their individual reputations and networks. This can help boost the profile of a certain type of research and re-emphasise its importance.[64]

2.5 The propositions in the Web survey

The above examples of the scientific added value of large-scale research facilities was tested by means of a number of propositions.

[62] Amongst other things, Merton drew attention to the habit of attributing a scientific breakthrough to the best-known and leading researcher, R. Merton, "The Matthew Effect in Science" in *Science* (1968).
[63] N. Vermeulen, *Supersizing Science. On building large-scale research projects in biology* (2009).
[64] J. Maienschein, "Why Collaborate?" in *Journal of the History of Biology*, 26(2), 167–183 (1993).

Figure 1 Scientific effects of large-scale research facilities (n = 32/33)



Source: Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).

The results are presented in the above figure. This clearly shows that large-scale research facilities have a positive scientific effect. Respondents indicate that there is a positive effect on the reputation of the research group if it is associated with a large-scale research facility. Some two thirds of respondents believe that this is also an advantage as regards acquiring research grants. According to the respondents, large-scale research facilities also contribute to creating new partnerships and to expanding the group's network. In addition, some 70% of respondents say that the research facility also boosts multidisciplinary and interdisciplinary collaboration. A small proportion (some 5%) of respondents say, however, that that is not the case at all. Last but not least, many respondents say that the presence of a large-scale research facility is also decisive for the research agenda in a particular field. During the Web survey, we also asked respondents to give examples of pioneering results achieved with the aid of large-scale research facilities. A limited selection of their answers is given in the box below.

Box 1 – Examples of pioneering scientific innovation/performance

- Major advances in research in in-vivo detection of the molecular signature of Alzheimer's disease.
- The description of morphological processes in rivers and along the coast was made possible by the availability of advanced hydrological software.
- The use of new plasma sources and the application of superconducting magnets.
- The development and production of the polio vaccine. This technology and the vaccines are now used worldwide.
- Various studies in the field of research on life courses (spacing of births, marriages between cousins, migration).
- A great variety of functional nanostructures for use in such areas as nano-optical, nano-electronic, nano-magnetic, nano-fluid, and bio-nano.
- Technologies for the qualitative and quantitative analysis of proteins and phosphorylated proteins that are now the global standard and are used in scientific research.

Source: Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).

2.6 Summary of added value from the scientific perspective

To summarise, the added value from the scientific perspective consists of the following elements:

- Pioneering scientific research could simply not take place without large-scale facilities:
    - large and unique facilities can carry out unique experiments and assemble data.
    - linking various different facilities increases the scope of research: more research data and synergy of data (a more comprehensive picture).
- Large-scale facilities can also contribute to a more efficient way of working in science: the set scientific goals can be achieved within a given time. May be scientifically relevant.
- The use of large-scale facilities is linked to the further integration of research. The various stages of research are becoming increasingly dependent on one another, and harmonisation and standardisation are becoming increasingly important. This requires greater coordination and gives direction to the research agenda.
- Large-scale research facilities are often a focal point for multidisciplinary research. Combining a number of different disciplines and parties often brings about an increase in scale, and large-scale research facilities encourage multidisciplinary research. The use of large-scale research facilities in all its forms also brings about innovation in the way science is managed. New types of management, new sources of funding, and new funding arrangements are necessary.
- Large-scale research facilities have a positive effect on the reputation of research groups, research organisations, and sometimes even whole research fields.

3. Creation of networks and human capital

Large-scale research facilities not only have clear added value for science but, in line with this, also for the creation of networks, the training of young people, and capacity building. What precisely those effects are is the subject of the present section.

3.1 Large-scale research facilities and social capital

The scientific literature shows that building up "social capital" is an important mechanism for large-scale research facilities to have an impact on science, the economy, and society in general.[65] "Social capital" generally refers to the benefits that arise from social networks – both formal and informal – and to the shared values and mutual trust that people develop on that basis. In the case of large-scale research facilities, one is dealing both with networks of scientists amongst themselves and with networks comprising both scientists and non-scientists, for example representatives of businesses, government bodies, and civil-society organisations. The scientific literature argues that large-scale research facilities make a significant contribution to building up social capital. That contribution results from the dual nature of such facilities. Large-scale facilities are not only complex capital assets based on advanced technology but also "social constructs" in which various parties see their interests, funds, objectives, and expectations fulfilled. A large-scale research facility is therefore more than an advanced "tool for science". Development, funding, construction, use, and maintenance necessarily involve several parties. Such extremely expensive research facilities are frequently funded from a number of sources, involve numerous specialised suppliers, and involve various users from different scientific disciplines and knowledge institutes. Ensuring that the facility operates properly requires collaboration between a large number of parties (various scientific disciplines, the business community, government, etc.). A great deal of effort and consultation is necessary to bring together all these parties so as to coordinate the various different interests. This social process of coordination and cooperation leads to the creation of networks – both formal and informal – and the construction of what is referred to as "social capital". Social capital plays a crucial role in bringing about the ultimate impact of these facilities on science, the economy, and society in general. The social capital that is built up facilitates and catalyses learning processes and knowledge-sharing by the parties concerned. This happens in three ways:

- Social capital increases the quantity and diversity of the knowledge potentially available to both parties because the parties' readiness to give one another access to their networks (both internal and external) increases.
- Social capital increases knowledge-sharing by the parties involved because trust is created and the principle of reciprocity is reinforced.
- Social capital increases the efficiency of knowledge transfer because there is greater overlap in knowledge, thus also increasing the amount of knowledge shared by the parties.

Interaction also draws the organisation's strategic targets closer to one another.

Studies of the impact of CERN show that social capital does indeed play a key role in creating "knowledge spillovers" from "big science" to the commercial sector.[66]

[65] E. Horlings et al., "The societal footprint of big science. A literature review in support of evidence-based decision making" (2010). The section on social capital is to a large extent based on this subject review article.

[66] E. Autio, A.-P. Hameri, and O. Vuola, "A framework of industrial knowledge spillovers in big-science centers". *Research Policy*, 33(1), 107–126 (2004), Byckling, E., A.-P. Hameri, T. Pettersson and H. Wenninger, "Spin-offs from CERN and the case of TuoviWDM". *Technovation*, 20(2), 71–80 (2000) and Nordberg, M., A. Campbell and A. Verbeke, "Using customer relationships to acquire technological

Scientists and businesses come together at large-scale facilities because they have complementary objectives and interests. Large-scale research facilities require advanced technology but they have limited budgets for investment. Businesses seek an environment within which they can develop, test, and validate technologies, and within which they can reduce the uncertainties and cost of their R&D. Collaboration is therefore advantageous for both parties. The study of CERN shows that it is specifically informal relationships between technical experts from different organisations that provide a good basis for cooperation.[67] Experts speak the same language, and their relationships constitute a "significant social practice" that is necessary for knowledge-sharing and shared innovation. Another study of CERN considered a large-scale research facility as a hub within social networks and as a "learning environment" within which various different parties share knowledge and learn from one another.[68] Such a learning environment can be created when a complex project is concerned involving numerous parties collaborating to achieve an overall aim. In that case, parties have complementary means and tasks, and they know what is expected from one another. The formal and informal interaction that takes place within the learning environment and networks are an important mechanism as regards the ultimate impact of large-scale facilities on science, the economy, and society in general. Businesses that pursue strategic objectives in the longer term would seem, incidentally, to benefit more from the cooperation and social capital that is built up than businesses that pursue commercial objectives in the short term. Another important study is that by SQW Consulting of the impact of large-scale research facilities in United Kingdom. SQW concludes that the main non-scientific benefits of a large-scale facility are to be found in the area of interaction between the various parties involved in developing, constructing, and utilising the facility. The search for new technological solutions for constructing facilities brings about the sharing of knowledge and technology between the scientists and industrial suppliers involved. Tacit knowledge is also shared between visiting scientists and the permanent staff of the facility during experiments. For the supply companies, interaction with scientists, technical experts, and users of the facility is extremely important. The social capital that is built up forms a "breeding ground" for innovation. The ultimate impact of innovation is not always clear, however. Amongst other things, it is dependent on the type of tendering process and the arrangements made regarding intellectual property. The main added value for specialised suppliers is probably in the way it boosts their reputation. The markets within which they operate are only small, however, meaning that the ultimate impact on the economy is limited. Indirect indications that social capital is an important added value generated by large-scale facilities can be found in the literature dealing with the "science parks" where various scientific and commercial parties seek proximity to one another so as to boost their innovativeness. Agglomeration effects play an important role in this: the parties can benefit from a shared infrastructure and can easily "find" one another. The nearness of a university is particularly advantageous for businesses at a science park, giving them better access to highly educated potential employees. Students can be seen as important mechanisms for knowledge transfer and for the creation of social networks involving scientists, businesses, and government. Work placements, graduation projects carried out with companies, and recruitment of graduates mean that students act as a kind of "social glue" and they often create long-term links between scientists and businesses.[69] In this way, science parks foster the creation of social capital between universities and businesses. The same story as that regarding science parks also applies in part to

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innovation: A value-chain analysis of supplier contracts with scientific research institutions". *Journal of Business Research*, 56(9), 711–719 (2003).

[67] O. Vuola, O., and A.-P. Hameri, A.-P, "Mutually benefiting joint innovation process between industry and big-science". *Technovation*, 26(1), 3–12 (2006).

[68] E. Autio, A.-P. Hameri, and O. Vuola, "A framework of industrial knowledge spillovers in big-science centers".

[69] B. Bozeman, "Technology transfer and public policy: a review of research and theory". *Research Policy*, 29(4–5), 627–655 (2000).

large-scale research facilities. Large-scale facilities may not generate the same agglomeration effects as science parks, but they can nevertheless act as catalysts for collaboration and knowledge-sharing. Extremely large facilities in fact have the same characteristics as the "anchor tenant" businesses that play a central role at science parks. The similarity is that both are a major force in attracting researchers and other businesses and can create links with various different parties. The specific features of large-scale facilities – state-of-the-art technology, open to external users, a meeting place for many different parties – can reinforce this role.[70] More generally, we can also learn lessons from the literature regarding the role of collaboration in R&D between a number of parties and disciplines. Research facilities would appear to play an important role in this kind of collaboration. The fact that a number of parties are dependent on the same complex facility leads to their becoming dependent on one another, a situation that demands that they collaborate. Although partnerships do not necessarily immediately generate tangible benefits, they nevertheless promote the building up of social capital. A complex network is gradually created of scientists, knowledge institutions, businesses, and other parties that offers participants major benefits in terms of access to knowledge, talent, facilities, and money. The scientific literature asserts that the "technological imperative"[71] of large-scale facilities demands that parties collaborate on R&D, thus facilitating the flow of knowledge into networks.

The lessons regarding the value of social capital would appear to have become solidly embedded in Dutch policy on science and innovation. In recent years, the Dutch government has put a lot of effort into a programmed approach, with promising clusters being chosen (key areas). An important requirement when drawing up this policy was self-organisation and public-private partnerships (or collaboration within the "triple helix"' of knowledge, government, and the commercial sector). The basic principle here is that networking leads to a build-up of social capital and improved knowledge-sharing between the participating parties. In this way, bridges are constructed between knowledge and its application, and valorisation is encouraged. An interim evaluation of the key-areas approach found that in most clusters this social capital is growing.[72]

3.2 The role of large-scale facilities as regards human capital

In science – perhaps more than in other domains – human capital plays an extremely important role. The human capital for researchers consists of their education, scientific and technological knowledge, experiential knowledge, know-how, tacit knowledge, and technical and practical skills. The question is what contribution large-scale research facilities make to building up researchers' human capital.

3.2.1 Large-scale research facilities as magnets for talent

The Innovation Platform's report on large-scale research facilities (2005) argues that such facilities act as magnets for talented researchers.[73] The best and most talented researchers wish to have the best facilities at their disposal because their scientific career or reputation is partly dependent on their having access to such facilities. It is for that reason that large-scale, unique research facilities have a great attraction for researchers ("brain gain"). Conversely, if a country fails to invest in an adequate research infrastructure, that failure may lead to "brain drain"; the best researchers will leave and base themselves at or close to state-of-the-art facilities. There is as yet no scientific literature that can provide empirical substantiation for the Innovation

[70] P. Boekholt. M. Nagle and F. Zuijdam, *Campusvorming. Studie naar de meerwaarde van campussen en de rol van de overheid bij campusvorming* (Amsterdam 2009).

[71] The term is taken from Chompalov, Shrum, and Genuth: I. Chompalov, J. Genuth and W. Shrum, "The organization of scientific collaborations". *Research Policy*, 31(5), 749–767 (2002).

[72] Innovation Platform, *Voortgang Sleutelgebieden en tussentijdse evaluatie van Sleutelgebieden-aanpak* (The Hague 2009).

[73] Innovation Platform, *Kennisambitie & researchinfrastructuur*.

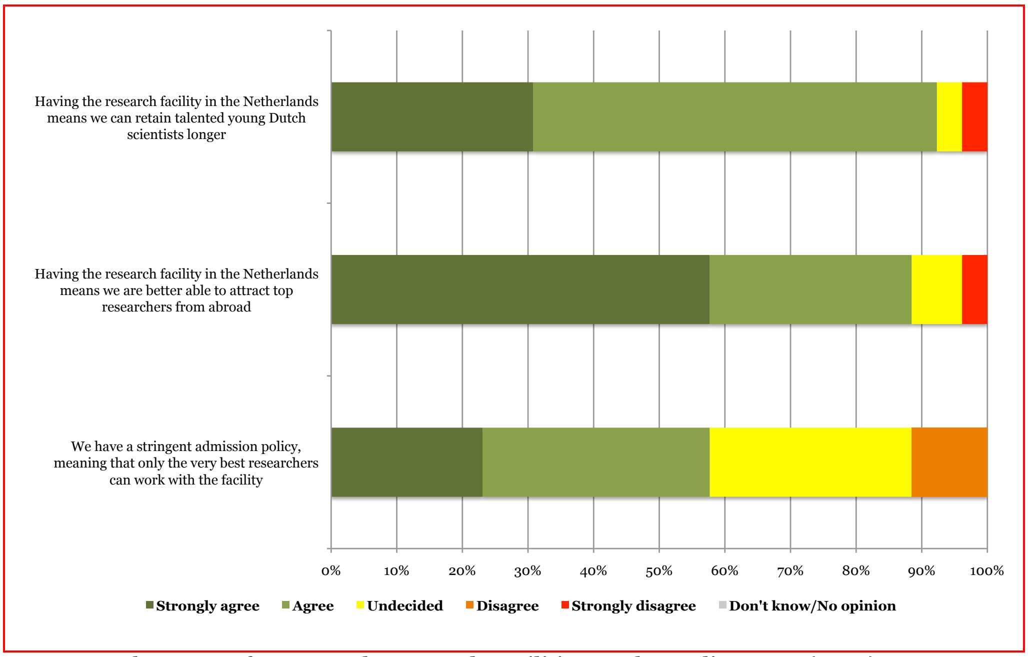
Platform's assertion. There are no studies that have explicitly investigated the attractiveness of large-scale research facilities for the best and most talented researchers. Nevertheless, it is generally asserted that a good research infrastructure is indeed one of the factors that determine researcher mobility. A study by the OECD once more summarises the drivers for mobility: "*Various factors contribute to the flows of the highly skilled. In addition to economic incentives, such as opportunities for better pay and career advancement and access to better research funding, mobile talent also seek higher quality research infrastructure, the opportunity to work with star scientists and more freedom to debate. Less amenable to potential government policy, but still important, are family or personal ties that draw talent to certain locations.*"[74] The quality of the research infrastructure is therefore one of the factors that leads researchers do go to work elsewhere and, as we have already seen, large-scale research facilities are an important element in this. The literature also reveals that social networks play a major role in building up human capital. A study by Berry Bozeman and Vincent Magnematin emphasises that science is not only a cognitive activity but that the dynamism between researchers – the social networks – also plays an extremely important role. This is sometimes referred to as "scientific and technological human capital", which is defined as "the sum total of the scientific and technological knowledge, relevant skills, and social connections and resources of scientists and engineers". In the concept of "scientific and technological knowledge human capital", individual researchers and their social networks play an important role in the circulation and transfer of knowledge: "*These networks integrate and shape scientific work, providing knowledge of scientists' and engineers' work activity, helping with job opportunities and job mobility and providing indications about possible applications for scientific and technical work products*".[75] We have already reached the conclusion in the above that large-scale research facilities are very important as regards the creation of social networks (social capital). We can conclude indirectly from this that large-scale research facilities are important in building up human capital. Many researchers are of the opinion that large-scale research facilities play a major role in attracting and retaining outstanding individuals. Large-scale research centres such as CERN and the Institut Laue-Langevin (ILL) are often cited as examples. An interesting case in this connection is the discovery of graphene by the Nobel Prize-winners Andre Geim and Konstantin Novoselov. Geim spent seven years as a senior lecturer at the High Field Magnet Laboratory (HFML) in Nijmegen, where he still holds a part-time endowed chair. Novoselov was also a researcher at the HFML and he took his PhD in Nijmegen. The HFML was completed in 2003 and is one of the four biggest magnet laboratories in the world. With the HFML, the Netherlands has an internationally renowned laboratory that attracts many foreign researchers who wish to carry out experiments there. The HFML also played an important role in the discovery of graphene. At the Radboud University Nijmegen, they are convinced that the presence of the HFML is a unique facility that has ensured that Geim remains associated with the university. Geim is not in fact the only Nobel Prize-winner who worked at a unique facility. In the field of high magnetic fields, Klaus von Klitzing was awarded the 1985 Nobel Prize in Physics for the work on the quantum Hall effect that he carried out at one of the four high magnetic field laboratories. The same applies to the Nobel Prize awarded to Daniel Tsui and Horst Ludwig Stormer for their discovery of the fractional quantum Hall effect (with Robert Laughlin for the theory).

3.2.2 The propositions in the Web survey

In the Web survey, respondents also commented on propositions regarding the relationship between large-scale research facilities and human capital. Their answers are represented in the figure below.

[74] OECD, The Global Competition for Talent Mobility of the Highly Skilled (2008).
[75] B. Bozeman, B., "Technology transfer and public policy: a review of research and theory".

Figure 2 Effects on human capital of large-scale research facilities (n = 26)



Source: Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).

The great majority of respondents say that large-scale research facilities have a positive effect on scientific talent. According to respondents, large-scale research facilities enable us to retain talented young Dutch scientists longer, and they improve our ability to attract top researchers from abroad. Many large-scale facilities also say that they have a stringent admission policy, meaning that only the very best researchers have access to the facility. This can also contribute to the best researchers wishing to work at such a facility, and it can boost the quality of scientific personnel in the Netherlands.

3.2.3 Large-scale research facilities and capacity building

Large-scale facilities also play a role in training young researchers and technical personnel. Large-scale facilities have research groups that also employ research assistants (AIOs) and supervise final-year students, thus training young researchers. CERN in Geneva, for example, has an extensive range of training programmes for young people. These include work placements, summer schools for students, a graduate engineer training programme, traineeships for graduates, and a junior and senior fellowship programme for PhD students. Six technicians and two administrative workers are also taken on for training each year.[76] The European Molecular Biology Laboratory (EMBL) in Heidelberg also has an extensive training programme, for example an international PhD programme and a programme for postgraduate researchers, but it also attracts students and trainees. The EMBL also has its European Learning Laboratory for the Life Sciences, where enthusiastic scientists teach and assist with programmes of practical training.[77] In Nijmegen, for example, twenty young researchers have taken a PhD at the HFML in recent years, and twenty final-year students have worked there.

The survey of the Netherlands' large-scale research facilities shows that 85% have PhD students on their staff who also actually make use of the facility. An average of 15 PhD

[76] See https://hr-recruit.web.cern.ch/hr-recruit/special/special.asp
[77] See http://www.embl.de/training/index.html

students work at each facility. Respondents also say that the majority (62%) of the facilities offer education and training modules. Some examples are given in the box below.

Box 2 – Examples of education programmes and modules

- Master's degree and PhD programmes and tutorials
- Summer schools
- Workshops, training sessions, and courses
- Lectures and instruction sessions
- Work placement options for senior secondary and higher vocational education, and university education
- Exchange programme with sister organisations

Source: Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).

Training both researchers and personnel has a wide impact. A study of the effects of a supercomputer in the Netherlands finds that training personnel for knowledge institutions and companies is an important strategic effect. On average, computer centres acquire a new supercomputer every five years. From that point on, the "old" supercomputer becomes affordable for other knowledge institutions and is also actually used by them. The staff of the computer centre and the direct users of the old supercomputer are extremely interesting employees for the knowledge institutions where the "old" supercomputer is then utilised. Somewhat later, the supercomputer is also used in the commercial sector. The same principle then applies. The employees that then have a lot of experience with supercomputers are very interesting for the commercial sector.[78] There is therefore a kind of cycle in which personnel are trained at the facility and find their way to other knowledge institutions and the commercial sector. This shows that large-scale research facilities make an important contribution to training young people and in education. This involves training both young researchers and technical personnel. Naturally, many other university groups and research institutes also train young people and provide teaching. The difference with large-scale facilities is to be found mainly in the quality of the training provided. Young people are enabled to carry out pioneering research with state-of-the-art equipment and sometimes even with unique facilities. Final-year students and research assistants at a large-scale research facility therefore have a head start on other young researchers. Another major difference is that large-scale facilities also train high-quality support staff, for example technicians and ICT professionals. Training involves more than just scientific research. Another important point is that large-scale research facilities can contribute to capacity building, a term that refers to support for education and training and the development of a knowledge infrastructure in less developed countries. Where large-scale research facilities are concerned, the term "cohesion factor" is also used. The literature refers to the cohesion factor as one of the possible socio-economic impacts. For the cohesion factor, providing international access to facilities and creating local networks of facilities is an important element. The thinking here is that giving remote access (via electronic links) to researchers in countries with facilities of less high quality (for example new EU Member States or developing countries) will enable them to carry out high-quality research from their own location.[79] The evaluation of "Research Infrastructures" in the Sixth Framework Programme (FP6) found no clear evidence of an increase in remote

[78] Ecorys, Economische effecten van de vestiging van een supernode in Nederland (2009).
[79] Remote access is provided, for example, to ESRF and ANTARES.

use of facilities, but European projects such as the EGEE have nevertheless helped to improve standardisation of protocols for the exchange of data between countries.[80]

A second element in the cohesion factor consists of the learning effects that arise within international consortia. One of the case studies carried out for the European Commission in the context of measuring the effects of the "Research Infrastructures" section of FP6 concerned the Géant network.[81] Within this large-scale e-infrastructure, the cohesion effect is to be found in the fact that the more advanced countries – for example the Netherlands with SURFnet – that already had fast data networks for universities and research centres have passed on a great deal of knowledge to other European countries about setting up and managing such networks from the technical point of view. That knowledge also has a wider spin-off because this e-infrastructure forms the backbone of numerous other decentralised infrastructures such as biobanks and collections. A final effect is to be found in the upgrading of the research infrastructure itself. The evaluation of the research infrastructures in the context of FP6 found indications in the case of a small number of European projects of a clear improvement in the quality of research facilities in the new Member States thanks to their participation in European initiatives. The study expects that in future half the projects within FP6 will help improve the quality of the research facilities in the new Member States.[82] Improving or setting up research facilities in less developed areas is nowadays one of the most important features of the European Structural Funds. From 2000 to 2006, 29% (EUR 2.8 billion) of all the structural funds aimed at promoting innovation was invested in research facilities. A similar level of investment is expected for the period from 2007 to 2013.[83] One good example is the Global Diversity Information Facility (GBIF). With a view to disseminating knowledge and learning effects, GBIF has set up a special monitoring programme. The aim of the GBIF is to digitise data and collections concerning biodiversity and thus to make them available to research facilities ("nodes") in the partner countries. Since 2003, GBIF has financed nine mentoring projects in which a local facility (or node) has helped another country to improve or set up its own node. One of the mentoring projects involved two European countries; in the others, the object of the mentoring was a developing country. In 2005, Spain assisted in setting up a GBIF node in Portugal by means of online assistance, workshops, and site visits. This led to specific action plans for setting up a GBIF node in Portugal and making the participating universities more aware of the possibilities regarding digitising collections.[84]

3.3 Summary of networking and human capital

To summarise briefly, the added value of networking and human capital involves the following elements:

- Formal and informal social networks, and the shared values and mutual trust that are built up within them ("social capital") are an important mechanism for large-scale research facilities to have an impact on science, the economy, and society in general.
- The social capital that is built up facilitates and catalyses learning processes and knowledge-sharing between the parties concerned.
    - it increases the quantity and diversity of knowledge;

[80] Matrix and Rambøl, Community Support for Research Infrastructures in the Sixth Framework Programme, Evaluation of pertinence and impact, European Commission, Brussels (2009).
[81] Technopolis and Interface, Evaluating the Pertinence and Impacts of EU support to Research Infrastructures, Final Report for DG Research and DG INFSO, Amsterdam (2006).
[82] Matrix and Rambøl, Community Support for Research Infrastructures in the Sixth Framework Programme, Evaluation of pertinence and impact, European Commission, Brussels (2009).
[83] Technopolis, L. Rivera and R. Miedzinski, Cohesion Policy and Regional Research and Innovation Potential, An analysis of the effects of Structural Funds support for Research Technological Development and Innovation 2000–2010 (Brussels 2010).
[84] http://www.gbif.org/participation/participant-nodes/mentoring/

    - it increases the volume of knowledge-sharing between the parties concerned;
    - it increases the efficiency of knowledge transfer.

- Social networks play an important role in building up human capital. Large-scale research facilities therefore contribute to human capital via social capital.
- There is no empirical evidence that large-scale facilities attract talented individuals; at most, a good research infrastructure is *one* of the factors that determine researcher mobility.
- Large-scale research facilities play an important role in capacity building. A lot of facilities play a role in training young researchers and technical personnel. The added value is to be found mainly in the quality of the training provided.
- Providing access to large-scale facilities helps less developed countries: access to state-of-the-art facilities, learning effects, and the upgrading of these countries' own research infrastructure are important impacts.

4. Added value from the economic perspective

This section deals in greater detail with the added value of large-scale research facilities from the economic perspective. We distinguish between direct and indirect economic added value and the effect of large-scale research facilities on economic innovation.

4.1 Economic added value

One important effect of large-scale research facilities is their economic added value, by which we mean the economic effects that they generate. The economic effects of such facilities are varied; we will explain the various effects below.

4.1.1 Generation of economic activity

The economic value of large-scale research facilities can be linked in the first instance to the economic activities that take place in the context of developing them – building, construction – and the purchase of related goods and services. The construction and development of large-scale research facilities generally demands major investment. That investment flows to a very considerable extent to private parties. Investment in large-scale research facilities therefore constitutes a major boost for the companies involved in developing those facilities. The market for tenders for the construction and development of large-scale research facilities is considerable. In United Kingdom, for example, the government has invested more than GBP 1 billion in the construction of such facilities in recent years.[85] In the EU's Seventh Framework Programme, the budget for research infrastructure has more than doubled, to in excess of EUR 1.7 billion.[86] The value for the whole European market for contracting for the development of large-scale research facilities is estimated at more than EUR 2 billion a year.[87] In the Netherlands, relatively little in the way of systematic funding is available for large-scale research facilities, although since 2008 the Netherlands Organisation for Scientific Research (NWO) has in fact reserved a budget. The Ministry of Education, Culture and Science has added an earmarked amount rising to EUR 20 million to the NWO budget. There is also investment on an ad hoc basis. In 2006, there was a grants round via the NWO amounting to EUR 100 million for large-scale research facilities. There is also investment in such facilities via other funding channels, for example the Economic Structure Enhancing Fund (FES), the Decree Regarding Subsidies for Investment in the Knowledge Infrastructure (BSIK), the Netherlands Genomics Initiative (NGI), and the Smart Mix subsidy programme. In 2007, EUR 35 million of FES funds was made available for large-scale research facilities, with the figure in 2009 being EUR 169 million.[88] The average cost of developing the large-scale facilities that participated in the survey came to M€ 36.7 per facility. That represents the average of a broad series, with peaks running up to M€ 150. The operating costs for the facilities are even more variable, with the lowest being given as EUR 2000 a year and the highest EUR 15 million a year. The average for this series was EUR 3,916,000 a year. The greater part of these operating costs are personnel costs (53%), while the rest is more or less equally divided across the other cost items such as energy, raw materials, ICT/software, interest and maintenance.[89]

85 House of Commons, Committee of Public Accounts, Big Science: Public investment in large scientific facilities. Sixtieth Report of Session 2006 – 07, October 2007.

86 European Court of Auditors, The Effectiveness of the design studies and construction of new infrastructures support scheme under the 6th Framework Programme, Brussels 2010.

87 European Commission, Third European Report on S&T-indicators, 2003.

88 Interim recommendations by Taskforce to Promote Large-Scale Research Facilities, February 2011.

89 Web Survey of Large-Scale Research Facilities, Technopolis Group, 2010.

Studies show that a major proportion of the investment involved benefits the local (and/or national) economy.[90] Contracts for developing a facility or providing specific products and services are more frequently awarded to local and national companies and less frequently, relatively speaking, to foreign parties. There are various reasons why local or national companies have a greater chance of winning the contract. In the first place, this is because they can generally offer the necessary products and services at a lower price. One major competitive advantage lies in the fact that they need to invoice lower costs for transporting goods, particularly where large or heavy components are concerned. Secondly, it seems reasonable to make use of local companies for maintenance or for other matters that demand constant attention. Thirdly, people's physical proximity is important. The work of developing a large-scale facility is often highly complex, often involving unique, specialised assignments with extremely detailed technical specifications. This means that close contact is necessary between the supplier and the facility. Access is easier for local suppliers and they can communicate more effectively than foreign companies. The conclusion is therefore that establishing a large-scale facility in a country is beneficial for the local and national economy. When a facility is financed by several countries, there is generally no precondition as regards the "fair return" principle for the procurement of goods and services. A major proportion of the investment involved benefits the local and national economy. In other words, the "earn-back" effects of a large-scale facility are in general greater than the amounts that the country concerned invests in the facility.[91]

The Web survey shows that where the Dutch facilities are concerned, the regional component is not very strong. A limited proportion (22%) of the suppliers and service providers used by the research facilities come from the region concerned. However, the overwhelming portion of the contracting is in the Netherlands itself: 64% is in the Netherlands itself and 36% elsewhere. The fact that the Netherlands is such a small country may explain why the regional component is smaller. The survey does confirm, however, that the majority of the relevant contracting is in the Netherlands itself.[92]

One example of such "earn-back" effects can be found in the case of the European Space Research and Technology Centre (ESTEC) in Noordwijk. The Netherlands invests in ESTEC together with other European countries; the Dutch contribution rose from M€ 67 in 1994 to M€ 88 in 2004. A major proportion of ESTEC's expenditure involves contracts in the Netherlands, and that expenditure increased considerably in the period referred to, from M€ 221 in 1994 to M€ 284 in 2004, an increase of 29%. If one compares the amount that the country invested in ESTEC with ESTEC's expenditure here, the conclusion is that that investment has been profitable: for every euro that the Netherlands invests in ESTEC, some 3.3 euros is contracted for here.[93]

It should be noted in this connection, however, that the beneficial effect on the domestic market concerns primarily "low-tech" products and services. When the products and services are more specialised and "high tech", the relevant contracts are more frequently awarded to foreign companies. Extremely high-value or specialised products and know-how are not always available in a given region or country. The facility concerned then needs to procure those products and services elsewhere, with their availability and quality then being decisive. Conversely, local or national companies that can offer the specific know-how or products concerned may also be invited to carry out work abroad. The companies that worked on the development of the Synchrotron Radiation Source in Daresbury (UK) built up specific know-how and expertise by doing so. In recent years, new synchrotrons have been constructed throughout the world, meaning that a market has been created, as it were, for companies that wish to tender for the work involved. Based on their specific know-

90 SQW Consulting, Review of the economic impacts relating to the location of large-scale science facilities in the UK (July 2008).

91 Ibid.

92 Web Survey of Large-Scale Research Facilities, Technopolis Group, 2010.

93 Triarii, ESTEC's value to the Netherlands, June 2005.

how and expertise, the local companies have been awarded a number of contracts abroad.[94] The contributions made by the Dutch high-tech industry and SMEs to the development of CERN and a number of aerospace projects (ESA) also put them in a good position to acquire orders for constructing the nuclear fusion reactor (ITER) in France. In the past few years, Dutch companies have been awarded direct contracts for ITER amounting to EUR 180 million, with some EUR 500 million in the form of spin-off orders.[95]

4.1.2 Employment

The economic activity involved in developing and using large-scale research facilities also creates employment. A distinction needs to be made, however, between temporary effects and long-term effects. The temporary effects involve jobs created as a result of the construction and development of a large-scale research facility. The actual number of jobs naturally depends on the size of the assignment concerned. Development of the Large Hadron Collider at CERN, for example, took eight years, with a budget of EUR 6 billion. In terms of employment, it involved more than 100,000 man-years of work. Building a new building for a supernode in the Netherlands will take 270 man-years, assuming a budget of EUR 45 million. Supplies to the construction companies involved will account for an additional 250 man-years. The total amount of work involved will therefore be more than 500 man-years.[96] If we include the figures from the survey, it becomes apparent that the average cost of developing a facility is almost EUR 37 million. This represents several hundred man-years of work. We already saw above that a major proportion of the investment involved in developing a large-scale research facility benefits the local or national economy. It follows that most of the jobs created are within the region or the country concerned. Some jobs are also created elsewhere, mainly involving specialised know-how or the supply of state-of-the-art equipment. It is not possible, for example, to call in Dutch companies to provide the hardware for a supernode in the Netherlands; the only companies involved in high-performance computing are foreign ones, such as IBM, Cray, Hewlett-Packard, Bull, and SGI. It will therefore be one of these foreign companies that supplies the hardware, meaning that the jobs resulting from installation of the supercomputer will not be created in the Netherlands. Besides temporary effects on employment, there are also more permanent effects, in the first instance the jobs created for the personnel who staff the facility. Using the facility requires personnel, both scientists and support staff (from ICT and technical maintenance to security). A study of the potential effects of the European Spallation Source (ESS) in Lund (Sweden) suggests that the presence of the facility will generate some 700 additional jobs annually (i.e. compared to the situation if the facility is not built). Over the next 25 years, this would mean some 25,000 additional jobs.[97] It is hardly possible, however, to find any empirical support for these conclusions in the study, and the conclusions are in fact based on a whole range of assumptions. A British study shows that a significant proportion of the staff of a facility are recruited within the region concerned. This applies not only to the scientists but also to many other jobs.[98] Secondly, long-term employment is generated with companies supplying materials and services for the facility, for example energy, water, raw materials, or ICT services. Calculations for the Dutch supernode suggest that between 10 and 25 additional full-time jobs will be created with the suppliers of energy and raw materials. A maximum of 40 full-time jobs will be created at companies that develop specific software for the supercomputer.[99] The survey shows that the average annual operating costs per facility amount to almost EUR 4 million. It is difficult to say

[94] See report by SQW Consulting 2008.
[95] See, for example, http://www.iter-nl.nl/nl/bedrijven.
[96] Ecorys, Economische effecten van de vestiging van een supernode in Nederland.
[97] C. Lindström et al., The ESS in Lund – its effects on regional development (2009).
[98] See report by SQW Consulting 2008.
[99] See report by Ecorys 2009.

precisely how many full-time jobs this involves, but what is certain is that it generates jobs at supply firms. Finally, jobs can be created due to "second-order effects". These include such things as the extra jobs created as a result of expenditure by the personnel and users of the facility (for example on homes, consumer goods, hotels, etc.). A study of the impact of the ESS in Lund surveyed the potential agglomeration effects. These involve, for example, more than 500 additional homes per year, 7000 m^2 of office space annually, substantial investment in improving public transport, and an increase in gross national product (GNP) of 0.08% (in total, an increase of EUR 214 billion over 25 years). The second-order effects can also involve companies establishing themselves close to the facility (thus improving the climate for attracting enterprises). The Delft firm of Science & Technology BV, for example, has opened a branch in Assen so as to be close to the LOFAR project. Science & Technology BV develops software and algorithms for accessing, analysing, and visualising scientific data. Such products are of great importance to the LOFAR project because of the enormous quantities of data that the project will generate and that need to be analysed and processed. In order to position itself effectively, Science & Technology BV therefore decided to open a branch close to LOFAR. A report on the economic impact of Cambridge University in the UK has calculated, for example, that some 12,000 people work at the university but that Cambridge as a whole represents some 150,000 jobs. In the immediate vicinity, Cambridge is said to account for some 77,000 jobs.[100] A report on the economic impact of Stanford University calculates that the university contributes EUR 1.2 billion to the local economy via its employees, students, visitors, businesses, and other university organisations.[101] Nevertheless, it is difficult to quantify these indirect effects, and no generally valid pronouncements can be made in this regard. More generally, the establishment of a large-scale facility can contribute to the further development of a region or a technology cluster. A large-scale research facility can attract other investment; this process is sometimes referred to as one of "path-shaping investment".[102] An example is the development of the Grenoble region. In 1967, Grenoble was selected as the location for the Institut Laue-Langevin (ILL), a large-scale neutron facility. The main reason for choosing Grenoble was the cheap electricity generated with hydroelectric installations in the mountains surrounding the city. The presence of the ILL later led to the European Synchotron Radiation Facility (ESRF) also being developed in the region and to the establishment of part of the European Molecular Biology Laboratory (EMBL). The presence of these leading facilities has brought about enormous development in the Grenoble region, which is now often referred to as Europe's "Silicon Valley".

4.1.3 Spin-offs and joint ventures

One final form of economic added value that is created takes the form of the spin-offs that are set up around a large-scale research facility. These are based on the knowledge generated with the aid of the facility or the knowledge generated in developing and running it. The spin-off brings this knowledge onto the market (in other words "valorises" it). The small companies that are set up generate turnover and jobs. The knowledge generated by the facility can also be marketed otherwise than by spin-offs, for example by the issuing of licences or through joint ventures with existing companies. The Web survey took stock of the spin-offs associated with the large-scale facilities in the Netherlands. At 25% of the facilities, spin-offs have been created on the basis of the knowledge and know-how regarding technical support and management for the facility; at 47% of the facilities, the spin-offs are based on the scientific

[100] Library House, The Impact of the University of Cambridge on the UK Economy and Society (2006).

[101] Public Partners Consulting Group, Stanford University Economic Impact Study 2008 (2008). This is a study of the regional impact of Stanford University, including the Stanford Linear Accelerator Center (SLAC), a large-scale research facility.

[102] O. Hollesten, M. Benner and G. Holmberg, Impacts of Large-scale Research Facilities – a socio-economic analysis (2004).

knowledge and know-how. The first of these categories comprises an average of 2.1 spin-offs per facility and the second 5.7.[103]

The European Space Agency (ESA) decided in 2003 to set up "Business Incubation Centres" (BICs), with a view to facilitating technology transfer from the Agency and developing new economic activity. Within 5 years, 58 new small businesses had been set up. Of those, 5 have since closed down again, but the rest are still operational. The success rate is therefore almost 92%. Of the 53 successful businesses, 14 have been taken over by a large company and 39 are still independent. The total turnover of the 39 independent businesses amounts to about EUR 13 million, and they provide 225 full-time jobs, i.e. 5 full-time jobs per business. By far the largest number of new businesses were set up in the Netherlands, no fewer than 21 of the 58.[104] The CERN research centre also has an active policy as regards technology transfer. A large number of researchers working at CERN carry out experiments with the particle accelerator. These can generate knowledge that can be marketed (valorised). In 2000, CERN began actively promoting valorisation of its research results. This can also involve knowledge and know-how used to develop and manage the LHC. A list of successful examples is given on the CERN website.[105] One of these is the firm of MetroLab, a world leader in precision teslameters. Amongst other things, these instruments are used by Magnetic Resonance Imaging (MRI) equipment, for example General Electric, Philips, and Siemens. EMBL also has its own Technology Transfer Office (TTO), EMBLEM. Technology transfer has led to a number of spin-offs.[106]

The Netherlands Institute for Radio Astronomy (ASTRON), the initiator of the LOFAR project, has set up a separate holding company, AstroTec Holding BV, to valorise the knowledge generated. The holding company focuses not so much on facilitating spin-offs as on licensing and joint ventures. This allows the technology developed at ASTRON to be valorised. ASTRON has taken a share, for example, in DySi, a Dutch data management company. AstroTec sees opportunities in the link with technologies developed within the LOFAR project for designing and managing intelligent sensor systems.[107]

4.2 Economic innovation

Besides the direct and indirect added value that large-scale facilities generate, they also contribute to economic innovation. That contribution can take two different forms, the first being that businesses make use of the research facilities themselves and the second being the innovation resulting from innovative contracting. We will deal with these two types below.

4.2.1 Use of the facilities by industry

Large-scale research facilities are an important means of pushing back the boundaries of science and technology. Pioneering research carried out with such facilities can make a major contribution to economic innovation. The knowledge generated can be used by the commercial sector to develop new products, services, and processes. Just like scientists, businesses seek an environment in which they can develop new technologies and where they can test things and validate them. A large-scale research facility can provide businesses with such an environment; it constitutes a "learning environment that helps firms in dealing with technological complexities and lowers

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[103] Web Survey of Large-Scale Research Facilities, Technopolis Group, 2010.
[104] ESA, *ESA Business Incubation Centres Alumni Report 2009* (April 2010).
[105] Http://technologytransfer.web.cern.ch/technologytransfer/en/Successful_Transfers/Successful_Transfers.html
[106] http://www.embl-em.de/
[107] See http://www.astrotec.nl

the uncertainty and costs of research and development".[108] Large-scale research facilities can be a valuable addition for the commercial sector; they can generate knowledge that a company cannot generate for itself or acquire via its existing network. Many companies are not in a position to invest independently in large-scale research facilities and are reliant on a publicly financed infrastructure if they wish to utilise them.[109] It was already argued in Section 3 that large-scale research facilities play an important role as regards the creation of various types of networks (social capital). The same applies to public-private partnerships. Large-scale research facilities would appear not only to be a key factor in the creation of scientific networks but also important as regards co-operation between science and the commercial sector. Studies show that industrial users in fact make relatively little use of large-scale research facilities. These facilities are largely accessed via or in collaboration with public knowledge institutions. The knowledge and experience of knowledge institutions is used in order to utilise the options offered by a large-scale facility in an efficient manner.[110] The response to the Web survey indicates that large-scale facilities are indeed a vehicle for public-private co-operation. Almost two thirds of the facilities cooperate with the commercial sector and the commercial sector also makes use of the facility. Some 16% of the research time at the facility is used by the commercial sector, and a wide variety of businesses also make use of the facility. The average number of businesses utilising each facility is 69, mostly major multinationals such as Philips, DSM, Shell, and MSD.[111] Large-scale research facilities can be a breeding ground for innovations in the commercial sector. Evaluation of the ICES-KIS2 projects (Interdepartmental Committee for Economic Structure Enhancement/Knowledge Infrastructure Working Party)[112] showed that it was particularly investment in large-scale research facilities – more than in projects for applied research – that contributed to reinforcing the economic structure. The facilities would seem to act as a driver for economic innovation. The ICT cluster in Watergraafsmeer, for example, is used by Unilever to develop a "bitter base". Linking a number of different ICT applications has created a tool with which the organisation can determine how bitter a given new product will be. For Unilever, this is an important application in the field of "food informatics". Another example is the development of all kinds of applications with the aid of the first SURF network. The SURF network is used by the industrial partners as a testbed for potential new applications, for example the provision of content via broadband. The fast network was necessary to be able to develop new products and services. The network has enabled participating companies such as IBM and Vodafone to bring products onto the market faster and to develop them more effectively from the technological point of view. The network has thus given them a decisive competitive edge. In the pharmaceutical industry, biobanks are playing an increasingly important role. This has to do with the rise of "translational research", in which there is a greater emphasis on the relationship between the laboratory and clinical practice. In translational research, individual genetic variation and biomarkers play a major role. The idea is that this contributes to better patient care, improves the development of drugs, and increases their efficiency and effectiveness. Ultimately, this leads to personalised medicine, with treatment no longer being on a "one-size-fits-all" basis but "tailor-made", depending on the molecular and genetic profile of the individual patient. For some cancer patients, such "personalised medicine" is already a reality,

[108] I.H. Lee and R. Mason, R. "Uncertainty, co-ordination and path dependence". Journal of Economic Theory, 138(1), 262–287 (2008) and Meijer, I. S. M., Hekkert, M. P., and Koppenjan, J. F. M., "The influence of perceived uncertainty on entrepreneurial action in emerging renewable energy technology; biomass gasification projects in the Netherlands". Energy Policy, 35(11), 5836–5854 (2007).

[109] E. Autio, A.-P. Hameri, and O. Vuola, "A framework of industrial knowledge spillovers in big-science centers". Research Policy, 33(1), 107–126 (2004).

[110] SQW Consulting, Review of the economic impacts relating to the location of large-scale science facilities in the UK (July 2008).

[111] Web Survey of Large-Scale Research Facilities, Technopolis Group, 2010.

[112] ICES-KIS-2 was an investment programme by the Dutch government to reinforce both the knowledge infrastructure and the economic infrastructure.

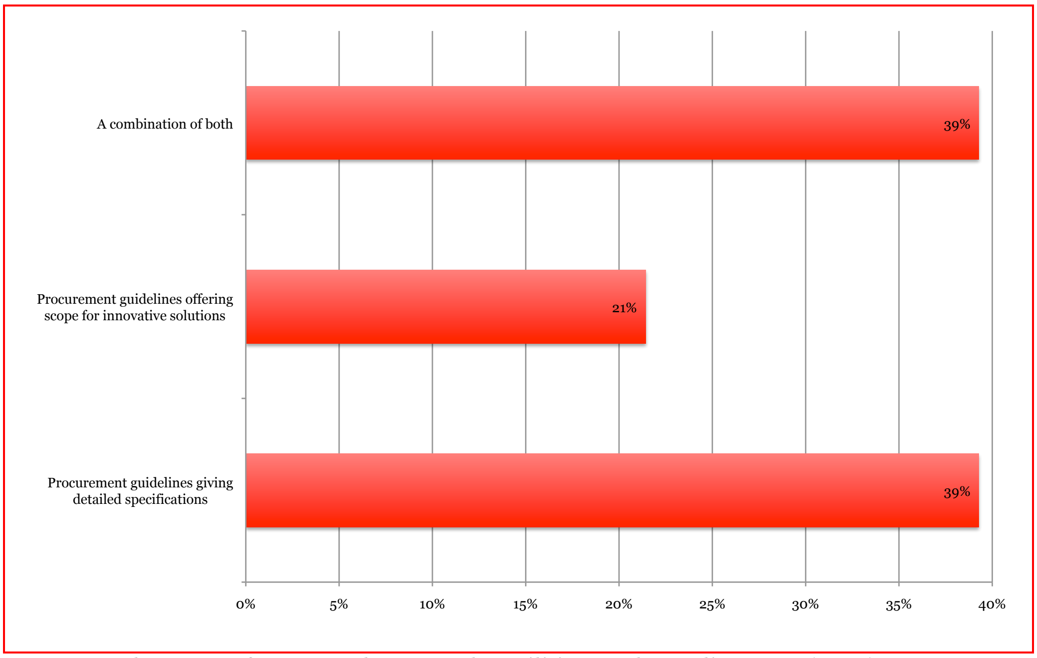
for example in the form of the leukaemia drug Gleevec or Herceptin, which is used to treat breast cancer. This is a very important development for pharmaceutical companies. After all, the further development of such targeted and effective products requires the availability of significant quantities of high-quality bio-specimens in biobanks. The development of the next generation of drugs is making the industry increasingly dependent on access to the material held in these biobanks.

One final example is to be found in the way that ASTRON collaborates with businesses. The organisation has carried out measurements for the further development of Wireless Local Area Network (WLAN), which are used to a very great extent in creating wireless Internet connections. ASTRON's measurements contribute to optimising WLANs and thus to their further commercial application.

4.2.2 Innovation through tendering

It is not only the use of large-scale research institutions that can drive innovation in the commercial sector but definitely also their construction and development. In the course of constructing and developing the facility, it is often necessary to come up with new technical solutions. Suppliers cannot provide these "off the shelf" but must develop new and innovative products. Large-scale research facilities therefore act as "launching customers" for innovative products and services provided by the commercial sector. These can then also be sold to other customers or in other markets. In some cases, large-scale research facilities actively support their suppliers in developing new products, for example by carrying out tests or themselves performing targeted research. National or international consortia are also sometimes created to develop such facilities so as to bring together the maximum amount of high-quality knowledge and know-how. This is often done when extremely stringent or specialised requirements apply to components.[113]

Figure 3 Contracting for large-scale research facilities (n = 28)



Source: Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).

[113] E. Autio, A.-P. Hameri, and O. Vuola, "A framework of industrial knowledge spillovers in big-science centers".

Large-scale research facilities do not always act as a launching customer. Suppliers may be requested to provide standard products and services that need to be produced according to highly detailed specifications. Large-scale facilities only play that role if the contracting procedure is a modernising or innovative one. The key feature of this type of contracting is that the facility involves the supplier in the assignment, thus creating a different relationship between client and contractor. The facility does not specify the assignment in detail but provides scope for the supplier's own contribution. The supplier must be challenged to come up with new and innovative solutions.

The Web survey of Dutch facilities shows a mixed picture in this regard (see the figure above). Some of the facilities (39%) use a set of procurement guidelines giving detailed specifications, 21% offer scope for innovative contracting procedures, and 39% make use of both methods.[114]

One example of how the method of contracting has brought about innovation in industry is the HFML. Construction of this facility involved a number of technical contractors and some unique knowledge and expertise was assembled. The power source for the HFML, which is technically extremely complex, was constructed by the Dutch firm of Imtech Vonk. The work that this firm carried out for the HFML serves as a showcase to bring in new assignments. As a result, Imtech has been awarded a number of new contracts, for example by the Hahn Meitner Institute in Germany. The same applies to the HFML's cooling system. This is unique because the cooling requirement changes very rapidly. The equipment was designed by Royal Haskoning and built by Wolter and Dros. Both companies use the HFML as a way of showcasing their technical ability in the field of high-tech projects. The second example is the GigaPort project, whose aim was to develop the next generation of infrastructure in the field of data communication. A European tendering procedure led to the contract being awarded to British Telecom and Cisco. The innovative method of tendering involved the two contractors themselves investing heavily in the applications for the network. Cisco, for example, developed entirely new routers for this network and was then able to sell this state-of-the-art technology to other customers.[115]

The ITER nuclear fusion reactor also plays a major role for Dutch industry. Dutch companies provide high-quality technology, often through partnerships with other Dutch and international companies. The total size of the orders comes to some EUR 60 million, with some M€ 120 being expected in the period ahead. These orders include numerous "incubator projects" involving the development of new technology. The contribution to ITER has also led to new contracts in the energy and aerospace markets totalling some M€ 10. All those involved therefore see their participation in ITER as a great success.[116] Just like ITER, CERN's LHC generates a great deal of new technology that the companies involved can also market elsewhere. Innovative contracting is therefore a powerful mechanism.[117] One example of successful innovative contracting is the non-magnetic steel produced by the firm of BÖHLER. This was needed so as to apply extremely low temperatures (4.2 Kelvin) in the synchrotron installation. The application that BÖHLER developed for the LHC is now also used in other fields, for example the energy and petrochemicals sectors.[118]

The benefits to companies of participating in an innovative international tendering procedure are varied. Specifically, they include:

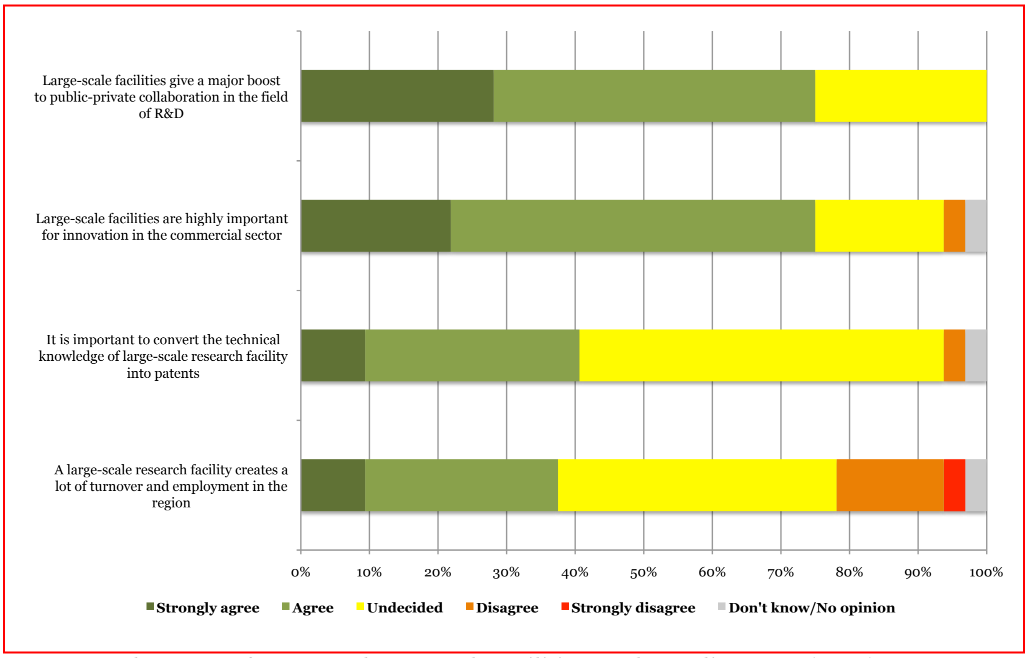
- A better competitive position internationally due to the improved technical and organisational standard within the companies concerned.

[114] Web Survey of Large-Scale Research Facilities, Technopolis Group, 2010.
[115] P. Boekholt, J. Deuten, M. Nagle and F. Zuijdam, Tussen impuls en continuïteit. Evaluatie ICES/KIS-2 (2008).
[116] See report on ITER's Industry Day, October 2008 and FOM, NRG and TNO, ITER NL-2. Innovation for and by ITER (2009).
[117] See http://www.cern.ch/technologytransfer.
[118] CERN, CERN technology transfer to industry and society (2005).

- A better competitive position due to combining specific high-quality knowledge and technology in focus areas (companies often collaborate within consortia);
- A better competitive position because of the incentive to make better use of knowledge and innovative entrepreneurship.
- Strengthening of the company because of tapping into new growth markets.

In the course of the Web survey, large-scale research facilities were asked to respond to a number of propositions concerning the economic effects of those facilities. The results are shown in the graph below.

Figure 4 Economic effects of large-scale research facilities (n = 32)



Source: Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).

Respondents say that the research facilities mainly have a positive effect on public-private collaboration and on innovation in general. Output from knowledge generation in the form of patents is considered to be less important. The majority of respondents adopt a neutral position as regards the proposition that it is important to convert knowledge into patents. The majority of respondents also do not support the proposition that the research facility creates a great deal of regional turnover and employment. This is in line with previous findings that what is involved in the Netherlands is mainly the national scale. In the course of the survey, we also asked the facilities about actual innovations that had been created with the aid of large-scale facilities and that had been successfully marketed. The box below summarises a number of examples.

Box 3 – Examples of successful innovation in the commercial sector

- The development of commercial gas sensors to monitor fruit and vegetables during transport and storage so as to maintain product quality and prevent nutritional loss.
- The development of "Desdemona Look-a-Likes" (movement simulation) and the sale of these in the United States and South Africa).
- In collaboration with instrument developers, lab-on-a-chip methods and protocols were developed and marketed commercially.
- Development of workflow mass digitisation for printed material, particularly for newspapers.
- Product innovation on the basis of the relationship between the pre-processing, structure, composition, and fluid migration in specific foodstuffs.
- Development and marketing of a recombinant Hepatitis B vaccine.

Source: Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).

4.3 Summary of added value from the economic perspective

The economic added value of large-scale research facilities can be summarised as follows:

- The development (i.e. building, construction) of large-scale research facilities and the procurement of related goods and services generates economic activity. This often involves large sums that benefit the local economy to a considerable extent.
- The use of a large-scale research facility also generates employment:
    - Temporary employment: jobs created as a result of the construction and development of the facility;
    - Long-term employment: the personnel who work at the facility and jobs with the companies supplying materials and services for the facility.
- Economic added value can also be created by the spin-offs that are set up around a large-scale research facility based on the knowledge generated by or with the aid of the facility.
- Large-scale facilities also contribute to economic innovation: they can generate knowledge that a company cannot develop or acquire for itself. Studies show that industrial users in fact make relatively little use of large-scale research facilities.
- It is not only the use of large-scale research institutions that can drive innovation in the commercial sector but also their construction and development. They therefore act as "launching customers" for innovative products and services provided by the commercial sector. This is only the case if the relevant contracts are the subject of innovative contracting.

5. Added value for society

In addition to their economic added value, large-scale research facilities also produce added value for society. In this section, we distinguish between three different types: instruments that have a social mission (focusing on research on issues that are of concern to society), facilities that contribute to social innovation, and the role that large-scale facilities play as regards informing and educating the wider public.

5.1 Tools for research on social issues

The primary purpose of research facilities is to carry out scientific research. There are numerous large-scale facilities, however, that have a social mission, in the sense that the research carried out with the aid of these facilities increases our knowledge and understanding of the problems facing society. The research results generated are ultimately intended to contribute to solving those problems (or "Grand Challenges" as the EU refers to them). In other words, the knowledge developed is not a goal in itself but is a contribution to solving various social problems. Large-scale research facilities add value because the necessary data can only be acquired via such a facility or because it can be collected far more efficiently (see also Section 2). The Web survey investigated the various missions of the Dutch facilities. Almost half (46%) say that their mission is a purely scientific one; the rest combine a scientific with a social mission.[119] There are many examples, both in the Netherlands and elsewhere, of research facilities with a social mission. In medicine, the link between research and clinical practice is very strong, and the same goes for large-scale research facilities in the medical field. The infrastructure of connected biobanks, BBMRI, has a clear social mission. The idea is that investing in a biomedical infrastructure of this kind can generate knowledge that ultimately results in improved health for the individual citizen and improved public health in general. The BBMRI can, for example, contribute to a switch from late diagnosis and therapy to early diagnosis and prevention. The enormous quantity of data available makes it possible, for example, to carry out genetic analysis and to identify the pre-symptomatic symptoms of a given disease. This then makes it possible to take action when the disease is still at an early stage and to develop a targeted prevention strategy. Another example in the medical field is ECRIN, a pan-European infrastructure for clinical trials and biotherapy. The development and validation of new therapies and drugs requires access to very large numbers of patients. ECRIN was set up in order to prevent fragmentation between clinical research and clinical trial units. By setting up a network and ensuring co-operation and coordination on a European scale, this ultimately creates a "one-stop shop" for researchers and companies. Besides integrating research and facilities within a pan-European structure, the facility is also intended to ensure continuing professional development, including by means of support and training. All this is intended to result in a sustainable international infrastructure.[120]

In the earth sciences and life sciences too, there are various facilities that focus on social issues such as sustainability, climate, and biodiversity. Life Watch brings together various elements of the research that is being done on biodiversity. This involves specifically facilities for collecting data, a network of observatories, software to integrate and analyse data, and virtual laboratories for developing models. The rationale behind Life Watch is that – despite all the research that has been done – we still know very little about the biodiversity of the world in which we live. Integrating different facilities can create a more comprehensive understanding of the life within various ecosystems and enables knowledge to be gathered in a much more efficient manner. In this kind of research, speed is a good thing in itself because biodiversity is

[119] Web Survey of Large-Scale Research Facilities, Technopolis Group, 2010.
[120] http://www.ecrin.org.

subject to constant change.[121] Another example is the Integrated Carbon Observation System (ICOS), a facility that integrates the various different systems for monitoring greenhouse gases such as CO_2 (carbon dioxide), CH_4 (methane), and NO_2 (nitrogen dioxide). The ultimate aim of the project is to achieve greater understanding of the cycle of the presence of greenhouse gases and to be able to forecast future emissions of those gases. This knowledge is essential in order to be able to take decisions regarding climate change and the role that greenhouse gases play in it.[122] The social sciences and humanities also have a number of large-scale research facilities with a social mission. In CentERdata, online surveys are used to collect a great deal of data about the labour market, pensions, social security, and consumer behaviour. Advanced econometric techniques are then used to analyse the data and to understand behaviour. The results can be used for policymaking in these fields, for example.[123] Another example is the Spinoza Centre for Neuroimaging, which has advanced facilities including a 3 Tesla and a 7 Tesla fMRI scanner. These facilities enable researchers to carry out pioneering neuro-scientific research, which also has implications for the social sciences. The new knowledge generated is crucial, for example, for treating mental illness but also for understanding and treating criminal behaviour and addiction, or to help us understand how people learn (which has applications in the field of education). Finally, a large-scale facility in the humanities is the Common Language Resources and Technology Infrastructure (CLARIN). CLARIN brings together in virtual form all the available tools and resources in the field of linguistics and speech technology for all the European languages and makes them available to researchers and other users. Such tools and resources can be used, for example, to search for information within extremely large quantities of data (information retrieval), to find answers to questions, perhaps even if they are to be found in documents in various different languages (multilingual question answering), or to convert speech into written language (and vice versa). Tools of this kind can be applied in both the public and commercial domains. The social applications include such things as the provision of public services by the authorities, search functions for libraries and archives, and access to our cultural heritage in a general sense.[124]

5.2 Contribution to social innovation

Large-scale research facilities can also have added value for society without pursuing an explicitly social mission. They can contribute to various types of social innovation, by which we mean various new products, services, and concepts that find their way into the public domain. Countless examples of such innovation can be given. In 1930, the Lawrence Radiation Laboratory in Berkeley constructed the world's first cyclotron. The laboratory quickly developed into a national and international centre for nuclear research, where physicists, chemists, engineers, and biologists collaborated on physics experiments with the aid of radiation. Their collaboration led to the further application of radiation to discover and treat disorders such as cancer. That is still one of the important contributions made by such facilities. One of the main uses of the high flux reactor in Petten (north of Amsterdam) is to produce radioactive isotopes. These are supplied to hospitals for use in diagnosing and combating cancer (radio-pharmacy). New therapies have also been developed with the aid of the Petten reactor, for example Boron Neutron Capture Therapy (BNCT). This involves injecting the patient with a nonradioactive substance that has the property of seeking out cancer cells. The pharmacon contains the element boron. If one then positions the patient within a beam of neutrons, the sites where the boron is located – i.e. the cancer cells –

121 http://*www.lifewatch.eu*.
122 http://www.icos-infrastructure.eu/
123 http://www.centerdata.nl/
124 http://www.clarin.eu/external/

are destroyed. This makes it possible to kill off the cancer cells without significantly damaging healthy tissue.[125]

Physics laboratories have also played a major role in developing PET and CT technology at hospitals. Positron Emission Tomography (PET) is an imaging technology based on the display of radioactive particles (radionuclides). It utilises radioactive substances (isotopes) that emit positrons as they decay. Positrons are particles with the mass of an electron but a positive charge. When an electron and a positron come together, both disappear and energy is released in the form of two gamma photons, which are then detected by special detectors, the “PET camera”. The detectors are positioned in a ring, thus making a three-dimensional picture possible. Attaching positrons to biomarkers makes PET extremely suitable for diagnostic imaging. Computed tomography is a method for carrying out research on the human body using X-rays. The permeability to the radiation of the body part being examined is measured from a large number of different angles in thin slices, after which a computer uses the results to build up a three-dimensional representation of the body part concerned. CT is also utilised for diagnostic purposes. Large-scale research facilities have made a major contribution to the development of this technology. The first image produced by a PET camera, for example, was demonstrated in 1997 at CERN. Another example is SURFnet. This fast network is used by a number of parties as a testbed for new applications. Thanks to collaboration with universities, students could be deployed as “early adopters” to develop new possibilities for data traffic using broadband technology. Research on applications with the aid of SURFnet has produced a number of important technologies, in particular the technique for transmitting high-quality video images via broadband has become an international standard. The SURFnet network was necessary in order to develop new products and services within a high-quality experimental environment. Notable results include the provision of television programmes via Internet and the development of theme channels provided via broadband. GigaPort has also made a major contribution to the development of the DigiD authentication system, which is used by various government services (including the tax authorities).[126] A final example is the impetus that large-scale research facilities have given to the development of the Internet. CERN’s LHC, for example, has given a major boost to a “next-generation” Internet. CERN is currently putting the finishing touches to a computer project that was initiated so as to be able to process the gigantic quantity of data, the annual equivalent of 56 million CDs. A “grid” has been constructed in Geneva that will be 10,000 times faster than the fastest current broadband connection. This is possible because it now makes use of optical fibre cables and modern routing centres. Once the number of servers has been increased from the present 55,000 to the proposed 200,000, it will be possible to transmit feature films within just a few seconds and the whole Rolling Stones catalogue in the blink of an eye.[127] The development of this GRID technology will also have a social impact, for example on the way we use the Internet or on the use of software and data via the Internet (“cloud computing”).

The box below gives a number of other examples of successful innovations with a social impact.

[125] See http://www.nrg.eu/public/medical_nl/valley/node4.html

[126] P. Boekholt, J. Deuten, M. Nagle and F. Zuijdam, Tussen impuls en continuïteit. Evaluatie ICES/KIS-2 (2008).

[127] I. Mohamed, “CERN lays foundations for next-generation internet with intercontinental 10 Gig Wan” in Computer Weekly (2005).

Box 4 – Examples of successful innovation with a social impact

- Demonstration of the possibility of terrestrial microgravity with the aid of magnetic levitation of organic material.
- High-quality systems for predicting storm surges and discharge surges are being developed throughout the world on the basis of Deltares software.
- Development and production of foot-and-mouth disease vaccines.
- Unique training programmes for Royal Netherlands Air Force pilots.
- Computerised weather forecasts (weather models based on input from measurement networks) and climate scenarios.

Source: Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).

5.3 Publicity and education

Large-scale research facilities and major scientific undertakings often appeal to people's imagination. Grateful use is made of this with a view to publicising science. Use is often made of large-scale research facilities to introduce the public to science in general and research in the relevant discipline in particular. In the Netherlands, the start-up of the Large Hadron Collider attracted a great deal of media attention, both in the newspapers and on TV, and tours of CERN are fully booked months in advance.

The Census of Marine Life shows just how varied this kind of public communication can be. The Sloan Foundation, which funded the project, made its funding dependent on there being interaction with the public, and the project therefore devotes a great deal of attention to the public profile of the research involved. This has resulted in websites that present the research, hundreds of articles in newspapers and magazines, a number of coffee table books about marine life, the film *Oceans* (which was screened all over the world), TV documentaries, numerous exhibitions and art projects, and moreover participation by schoolchildren in research projects along the coast. "Big science" therefore not only raises the profile of science but also makes science more familiar to the public. The High Field Magnet Laboratory (HFML) in Nijmegen receives about a thousand visitors annually, made up of schoolchildren, employees of businesses, guest researchers from other departments, and representatives of the city and the province (and visitors whom they bring with them). The HFML is a kind of advertisement for technical and scientific ingenuity. It undertakes a wide range of activities of its own accord to familiarise the general public with research carried out with the aid of the laboratory. The film clip showing the experiment with the levitating frog drew worldwide attention (including on Discovery Channel, National Geographic, the BBC, CNN, and NBC), was awarded an Ig Nobel Prize,[128] and is given as an example in a number of school textbooks. The Heidelberg Forum of Life Sciences and Society has been set up at the EMBL. Its aim is to publicise the research carried out at the EMBL institutes, focusing particularly on the local community and linking the research to social issues. Lectures and conferences for various target groups go into the question of how research can help deal with these issues and what scientific issues are involved in research in molecular biology (such matters as the use of stem cells or the cloning of animals and people). The Forum also organises open days for the public at which various experiments are demonstrated. The open days are attended by about a thousand people.[129] Large-scale research facilities can also make links between science and society in an entirely different manner. In order to construct some large-scale infrastructures, researchers are dependent on the public, patients, or other

[128] The Ig Nobel Prizes are a parody of the real Nobel Prizes. They are awarded in the autumn of each year, a week before the real Nobel Prizes are announced, for research that first makes people laugh but then makes them think.

[129] http://www.embl.de/aboutus/science_society/hd_forum/

stakeholders, for example in the case of biobanks or large-scale surveys in the social sciences. The involvement of the public or patient groups with a large-scale facility can in some cases generate flows of information to such stakeholders. The people concerned are also informed – from the perspective of commitment and responsibility: just what happens to their contribution? – about the progress and results of the research. Population biobanks are a good example of this and they could not in fact exist without the cooperation of ordinary citizens who are prepared to donate bodily material for the purpose of large-scale research. This means that biobanks need to set up channels via which to communicate with the public, on the one hand so as to find sufficient donors and, on the other, so as to inform the public about the research and to account for the work of the facility. The patient organisations that are involved with the biobanks also appreciate that they have a responsibility to their rank and file, all the more so because such organisations sometimes contribute financially to building up the facility. This is an example that shows that large-scale infrastructures may have a responsibility that goes beyond merely scientific quality. If society as a whole is involved and makes an essential contribution, then the facility must be accountable to society.[130] Large-scale research facilities also contribute to education. For one thing, this is through the knowledge that they generate, which is incorporated into the curriculum because of the link between science and teaching. Facilities also organise activities aimed at school pupils and students. Researchers at the Netherlands Institute for Space Research (SRON) give monthly "space classes" for secondary school pupils. These deal with space research and enable the pupils to look through telescopes. The researchers also explain how space research is actually carried out, and they discuss the role of the space instruments and detectors developed by SRON.[131] Other facilities have similar educational models. DANS, for example, has modules for social science students, while FOM Rijnhuizen (plasma physics) has developed special programmes of lessons for secondary school pupils. Finally, large-scale research facilities can also be a means of making a particular discipline more attractive and promoting its study. The HFML in Nijmegen, for example, contributes to making the image of the natural sciences more attractive. The link between Eindhoven University of Technology (TU/e) and the ITER project has produced spin-off in university education. TU/e has introduced a special master's degree in nuclear fusion technology aimed at educating talented young people in this field; the new programme is also a way for the university to attract students.[132] After all, ITER appeals to people's imagination and can encourage students to decide to study at TU/e. The box below gives a number of examples of activities at the various Dutch facilities aimed at the general public.

Box 4 – Examples of activities aimed at the general public

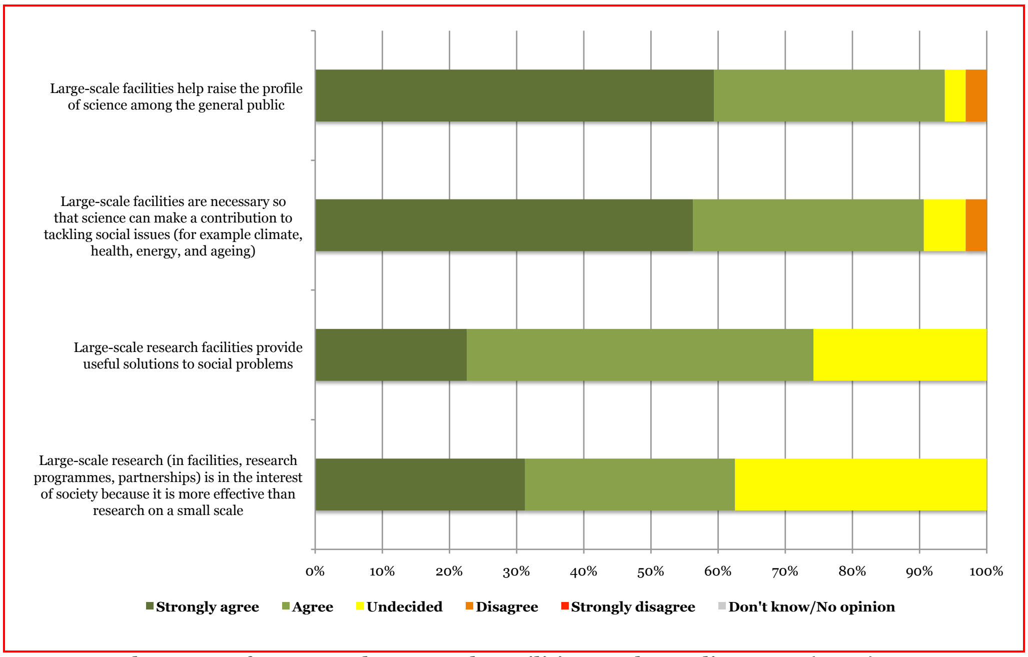
- Contributions to newspapers, radio, and TV.
- Tours, exhibitions, and demonstrations.
- Lectures, symposiums, and seminars for a wide range of target groups.
- Open days.
- Websites.
- Films about the scientific work of the facility.
- Invitations to the press and parliamentarians.
- Projects for secondary schools.

Source: Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).

[130] I. Meijer et al., BBMRI: an evaluation strategy for the socio-economic impact (Technopolis Group, 2010).
[131] http://www.sron.nl (education).
[132] http://www.phys.tue.nl/fusion/

In the course of the survey, respondents were asked to comment on a number of propositions relating to the social effects of large-scale research facilities. The results are presented in the figure below.

Figure 5 Social effects of large-scale research facilities (n = 31/32)



Source: Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).

The way research facilities help raise the profile of science among the general public received a particularly favourable response. The overwhelming majority of the facilities also consider large-scale facilities to be necessary in order to make a contribution to tackling social issues. However, not all of the respondents consider that this actually leads to useful solutions. This would seem to indicate that the focus of the research is still primarily on the scientific contribution made. The proposition that large-scale research is more effective than small-scale research is supported by somewhat more than 60% of the facilities surveyed.

5.4 Summary of added value from the social perspective

The social added value of large-scale facilities consists of the following elements:

- There are numerous large-scale facilities that have a social mission, in the sense that the research carried out with the aid of these facilities contributes to solving problems facing society.
- Large-scale research facilities can have added value for society in that they contribute to various types of social innovation: various new products, services, and concepts that find their way into the public domain.
- Large-scale research facilities also play an important role in scientific communication and scientific education. They are utilised to familiarise the general public with science. They can also be a means of making a particular discipline more attractive and promoting its study (and thus attracting students).
- Some large-scale research facilities owe their very existence to the contributions made by the public, patients, or other stakeholders. This leads to a special kind of commitment and obliges the facilities to provide information and render an account of themselves to those stakeholders.

6. Conclusions

This study has dealt at length with the role and added value of large-scale research facilities, illustrating these with the aid of numerous examples. It must be emphasised, however, that the available scientific literature as yet includes little empirical evidence of the added value of large-scale infrastructures and large-scale research. The study does provide substantiation in some respects, but this concerns only the Dutch situation. The scientific literature shows that large-scale research facilities play an important role as regards the creation of new networks and communities, in other words social capital. This social capital then leads in its turn to scientific, economic, and social impacts. Where many other kinds of social usefulness are concerned, however, there is still little in the way of empirical evidence. This report must therefore be viewed – emphatically – as the start of research into the role and added value of large-scale research facilities rather than as the temporary finishing point at which the elements are again summarised. Many of the matters referred to in this report will need to be gone into in greater detail and substantiated empirically.

The study commissioned by the Ministry of Education, Culture and Science and the Taskforce to Promote Large-Scale Research Facilities has therefore turned out to be not so much a synthesis of the existing research but rather as being in the nature of an exploratory investigation. Examining the relevant literature, but above all considering numerous examples and case studies, has made it possible to construct a framework specifying the various elements that make up the added value of large-scale research facilities. We will give a brief summary of the main elements below.

6.1 Conclusions regarding added value from the scientific perspective

Large-scale research facilities are crucial to the advancement of science in all scientific fields. Pioneering scientific research could simply not take place without large-scale facilities. It is only with large-scale, unique research facilities that one can make certain material visible or carry out pioneering experiments. Linking various different facilities can increase the scope of research enormously. By linking facilities to a large infrastructure network, researchers can bring about an exponential increase in the number of observations and experiments that are carried out. The network generates far more research results than could ever be done by all the individual groups together. The value of linking up research data is much greater than the sum of the parts.

Large-scale research facilities are not only of crucial importance for acquiring new knowledge but have also contributed to a more efficient way of working in the world of science. Large-scale infrastructures are sometimes necessary in order to achieve the set scientific goals within a given time. Shortening the time needed to carry out research is not only advantageous from the financial point of view but can also have major scientific and social advantages.The role and added value of large-scale research facilities need to be considered against the background of the scaling up and concentration of research. The development of large-scale research facilities and technologies has made a major contribution to this. Such facilities ensure, on the one hand, that the research is centralised around unique instruments and, on the other, that increases of scale are achieved by combining and integrating complex, linked research facilities. The use of large-scale facilities and the scaling up of research is to a great extent associated with the increased integration of research. This can be observed both in the centralisation around a unique facility and in the connecting up of instruments to form a large-scale infrastructure. The various stages of research are becoming increasingly dependent on one another, and harmonisation and standardisation are becoming increasingly important. In line with this, scaling up also leads to greater coordination. Bringing together people, expertise and agendas gives direction to a future research agenda. Large-scale research facilities are often a focal point for multidisciplinary research. Research is becoming increasingly multidisciplinary and transdisciplinary, for one thing because scientific and social problems are often so complex that it is not possible to provide an answer from merely a single scientific perspective. Combining a number of different disciplines and parties often brings about an increase in scale and creates a need for large-scale research facilities. The use of large-scale research facilities in all its forms also brings about innovation in the way science is managed. The management of these facilities can often not be fitted in to the local structure of governance, meaning that new management systems must be devised. In addition, existing funding structures are also frequently not appropriate for large-scale facilities. Many European countries are facing the challenge of finding both new sources of funding and new funding arrangements. Last but not least, large-scale research facilities also have a positive effect on the reputation of research groups, research organisations, and sometimes even whole research fields. Researchers who use such facilities can carry out state-of-the-art research, which then has a positive effect on their reputation. Conversely, large-scale research facilities also often attract the best researchers and research groups.

6.2 Creation of networks and human capital

The scientific literature shows that building up “social capital” is an important mechanism for large-scale research facilities to have an impact on science, the economy, and society in general. “Social capital” generally refers to the benefits that arise from social networks – both formal and informal – and to the shared values and mutual trust that people develop on that basis. In the case of large-scale research facilities, one is dealing both with networks of scientists amongst themselves and with networks comprising both scientists and non-scientists, for example representatives of businesses, government bodies, and civil-society organisations. Social capital plays a crucial role in bringing about the ultimate impact of these facilities on science, the economy, and society in general. The social capital that is built up facilitates and catalyses learning processes and knowledge-sharing by the parties concerned. This happens in three ways:

- Social capital increases the quantity and diversity of the knowledge potentially available to both parties because the parties’ readiness to give one another access to their networks (both internal and external) increases.
- Social capital increases knowledge-sharing by the parties involved because trust is created and the principle of reciprocity is reinforced.
- Social capital increases the efficiency of knowledge transfer because there is greater overlap in knowledge, thus also increasing the amount of knowledge shared by the parties. Interaction also draws the organisation’s strategic targets closer to one another.

The literature also reveals that social networks play a major role in building up human capital. We can conclude indirectly from this that large-scale research facilities are important in building up human capital (via social capital). It is in fact often asserted that unique research facilities have a great attraction for the best and most talented researchers, who of course wish to have the best facilities at their disposal because their scientific career or reputation is partly dependent on their having access to such facilities. There is as yet no scientific literature, however, that can provide empirical substantiation for this assertion. At most, a good research infrastructure is *one* of the factors that determine researcher mobility. Various assessments do show that large-scale research facilities can play a major role in capacity building. A lot of facilities play a role in training young researchers and technical personnel. The added value is to be found mainly in the quality of the training provided. Young people are enabled to carry out pioneering research with state-of-the-art equipment and sometimes even with unique facilities. Final-year students and research assistants at a large-scale research facility therefore have a head start on other young researchers. Another major difference is that large-scale facilities also train high-quality support staff, for example technicians and ICT professionals. Training involves more than just scientific research. Large-scale facilities can also promote capacity building, in the first place by providing access, and creating local networks of facilities. Access to the facilities enables researchers in countries where the facilities are of less high quality to still carry out state-of-the-art research. Secondly, international consortia generate a whole range of learning effects that can serve to improve the infrastructure in those countries. Thirdly, their presence also contributes to upgrading the research infrastructure itself in countries with facilities of less high quality.

6.3 Economic value

The economic value of large-scale research facilities can be linked in the first instance to the economic activities that take place in the context of developing them – building, construction – and the procurement of related goods and services. The construction and development of large-scale research facilities generally demands major investment. Studies show that a major proportion of the investment involved benefits the local (and/or national) economy. Contracts for developing a facility or providing specific products and services are more frequently awarded to local and national companies and less frequently, relatively speaking, to foreign parties. Establishing a large-scale facility in a country is therefore beneficial for the local and national economy. It should be noted in this connection, however, that the beneficial effect on the domestic market concerns primarily "low-tech" products and services. When the products and services are more specialised and "high tech", the relevant contracts are more frequently awarded to foreign companies. The use of such facilities also creates jobs. A distinction needs to be made, however, between temporary effects and long-term effects. The temporary effects involve jobs created as a result of the construction and development of a large-scale research facility. The longer-term effects involve, on the one hand, the jobs that are created for the personnel who work at the facility – both scientists and research staff – and, on the other, the jobs created for suppliers of materials and services for the facility. for example energy, water, raw materials, or ICT services. Jobs may also be created due to "second-order effects". These include such things as the extra jobs created as a result of expenditure by the personnel and users of the facility – for example on homes, consumer goods, hotels, etc. – or by the boost given to further development of the region or of a technology cluster. Economic added value can also be created by the spin-offs that are set up around a large-scale research facility. These are based on the knowledge generated with the aid of the facility or the knowledge generated in developing and running it. The spin-off brings this knowledge onto the market (in other words "valorises" it). The small companies that are set up generate turnover and jobs. The knowledge generated by the facility can also be marketed otherwise than by spin-offs, for example by the issuing of licences or through joint ventures with existing companies. Large-scale facilities also contribute to economic innovation. They can be a valuable addition for the commercial sector; they can generate knowledge that a company cannot generate for itself or acquire via its existing network. Studies show that industrial users in fact make relatively little use of large-scale research facilities. These facilities are largely accessed via or in collaboration with public knowledge institutions. It is not only the use of large-scale research institutions that can drive innovation in the commercial sector but definitely also their construction and development. In the course of constructing and developing the facility, it is often necessary to come up with new technical solutions. Suppliers cannot provide these "off the shelf" but must develop new and innovative products. Large-scale research facilities therefore act as "launching customers" for innovative products and services provided by the commercial sector. These can then also be sold to other customers or in other markets. In some cases, large-scale research facilities actively support their suppliers in developing new products. Large-scale research facilities do not always act as a launching customer. Suppliers may be requested to provide standard products and services that need to be produced according to highly detailed specifications. Large-scale facilities only play that role if the contracting procedure is a modernising or innovative one.

6.4 Added value for society

The primary purpose of research facilities is to carry out scientific research. There are numerous large-scale facilities, however, that have a social mission, in the sense that the research carried out with the aid of these facilities is not a goal in itself but must contribute to solving problems facing society. Large-scale research facilities add value because the necessary data can only be acquired via a large-scale infrastructure or because it can be collected far more efficiently. Large-scale research facilities can also have added value for society without pursuing an explicitly social mission. They can contribute to various types of social innovation, by which we mean various new products, services, and concepts that find their way into the public domain. Large-scale research facilities also play an important role in scientific communication and scientific education. They often appeal to people's imagination, and are therefore frequently used to introduce the public to science in general and research in the relevant discipline in particular. Many such facilities also organise activities and develop lesson modules aimed at school pupils and students. They can also be a means of making a particular discipline more attractive and promoting its study (and thus attracting students). Finally, some large-scale research facilities owe their very existence to the contributions made by the public, patients, or other stakeholders. This leads to a special kind of commitment and obliges the facilities to provide information and render an account of themselves to those stakeholders.

6.5 In conclusion

The above considerations show that the role and added value of research facilities is extremely varied. The impact of large-scale research facilities extends into a number of domains, and they have both direct and indirect effects. The various impacts that such facilities can have are also time-dependent. In some cases, they generate their effects within the short term, but it sometimes takes years before their impact becomes apparent (and quantifiable). The framework outlined above consequently has several dimensions. More detailed investigation will be necessary to make the framework presented in this study more specific and to fill in the details. Many of the elements involved will also need to be substantiated more effectively from an empirical perspective. In line with this, further consideration will also need to be given to a framework for evaluating and monitoring large-scale research facilities.

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Appendix B Methodology of Web survey

Given the lack of empirical evidence for the added value of large-scale research facilities, it was decided to conduct a Web survey of a large number of national research facilities in order to clarify that added value. As in the present report, a distinction was made between scientific added value, economic impact, and effects on society. The facilities to be surveyed were selected on the basis of a study, carried out in 2008 by the Rathenau Institute, which showed that more than 60 facilities operate in the Netherlands.[133] Between October and December 2010, the Web survey was developed (in collaboration with the Rathenau Institute), all the facilities were requested to fill it in, and the initial results were analysed. A total of 67 different facilities were approached. In order to ensure the highest possible response, the original request and a reminder sent some two weeks later were backed up by phone calls to the facilities that had yet to respond. Ultimately, 49 respondents filled in the survey, with 39 filling it in completely. A total of 7 respondents indicated that they did not wish to participate in the survey. The response percentages are given in the table below.

Total number of facilities approached	Number of questionnaires filled in			Response percentages		
	Total	Complete	Partial	Total	Complete	Partial
67	49	39	10	73.1%	58.2%	14.9%

Source: Web Survey of Large-Scale Research Facilities, Technopolis Group (2010).

[133] E. Horlings and A. Versleijen, Groot in 2008. Momentopname van grootschalige onderzoeksfaciliteiten in de Nederlandse wetenschap (The Hague 2008).

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