Portfolio for research and innovation

cooperation
creativity
game changers

Portfolio for research and innovation

Combining forces and strategic choices are necessary to keep and expand the top position of Dutch Science. The Dutch government intends to mobilise scientific strengths to address major societal challenges and economic opportunities. For this purpose the government appointed the Knowledge Coalition to set up a Dutch National Research Agenda in 2015.

The Dutch National Research Agenda stimulates cooperation, creativity and innovation en links stakeholders with themes. The agenda contains 140 complex themes with an interdisciplinary character. Many crossover routes are possible in the landscape of 140 questions. To explore the scientific issues a digital version of the agenda is available on www.vragen.wetenschapsagenda.nl.

Over the past six months, thousands of researchers and other interested parties have attended dozens of workshops in order to reduce the questions to twenty-five ‘routes’, i.e. coherent sets of questions around which communities of stakeholders in science, enterprise, government and society are clustered. The Portfolio for research and innovation describes these routes. The portfolio identifies those domains in which the Netherlands can make a real difference and has comparative advantages over other countries. It is therefore an ambitious and conceptually solid strategic agenda for investment in research and innovation.

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Dutch national research agenda

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Content

Introduction
From questions to opportunities

Research and innovation are vital to solve the major challenges of our time and to create opportunities for the future. We can start creating opportunities by asking questions. Published in December 2015, the Dutch National Research Agenda describes 140 urgent issues that call for research and innovation. These 140 cluster questions are based on 11,700 questions submitted by the Dutch population after a broad consultation process.

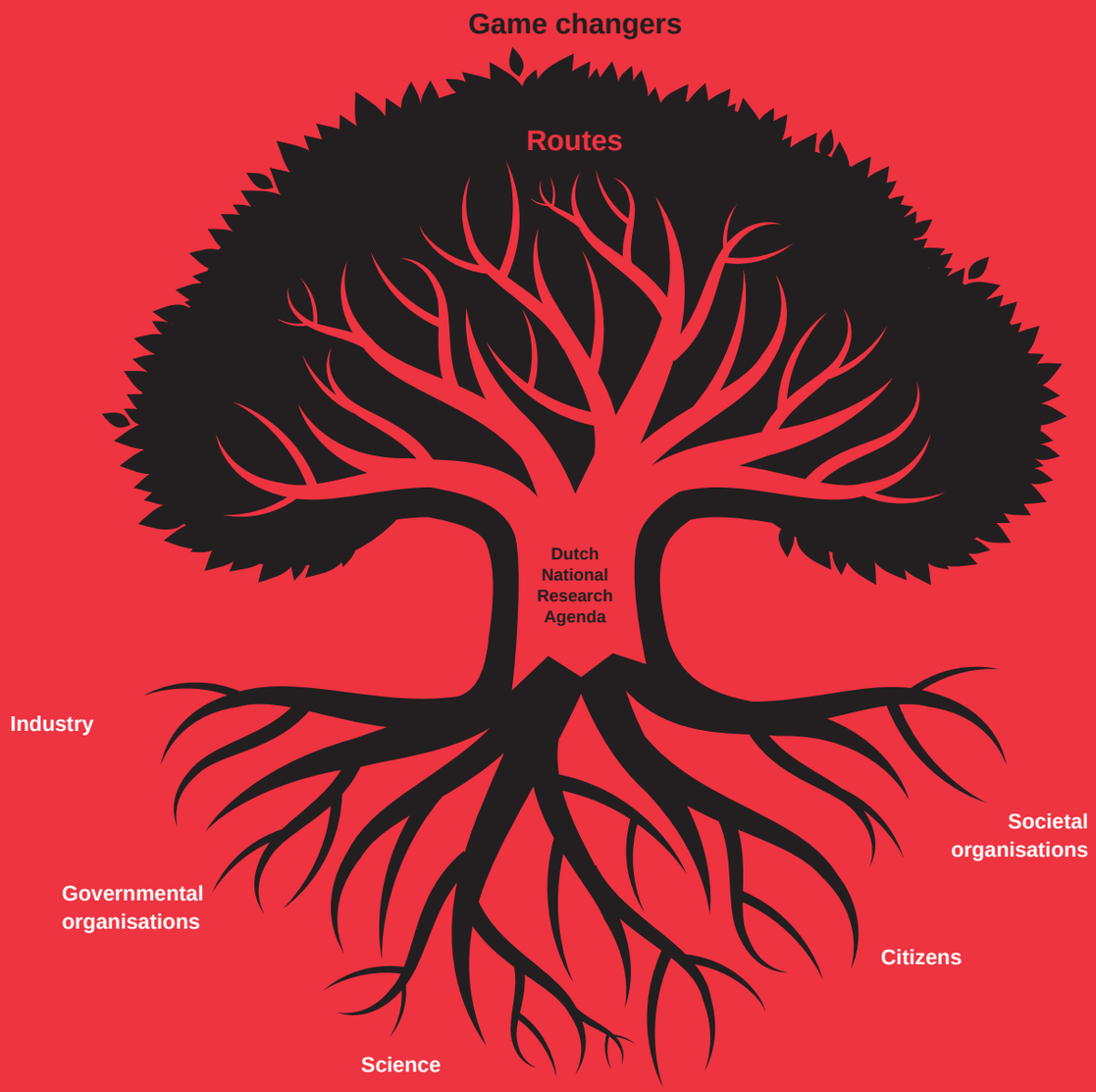
The present *Portfolio for research and innovation* describes the result of the next phase in that process, in which we move from the individual research questions to developing routes through those questions composed of subsets of interrelated questions. These routes connect science, technology and innovation. They indicate which opportunities we have and should take advantage of in consultation with civil society partners and enterprises, and what these efforts will eventually generate for society and the economy. These opportunities were identified during workshops attended by between two and three thousand people.

This portfolio elaborates on all the routes described in the Dutch National Research Agenda, sometimes under a slightly different name. In addition, parties in the field have proposed nine additional routes. Because all these routes cut across disciplines and sectors, there is no obvious way to group or classify them. They have also not been prioritised in any way.

The Dutch National Research Agenda can be symbolised by a tree, with roots, trunk and crown. The roots represent the origins and basic foundations of the tree: the curiosity expressed by society and the many questions submitted by individuals, civil society organisations, enterprises, government authorities, and scientists. The trunk stands for the 140 cluster questions presented in the Dutch National Research Agenda itself. The crown stands for the *Portfolio for research and innovation*. The branches are the routes that rise up from the trunk and the leaves on those branches represent the prospect of breakthroughs in research and innovation identified in the routes. As a whole, the tree stands for a unique participative process, a collective project of unparalleled dimensions.

How to use the Portfolio

The portfolio serves two purposes. First of all, it identifies investment priorities for Dutch research. It is available as a separate publication, but it is also part of the investment agenda that the Knowledge Coalition partners – the Royal Netherlands Academy of Arts and Sciences (KNAW), MKB-Nederland, the Netherlands Federation of University Medical Centres (NFU), the Netherlands Organisation for Scientific Research (NWO), the TO2 Federation, the Association of Universities of Applied Sciences, the Confederation of



Netherlands Industry and Employers (VNO/NCW) and the Association of Universities in the Netherlands (VSNU) – has proposed to the Dutch government. In addition, the portfolio offers a basis for collaboration between researchers. Communities of stakeholders in science, enterprise, government and society have aligned themselves along the routes.

The portfolio is a snapshot. Based on today's insights, it identifies promising themes that could lead to pioneering breakthroughs in research and innovation; breakthroughs that could bring about far-reaching changes in the arena in which science, economics and society converge. These insights are anything but static; they will continue to evolve. It is therefore possible that new routes through the Dutch National Research Agenda will be charted and developed in the years ahead, with new opportunities being identified as a result. Eventually, there will be a new participative process that will revitalise and recalibrate the Dutch National Research Agenda itself.

Game changers

The portfolio describes opportunities that have currently been identified for each route. Most of the routes point out various subjects that they refer to as game changers. Game changers are perspectives or approaches that have the potential to take research forward in radical new directions. They differ in their essentials. Some are content-related and describe the research themes that could spark breakthroughs, i.e. the subjects that should have priority when it comes to investment. Others concern critical success factors or the necessary research infrastructure. There are also routes that identify crucial methodological innovations as game changers.

The routes vary in terms of the breadth and depth of their content. Some describe a wide variety of potential opportunities, while others explore a small number of these in great detail. There are also routes deliberately designed to cut through other routes, for example ‘Creating value through responsible access to and use of big data’, ‘Measuring and detecting: anything, anytime, anywhere’ or ‘Sustainable development goals for inclusive global development’. There are subjects that reappear in multiple routes, with each route tackling them from its own perspective. The epilogue goes into this in greater detail.

The routes are not a mere list of research opportunities, however. They also look at how research can be made useful for society and at how to close the innovation gap. Some routes also propose new institutes or new large-scale alliances. Education is another recurring subject. Many routes not only identify new research as important, but also a solid education in specialist areas of knowledge and in 21st-century skills. Finally, all the routes emphasise taking a socially responsible approach to achieving the opportunities that they propose. They are referring to the social, legal and ethical consequences of research, for example privacy and security sensitivities, acceptance by society, and governance.

Many of the routes also wish to encourage new research approaches. A number of them refer to trial sites, for example living labs or field labs, as a means of attaining genuine multidisciplinary collaboration. Several other routes also refer to citizen science, with ordinary people asking questions, collecting data, and interpreting and sorting out the implications of research.

Final remarks

By identifying opportunities within these routes, we have taken the next step towards proposing meaningful and useful investments in research and innovation. The research proposed in the route descriptions will eventually make a major contribution to resolving numerous societal issues, to achieving sustainable economic growth, and to boosting the international status of Dutch research.

The blue route: water as a pathway to innovation and sustainable growth

More than seventy per cent of the earth's surface consists of water. Water is vital to every known form of life. It is essential to food production, it carries away waste and makes transport possible. It is also important to energy generation and the circular economy. This 'blue route' focuses on understanding, utilising and protecting oceans, seas, deltas and rivers, as well as saltwater, fresh water and groundwater, in order to improve sustainability, wellbeing and prosperity worldwide.

Sea level is rising, climate change is impacting the oceans, the water is polluted with plastic waste, clean drinking water is scarce, and the habitable land is overcrowded. And it is precisely at the vulnerable interface between water and land that we find fertile soil and ever-growing populations.

This route therefore is a very important one. On the one hand, it is about gaining a better understanding of interconnected aquatic, terrestrial, atmospheric and marine processes and ecology. On the other hand, we want to make sustainable use of the water by developing new technology and production systems and creating new residential and commercial spaces. To do that, we need to protect the water and protect ourselves against it.

Living with water

This route explicitly links the traditional science clusters with technology and the social sciences. In addition to the ecological, economic, analytical and technical aspects of water, there are other important factors, including the associated local, regional and global governance and spatial policy issues. Living and working with water makes sustainable growth possible, even when the sea level is rising and urbanisation and the world population are increasing. This route links applied research with basic and normative research concerning climate change and water safety, water and resource security, marine transport, sustainable offshore and coastal energy generation, energy storage in surface waters and groundwater, the marine infrastructure, spatial planning, urban planning, land reclamation, water and air quality, sustainability, land-based and aquatic food and biomass production, as well as issues related to the condition of the soil, subsidence, and biodiversity in the broadest sense.

Urgency

The changing conditions of water on earth are an issue that affects us all. Rivers, seas and oceans can be both a threat and an opportunity. The World Economic Forum believes that global water crisis is the greatest risk to the world economy. The consequences of climate change are also high on the list of top ten threats in terms of both frequency and impact. In addition, half the world's population lives in deltas or along coasts or rivers and this fraction is expected to increase to 70 per cent by 2050. Especially deltas have enormous potential for human development, but at the same time are extremely vulnerable to rising sea level, subsidence, pollution and the influence of natural forces and the weather. Water offers us new sources of energy, raw materials, food and transport, but under rapid climate and socio-economic change adaptation of our water systems is needed. We simply cannot allow ourselves to remain idle. By understanding the global water system in order to protect and take advantage of it, we can combine economics and ecology and prepare for change. The Netherlands grew into a nation at the water's edge. We can now continue to grow on, along and in the water.

Innovation and prospects

The approach taken in the blue route is innovative and unifying.

1. In order to uncover innovative and sustainable ways of 'living with water', we aim to combine understanding, utilisation and protection. The blue route encourages close and coordinated collaboration between science, technology and the social sciences, between basic and applied research, and between economics and ecology.
2. The blue route aims to answer questions about the unknown. Humankind has been to the moon and is en route to Mars, but we still do not know enough about our own oceans. To explore them, we must understand the links between ecology, life cycles and processes in deep and shallow water. For example, the Atlantic drives the climate processes that define the dynamics of the Dutch Delta. The North Pole region is similar in that respect. We need to know more about how these systems work.
3. The blue route entails a shift from 'the fight against water' to 'building with water' and on to genuinely 'living with water'. This offers us new prospects for food, energy, raw materials, transport and housing along, on and in the water.
4. The blue route breaks with the traditional linear innovation process: innovations are created in open networks, with all the stakeholders in science, society and enterprise engaged in co-creation. We prefer a 'living labs' approach whereby specific regions – the Amsterdam-Rotterdam agglomeration, the South-Western Delta, the Wadden Sea Region and the North Sea – function as experimental sites for understanding the overall system.

The following four lines of approach will produce four game changers.

Living in the Delta

How do we develop a Sustainable Urban Delta in which different populations can live, work and eat together safely, healthily and sustainably?

The rate of urban expansion in delta regions worldwide is exponential, and their habitability and liveability have come under serious threat. Sea-level rise, subsidence, extreme discharge in rivers, drought, pressure on precious space, groundwater depletion, salinisation and water pollution are problems that we must arm ourselves against. Taking the Netherlands as a living example, we wish to work on the Sustainable Urban Delta. New scientific challenges can be identified as we learn more about river and coastal systems, urban water systems, adaptive delta management, more efficient (circular) use of fresh water, and 'building with nature' solutions.

Water as a source

How can we make sustainable and economically responsible use of the water and the energy, natural resources and food located on, in and under that water?

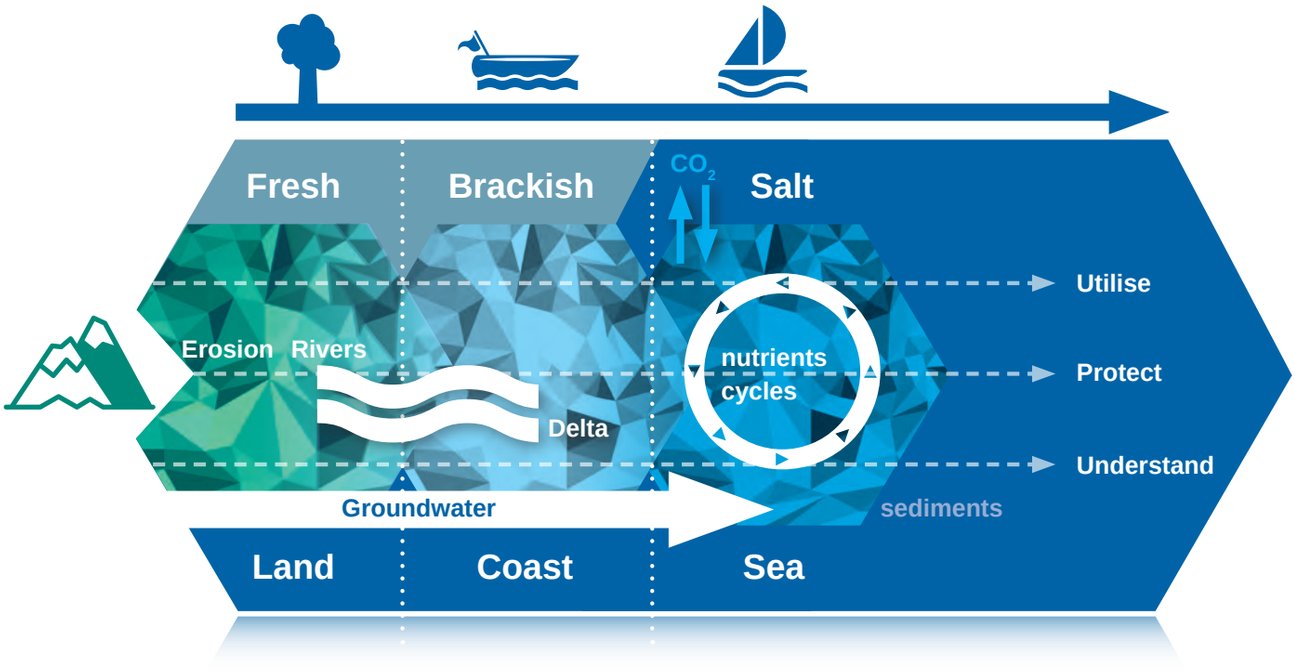
Water is a source of life. It is essential for of plant and animal food supply. New water management methods – for example temporary storage in groundwater, recycling of waste water, and the use of brackish water – can increase the availability of water in densely populated areas. New food supply methods for both humans and animals – sustainable fisheries, aqua farming and seaweed cultivation – have the potential to increase the amount of available agricultural acreage near urban areas. Hydropower, tidal currents, wave power, osmosis and wind power on lakes and offshore have enormous potential for sustainable energy generation. Finally, ocean, sea and river beds are a source of sediments, minerals and other essential resources that we can extract and use sustainably.

Water as a blue pathway

How can we redesign vessels with carbon-neutral and autonomous navigation systems and futureproof our ports and waterways to make shipping sustainable and safe?

Water is the blue pathway, the most important route for transporting goods to our mainports, both now and in the future. But that pathway must be cleaner and safer. To create carbon-neutral ships, we need to know about hydrodynamics and energy systems and develop the relevant technology. Opportunities lie in natural propulsion, for example by the wind, and new materials. Autonomous navigation systems are one possible way of making shipping and waterways safer. They require advanced sensors, systems, big data analysis and design methods. The ships, waterways,

The blue route



marine structures and mainports of the future will be integrated into their surroundings. Their design must allow for their impact on their surroundings in terms of emissions, noise or disruptions.

Living on water

What opportunities do floating homes and businesses, aquaculture, and hydropower offer at a time when the sea level is rising, the climate is changing and we are running out of space?

At a time when the sea level is rising and the world's population is increasing, the sea offers us space and options: we can live in floating homes, grow food on and in the water, use water to generate and store energy, and so on. The technical challenges are enormous. How do we develop gigantic floating structures that are strong enough to weather storms and currents safely? How can we link these systems to one another? How do we organise traffic and transport? These questions also have an ecological component to them: What will the impact of these large, floating communities be on, under or around the water? How do we make the system completely circular in terms of water, energy, raw materials and waste?

Living labs

All these prospects are conducive to the 'living lab' approach, in which scientists, enterprises, authorities, students and the public work together and even live together in a new reality. A living lab combines scientific, social and technological innovation into a single programme; it generates new products but also influences the behaviour of end users because they are directly involved and have new options. The living lab approach also functions as an important bridge between basic and applied research and practice-based learning, with the active participation of students in higher education. Finally, living labs also function as living demonstrations in which the Netherlands shows the world how to live sustainably with water.

Building blocks of matter and fundaments of space and time

Young children are curious creatures and ask all sorts of questions, like 'Why is the sky blue?' The same passion drives this route, which asks fundamental questions about matter, space and time, and the cosmos. Earlier research into these questions led to enormous breakthroughs, including the internet, GPS and WiFi. The Dutch National Research Agenda contains a huge number of questions about this subject, so this route is sure to be fascinating to the public. In the search for answers, new research talent and advanced, innovative technology are indispensable. To allow talent to flower in future generations of scientists, we need to focus on education and science communication in this domain.

What do space, time and matter consist of? What is dark matter, and what is dark energy? What are black holes? What is the Big Bang, and can we measure its force? How do complex structures emerge from simple building blocks, on smaller or larger scales, on earth and in the cosmos? What is the mathematics behind symmetry? These questions are fundamental to our understanding of nature and our place in the universe.

To answer these and similar questions, we need to observe the universe and conduct experiments in particle physics. Such observations and experiments are often a technological tour de force and involve complex infrastructures, for example particle accelerators at CERN, telescopes on Earth and in space, supercomputers, and ultra stable laser interferometers. In addition, solid connections are crucial between the different disciplines and sectors, specifically the natural sciences as a group, philosophy, informatics and IT, mathematics, engineering, and industry. The necessary technological infrastructure requires connections with the High Tech Systems & Materials top sector and the Roadmap for Advanced Instrumentation.

Building blocks of the universe

Our knowledge of the basic building blocks of matter and the universe has grown spectacularly in recent decades. This has led to a fascinating question: can we understand the existence, evolution and structure of our entire universe in terms of its basic building blocks?

Astronomy and elementary particle physics are both successful at describing phenomena in their own domains. Now we want to merge these two disciplines under a single heading and understand how they are related to cosmology. What does the discovery of the Higgs particle mean for our understanding of the evolution of the cosmos? Can dark matter and dark energy be understood in terms of elementary building blocks? Does mathematical symmetry and perhaps number theory underpin basic theories about space, time and matter?

To tackle questions about the particle universe effectively, new alliances are needed between different disciplines and with innovative industry. The main opportunities can be found in astroparticle physics and cosmology, two multidisciplinary fields that link particle physics and astronomy. Astroparticle physics uses all possible elementary particles and forces as messengers for carrying information, for example high-energy photons, neutrinos, the cosmic radiation of protons, and heavy ions and gravitational waves. This multi-messenger approach is also vital in the search for the identity of dark matter.

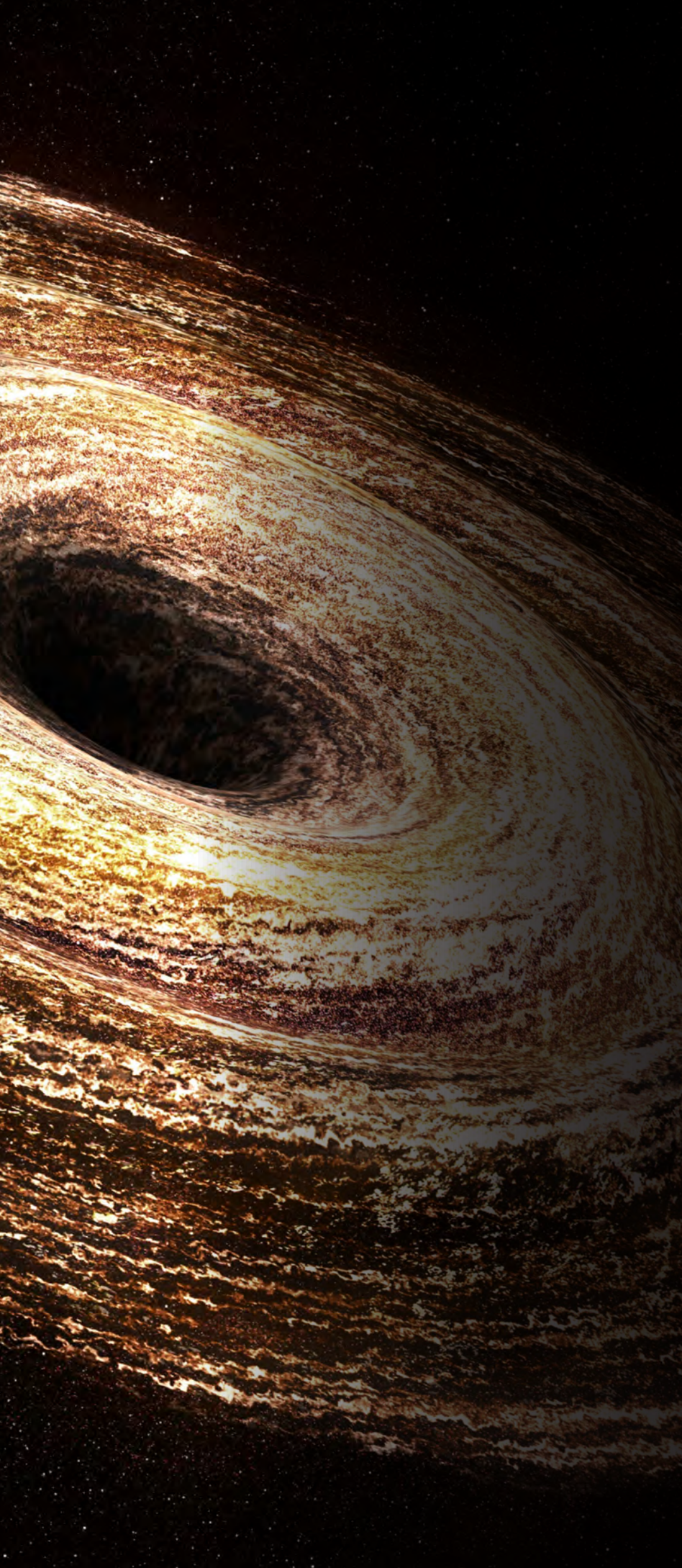
In his General Theory of Relativity of 1915, Albert Einstein described a radical new relationship between space, time and gravity. On 11 February 2016, the international LIGO Virgo consortium announced that it had detected, for the first time ever, gravitational waves: the ripples in the fabric of spacetime itself, produced during the most cataclysmic events in the universe, such as a collision between two black holes or the beginning of our own universe. In this case, the gravitational waves had been produced by the collision between two black holes 1.3 billion years ago. The second observation was announced four months later. This sensational development has opened up a new vista on the universe. The ESA's eLISA mission, which will launch a similar detector into space in 2034, will be able to register gravitational waves produced by supermassive black holes.

This route advocates two pioneering initiatives on Dutch soil, with science, industry and technology uniting to answer fundamental questions about our universe.

Einstein Telescope

The Einstein Telescope (ET) is expected to lead to groundbreaking scientific discoveries. It will be the ultimate observatory for studying the fabric of spacetime by detecting gravitational waves.

The role of the Einstein Telescope will be similar to that of ESA/ESTeC in Noordwijk in the Netherlands. It will function as a second international research institute in the Netherlands and will play a role similar to that of CERN in Switzerland. The geological structure of the southern part of the Province of Limburg makes it a suitable place to house the facility. The Einstein Telescope will consist of three cryogenic interferometers with 10-kilometre-long arms. They will be installed in Limburg approximately 200 metres below the surface to reduce seismic noise. The instrument will register relative changes in length more accurately than they have ever been measured. The Einstein Telescope is an



unparalleled opportunity to perform precision measurements in the regime of strong and dynamic gravitational fields. This will enable us to map the universe in an entirely new manner, give us access to an energy scale that goes well beyond the limits of particle accelerator energy scales, and allow us to test our theories of gravity with ultimate gravitation.

Dutch Institute for Emergent Phenomena (DIEP)

At every new order of scale, many of the individual building blocks display collective behaviour that is rich, complex and, in many cases, unexpected. Known as emergent behaviour or simply emergence, it occurs when different parts interact with one another, linking all the possible orders of scale, from particle physics to the cosmos. The new laws and properties that determine this collective behaviour display a striking universality; they are largely controlled by overarching organising principles such as symmetry breaking, self-organisation, phase transitions, and critical behaviour.

The transdisciplinary challenges and intriguing possibility that all emergent phenomena are manifestations of the same underlying principles make it vital to bring researchers from different areas of science together. It will take a trendsetting international institute to do this, one devoted to exploring problems in the interdisciplinary field of emergence. That institute is the projected Dutch Institute for Emergent Phenomena or DIEP. DIEP will work with multidisciplinary research programmes to become an incubator for new ideas, a metaphorical pressure cooker in which researchers work in teams on multidisciplinary emergence issues. Given the importance of mathematical modelling of universal emergent phenomena and the associated numerical questions, DIEP’s researchers should also have access to highly advanced computational facilities and expertise. Another DIEP key priority is to train the next generation of scientists, who should be inspired to tackle the big research questions of their age in transdisciplinary alliances.

Education and science communication

Not all children have the same opportunity to study science. Girls, ethnic minority children and those with low-educated parents are clearly underrepresented in science programmes. The aim of this game changer is to make the student population majoring in science as diverse as the Dutch population by 2040. That way, we can take advantage of all the science talent that we already have in the Netherlands. The approach to education and science communication will be scientific and evidence-based.

Pioneering instruments

Accurate measurements are at the heart of our knowledge of the structure of space and time and the building blocks of matter. By setting up expertise centres, we can ensure that the technological know-how and experience accrued especially for these observations benefit all Dutch users. For example, the understanding of networks acquired at LOFAR can be used to speed up internet connections. The development of dedicated cryogenic detectors for the ESA's Athena mission has produced extremely low-noise sensors. Being able to measure the electronic, magnetic and optical properties of materials simultaneously will produce new insights. Instruments designed for space missions are also extremely robust and reliable, making them suitable for use on earth in extreme circumstances. By clustering our knowledge of technology in expertise centres, all Dutch researchers will be able to work at the forefront of technology and science in a cost-effective manner. The proposed expertise centres should serve as incubators for training young researchers, supporting high-tech start-ups by offering them space and shared facilities, and organising theme-based workshops for researchers at institutes, research universities and universities of applied sciences, and enterprises. The centres will actively support new users and make pioneering technological know-how available to a large Dutch user community.

Investing in opportunities

To capitalise on the opportunities we have identified, we need an ambitious programme of investment. Participation in major international projects run by CERN, ESA, ESO and others requires us to take a long-term perspective. The Einstein Telescope and DIEP offer outstanding opportunities to bring internationally unique facilities to the Netherlands.

It takes dozens of years and major international alliances to design, construct and utilise a particle accelerator or telescope. Other factors include the interplay of diplomacy, international cooperation, physics, astronomy, IT, telecommunications, control systems engineering, construction firms, suppliers and logistics. This route is therefore a multidisciplinary challenge and represents a fantastic opportunity for researchers, enterprises and engineers who can also count on the support and interest of the general public.

Circular economy and resource efficiency: sustainable circular impact

This route aims high. Its ideal is a sustainable circular economy in which we reuse raw materials in their entirety, do not produce any waste, and generate all the energy that we use sustainably. The circular economy will contribute to the long-term prosperity of our society; it will generate economic growth, secure the availability of resources, and reduce pressure on the environment. In addition to new technology, the transition to a sustainable circular economy requires structural changes in the way we shape our society. As a result, this route can be nothing other than multidisciplinary in nature.

A sustainable circular economy is based on the idea that we reuse or recycle 100% of products, components and raw materials and preserve natural resources in a robust ecosystem. This concept is the basis for achieving a better balance between resource supply and demand in the future. In a sustainable circular economy, cycles are closed-loop in nature and optimised, in part owing to the circular design of products and processes. Explicit examples of natural resources so scarce that they demand closed-loops are rare metals for industrial products and phosphate rock for agriculture. To continue guaranteeing a healthy, attractive living environment, we need to preserve and boost our natural ecosystems. A healthy ecosystem is also a natural source of raw materials and a basis for various closed-loop cycles. Renewable natural resources (especially organic ones) are an important source of inspiration in this respect.

Game changers

Sustainable circular impact from a systems perspective

In its essence, the transition to a sustainable circular economy involves our adaptation to complete value networks, from product design to new business and market models and new forms of consumer behaviour. It requires an understanding of the structures and institutions, behaviour, policies and technological advances that can impede a sustainable circular economy – or drive it forward. What changes are possible and necessary? What barriers need to be removed? And what incentives to encourage the relevant stakeholders to adopt the right behaviour are effective and acceptable?

Our approach to developing a circular economy must be completely systemic and include R&D into the necessary innovations in technology, organisations, communities, financing methods and policymaking. This poses major challenges and opportunities for new relationships and interdisciplinary and transdisciplinary research. The necessary breakthroughs must be achieved by having researchers join forces with enterprises and the authorities. Collaboration – including at international level – is needed to ensure that new knowledge is shared without delay, and to investigate the extent to which new insights are generally applicable or, for example, culturally determined or local in nature. We have yet to design, develop and implement many of the elements that will make up the sustainable circular economy of the future, but we must also identify and preserve what is good about our present-day linear economy.

Closed-loop cycles

In a sustainable circular economy in which raw materials are produced, used and recycled efficiently, closed-loop product and process cycles are crucial. Both production processes and materials and products must undergo a major transition. The life cycle of products will be extended, for example by adding value to them. Components will be designed so that the entire unit – or at least its individual parts – can be reused.

One solution is standardisation, both by modifying existing standards and developing new ones. At the end of a product's life cycle, it must be possible to recover the raw materials that make up the components and reuse them while losing as little quality as possible. This requires inspection, characterisation, separation, isolation or reprocessing.

It is also important to continue working on innovative, energy-efficient and inexpensive production processes that generate as few by-products or material losses as possible and that are as logistically streamlined as possible. New materials and new materials systems must be develop that make use of biomass, non-scarce elements and non-toxic materials. Smart materials technology can be used to avoid the use of nearly non-recyclable materials and to make recycling easier.

One example is the recycling of vast quantities of household waste, demolition rubbish and sewage water that contain valuable raw materials. After concentration or separation, such materials can be reprocessed.

In a circular food production system, water, energy and nutrient cycles are closed-loop systems at the right order of scale, ranging from local to global. And the recycling of organic material must be linked to technology cycles by developing a sustainable, bio-based economy in which chemicals and materials are made of renewable organic sources. There is much that we can learn from ecological chains and cycles in this respect, and from feedback mechanisms and interactions in complex adaptive biological systems. We must apply these principles wherever possible in order to make the transition to a sustainable circular economy.

Sustainable circular business innovation

In a sustainable circular economy in which economic value is created in an industrial network, sustainable circular product design must be combined with sustainable circular business innovation. In a sustainable circular business model, enterprises aim to achieve financial, ecological and social value creation. The new sustainable business models must be inclusive, flexible and resilient, and should always be in balance with insights derived from analyses of nature. We can make this reorientation possible by means of interconnected closed-loop biological and technological cycles. These new positions demand a new value proposition for consumer goods, for example in terms of providing access to a product or offering a result. Copiers are a well-known example: we pay to use them by print-out. The product remains the property of the producer, which can then create added value. He can, for example, design products to be sustainable so that they retain their value for longer, extend the product life cycle and improve product use during the utilisation phase, or upgrade the entire product after that phase or at least prepare their components for reuse.

Public understanding and acceptance

Implementing a sustainable circular economy requires the public and consumers to recognise and acknowledge its core values, accept the changes accelerated by circularity, and support the circular economy by their behaviour. Because many different actors will be obliged to change numerous behaviours, it is best to identify generic factors that people find motivating or that allow them to display various behaviours that speed up the development of a sustainable circular economy. It is also important to investigate when transitions from one behaviour to another can take place in various domains and situations, and how this leads to lifestyle changes. That makes it possible to explore which interventions, policies and business models are effective and needed to change people's behaviour.

For example, when is awareness-raising effective and at what point does it become necessary to facilitate or guide changes in behaviour? It is important to understand the factors that influence policy effectiveness so that policy can be optimised and lessons can be

learned and applied elsewhere. Effective public consultation and participation mechanisms can help build a basis of support for a sustainable circular economy.

Consistent policy context

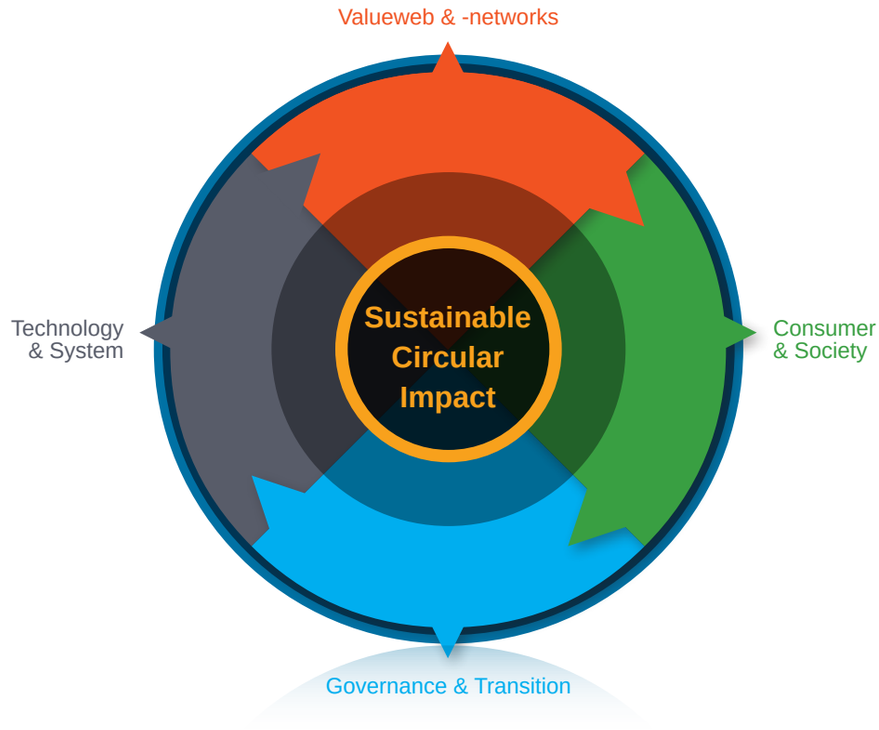
Developing a sustainable circular economy as a systems transition depends on having a consistent policy context at every order or scale, whether European, national, regional or local. Success requires a collective agenda of key themes with mutually agreed definitions, targets and indicators for the decades ahead.

The complexity and timeframe involved mean that traditional top-down planning does not work. The various stakeholders will have to engage in an iterative, collective learning process in order to work out the best future for themselves. A systematic approach is required at every order of scale, with cooperation between the levels and relevant parties being crucial at every turn. The scale aspects and interactions have received too little attention so far to arrive at a sustainable circular economy. Questions that need to be addressed include: in which domains should European nations join forces and in which should they act separately?

When is it most effective for enterprises and people to organise matters themselves, and when should government play a facilitating or coordinating role? Local innovation is the current practice among those working on the sustainable circular economy, often by social entrepreneurs. It is therefore vital that initiators and trendsetters can count on a consistent policy context that supports sustainable circularity goals.

Connections

Research on the sustainable circular economy requires an interdisciplinary approach, with researchers in science and technology, the social sciences and the humanities working together. New theories need to be developed and tested. A multi-method approach is necessary to safeguard internal and external validity.



This could include the combined study of the nature, structure and function of materials and resources, experimental research, experimental development, field trials or trial sites, questionnaires, observations, and qualitative interviews.

The disciplines involved must coordinate their approach in order to understand the interaction between raw materials suppliers, producers, consumers and service providers and the relationship between resources, manufacturing, products, services and business models. A further concern is to ensure that research can be easily converted into practical innovations. There are many secondary problems that have yet to be solved. We must therefore identify precisely where the most promising solutions might be found and which breakthroughs we need to achieve in order to make resource flows considerably more sustainable and to set up entirely circular production processes where possible.

Retaining and, where possible, increasing the Netherlands' capacity for economic growth is an important prerequisite. Many different parties in the Netherlands and beyond are working to effectuate or speed up the transition to a sustainable circular economy by applying the concept in actual commercial products and services. This route will give all these parties a platform for intensive, productive interaction.

Sustainable production of safe and healthy food

By 2050 there will be 9 billion mouths to feed on our planet. As prosperity grows worldwide, they will be consuming even more food. Unfortunately, it is becoming increasingly difficult to produce that food: water, essential nutrients and energy are becoming scarce. The soil is being depleted and farmland is being lost due to erosion. Harvests fail more often than in the past, and yields are smaller due to climate change. We need sustainable, efficient and safe food production. We must work on creating an integrated food production system that produces zero waste, spares natural resources, and enhances the soil ecology and biodiversity.

The way food production is organised today helps to ensure an ample supply of good quality, affordable and safe food products. On the other hand, economies of scale and the emphasis on efficiency also lead to soil depletion, the intensive use of pesticides, the loss of nature and biodiversity, and the impoverishment of rural areas.

Consumers have relatively little confidence in the food sector, mainly because it is not transparent and because many consumers no longer know where their food comes from. The overabundance of cheap, high-calorie food has also led to a rise in diet-related disorders, including type II diabetes and cardiovascular disease.

A necessary transformation

There is much to change in the present organisation of global food production with respect to sustainability and consumer engagement. Present-day production methods are incapable of feeding the growing world population affordable, healthy and safe food in any sustainable way. To solve this problem, we need to change the system radically, starting from new basic principles and giving consumers a fully-fledged role. This system, in turn, has to be capable of cooperating with bio-energy, bio-refinery and other systems. An integrated food production system of this kind will produce zero waste, spare natural resources, and enhance the soil ecology and biodiversity. This is the only way to ensure that future generations will have enough good quality food to eat. It will enable informed consumers to make responsible food choices, attuned to their lifestyles and life phases.

The necessary transformation requires a combination of organisational, social and technological innovations made possible by eight different game changers.

Worldwide, the Netherlands is regarded as the shining example of knowledge and innovation in the field of food production and nutrition. The Dutch Horticulture & Propagation Materials and AgriFood sectors are at the top of the world rankings in terms of scientific impact and cooperation with enterprises. Together with robust production sectors and a very advanced academic knowledge infrastructure, this powerful complex is a global market leader in production technology and propagation materials. The Netherlands is excellently positioned to work on these game changers. Precisely the high-productivity Dutch sectors are reaching their limits in terms of sustainability in our densely populated, urban landscape. All these factors combined make the Netherlands the ideal trial site for achieving trailblazing results along this route, and for exporting new solutions.

Game changers

The competent consumer

There is enormous confusion about healthy, safe and sustainable food. How does food affect me and the world, now and in the future? Eating the wrong food or excessive amounts is harming the health of huge parts of the population. It is asking a lot of consumers to make the right choices by themselves. Food that is healthy and safe for some people might be less healthy and safe for others, depending on their age, state of health and exercise habits. There is also an irrational and largely unexplored side to our food choices. We can only solve this problem if we have a better understanding how individual choices are made and if consumers are capable of making responsible food choices related to their lifestyle, life phase and their view on food safety. A better understanding of human choice behaviour and human risk perception is required. We also need to develop technology that allows consumers to immediately grasp the consequences of their actions, so that they can make conscious, properly motivated and informed choices.

Closing the loops

Agriculture and horticulture are responsible for 70 per cent of all freshwater consumption. They also account for approximately 30 per cent of worldwide energy consumption. The current food production system is also responsible for exhausting and wasting natural resources, depleting farmland, and destroying biodiversity. A radical switch from linear to circular food production systems is necessary. We can achieve this by recycling water, energy and nutrients as much as possible at the right orders of scale, ranging from local to global. That will require an integrated approach that encompasses arable farming, livestock farming, horticulture, water, energy and the chemicals industry. This approach has to involve the use of trial sites or so-called ‘living labs’ where research institutions, authorities, enterprises, and organisations of farmers, environmentalists and consumers work together in their search for strategies that will support the transition to circular production and processing methods that can be applied broadly in the Netherlands and elsewhere.

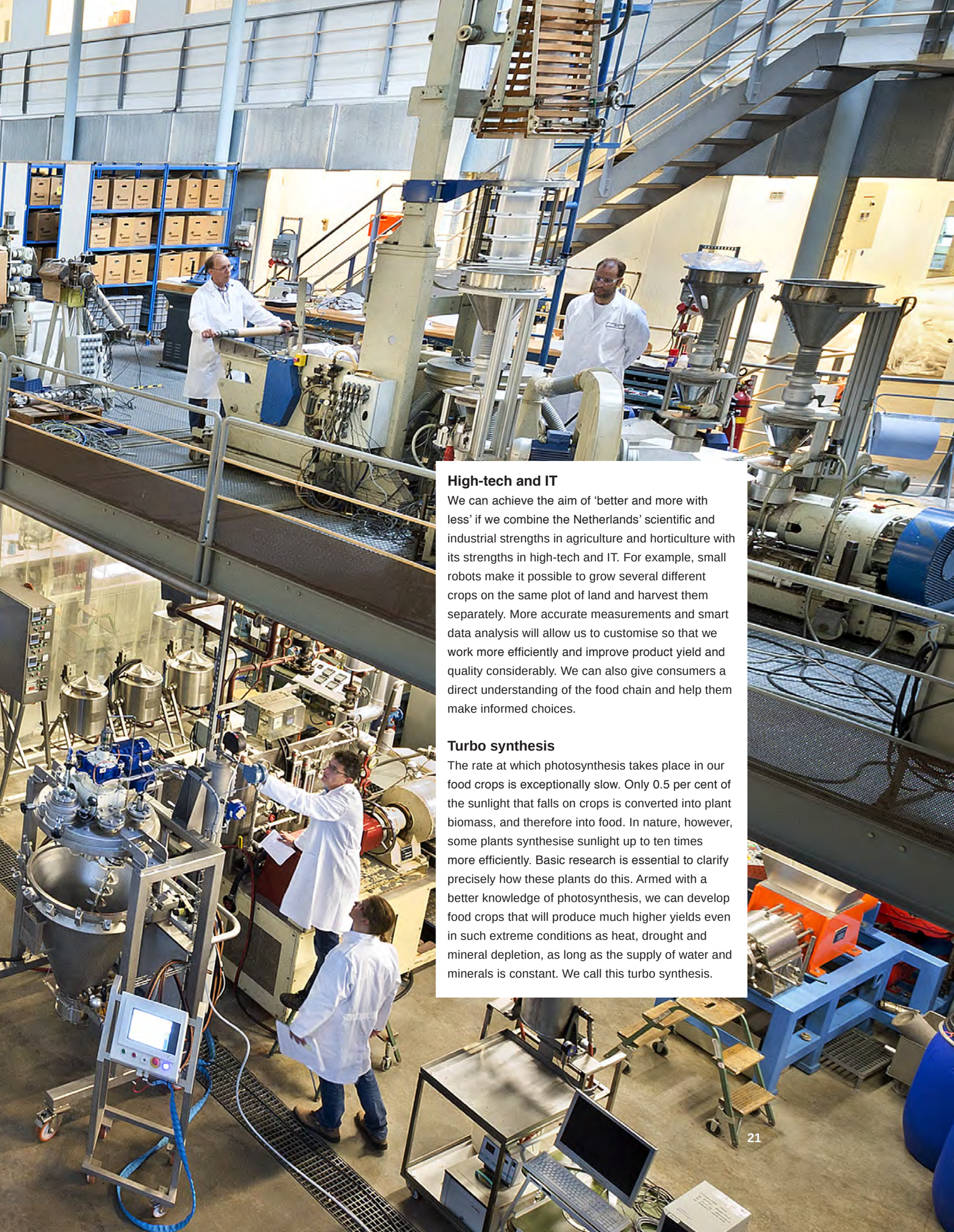
Green biodiversity

The sharp focus on production efficiency in agriculture and horticulture has made production systems more vulnerable and unstable, leading to a growing list of emergencies and corrective interventions. These interventions are related to the decline in genetic diversity, the rise of diseases and pests that might also threaten human health, the increase in stress factors such as climate change, and a drastic deterioration in soil quality.

We have to make our production systems more resilient. We can only do this by bringing back biodiversity at the various levels of our production system, leading to a resilient production ecosystem. This means utilising genetic traits present in nature, utilising the many helper functions of the microbiome in and round plants and animals, and developing new cultivation and livestock-keeping systems, for example via the transition from a monoculture to mixed cropping with the help of precision machinery.

Blue biodiversity

Food that comes from the sea – fish, shellfish, crustaceans and seaweed – is nutrient- and protein-rich. Fish is already the most important source of protein in the densely populated coastal regions of various developing countries. However, overfishing and pollution have put enormous pressure on this ecosystem. We have to make this production system more resilient. This means developing new, integrated concepts for the sustainable production of fish, shellfish and crustaceans, as well as algae and seaweeds in the shallow parts of our seas and oceans. Examples include combining offshore wind farms for sustainable energy production and natural coastal defence systems. This approach will lead to new, integrated methods for producing seafood and bio-based marine materials that can be applied in the Netherlands and other coastal areas worldwide.



High-tech and IT

We can achieve the aim of ‘better and more with less’ if we combine the Netherlands’ scientific and industrial strengths in agriculture and horticulture with its strengths in high-tech and IT. For example, small robots make it possible to grow several different crops on the same plot of land and harvest them separately. More accurate measurements and smart data analysis will allow us to customise so that we work more efficiently and improve product yield and quality considerably. We can also give consumers a direct understanding of the food chain and help them make informed choices.

Turbo synthesis

The rate at which photosynthesis takes place in our food crops is exceptionally slow. Only 0.5 per cent of the sunlight that falls on crops is converted into plant biomass, and therefore into food. In nature, however, some plants synthesise sunlight up to ten times more efficiently. Basic research is essential to clarify precisely how these plants do this. Armed with a better knowledge of photosynthesis, we can develop food crops that will produce much higher yields even in such extreme conditions as heat, drought and mineral depletion, as long as the supply of water and minerals is constant. We call this turbo synthesis.

Animal protein, but different

People need protein in their daily diet to be and remain healthy. Due to a growing population and rising prosperity levels worldwide there is a rapid increase in the demand for protein-rich food. This game changer provides the development of a protein-producing platform for global protein production, radically different than existing methods in agriculture, livestock farming or fishery. The essence of this game changer combines several different categories of expertise: about animal proteins and protein synthesis including folding, transport and storage; about efficient production systems; about economies of scale, reprocessing and processing; and about safety and consumer acceptance. All this will give rise to a protein production platform that can produce the right amino acid, peptide or protein pattern on demand, sustainably and efficiently, in any quantity or manifestation desired, anywhere in the world. The end product will be entirely in line with consumer wishes. This 'different' animal protein can solve many problems resulting from our current, inefficient alternatives.

Nutrition security and inclusiveness

The robustness of the world food system depends on many different factors, including the efficient use of natural resources (soil, water, minerals and labour) and resistance to diseases and pests. Trade, pricing and logistics also play important roles, as do such societal factors as inequality, regulatory systems, urbanisation and education. How these factors influence the way the world food system operates differs greatly from country to country and from region to region.

By focusing on healthy and sustainable food, and by examining the governance of the global food system, this route will offer scalable solutions that will make overall food production, processing, distribution and access more efficient, effective and fair. This cross-sector approach is an important part of the solution because it not only develops new options but also boosts synergies between component solutions originating in other disciplines, thereby allowing for many different natural and socio-economic circumstances worldwide.

Energy transition

The purpose of this route is to build a sustainable and secure energy supply and a strong, green knowledge-based economy. To keep the global temperature rise well below 2° Celsius and ensure energy security, we must make radical and rapid changes to our energy system. With an integrated approach, the Netherlands can take its place among the world's leaders in the energy transition. This also provides an opportunity to build a strong green knowledge-based economy, to create jobs in the sustainable energy sector and to strengthen our export position.

The Netherlands has taken important steps in recent years towards achieving a sustainable energy system. The urgency and complexity of the transition and increasing international competition imply that much more is needed, both in terms of quality and quantity. For example, even economically attractive technical solutions are not automatically implemented at a large scale and even a carefully developed policy incentive does not automatically result in market success for sustainable energy technologies.

The game changer for a successful transition to a sustainable and secure energy system is an integrated approach to technical, social, economic, legal and spatial challenges that allows excellent building blocks to be implemented quickly and on a large scale.

Cooperation is necessary between the humanities, social and behavioural sciences and the natural sciences and engineering; the government, knowledge institutes, the business community and non-governmental organisations; and between various economic sectors. The urgency, complexity and increasing competition also imply that a higher ambition level is required in terms of energy innovation if the Netherlands is to achieve optimum economic benefit from the opportunities that the global transition presents

This route goes right to the heart of the Netherlands' energy and climate policy and is consistent with *Mission Innovation: Accelerating the Clean Energy Revolution*, an initiative taken by countries that aim to accelerate the transition and that made agreements at the COP21 Paris climate conference to do just that

Ten challenges for the energy transition

This route describes ten important and urgent Challenges that need to be addressed in long-term programming in close collaboration between public and private parties. If it is to be successful, such a programme must include all aspects, from basic research to development, demonstration and implementation, and including 'living labs'. Only then can pioneering innovations find their way into the public domain and the market, quickly and on a large scale, and truly accelerate the energy transition. And only then can the Netherlands seize the economic opportunities available in this highly competitive international sector.

Buildings as power plants and vehicles as energy buffers

Not only can buildings and vehicles be made much more energy-efficient, they can also be given an active role in the energy system. New and better technologies, products and services can optimise the energy performance of buildings, building clusters or urban areas, and combine this with comfort, convenience, attractiveness and lower running costs. In addition, the fast, cheap, low-risk and low-impact 'deep renovation' of existing buildings makes it possible for the large existing stock to successfully contribute to the energy transition. Buildings and vehicles act as buffers between a variable energy supply and demand for low-temperature (residual) heat or electricity; market models and legislation are optimised for such applications; owners, operators and users are encouraged and motivated to use buildings and vehicles for this purpose.

Clean and flexible industry

Industry will go through a transformation: from being just a user to being an energy user and a supplier of flexibility and storage. Future production processes will have no net CO_2 emissions, they will be much more energy-efficient and will use sustainable resources. Sustainable energy (electricity and heat) will replace energy from fossil fuels. Biomass and captured CO_2

and nitrogen from the air will form new sustainable raw materials, with potentially negative emissions. This requires technologies and processes that are much more energy-efficient than those currently available, that have the flexibility to absorb fluctuations in the supply of raw materials and renewable energy, and that involve low investment costs. In the long term, this transformation will close loops and enable regions to be largely self-supporting in terms of energy and raw materials.

Every surface generates sustainable energy

Sustainable energy generation is a corner stone for a sustainable energy economy. This means highly efficient and cheap solar, wind and geothermal energy applied on a large scale and in an attractive, socially acceptable way in the limited space available in the Netherlands: buildings, infrastructure, landscape and the subsurface. Sunlight-to-electricity conversion efficiency needs to double. Flexible solutions need to be developed for integration and function combination in buildings and other objects. Fuel production using sunlight will become a fully-fledged component of the energy system. The potential for the compound use of the sea (combinations of wind, sun, bio-energy, bio-materials and energy storage) will be unlocked and the value of offshore wind energy will increase. The use of geothermal energy will be economically sound and sustainable. Integrated spatial development models will support the large-scale introduction of sustainable energy generation.

Intelligent energy systems

Advanced ICT combined with smart networks is required to get centralised and decentralised sections of the energy system and its users working effectively and efficiently together with the variations over various timescales and to guarantee reliability, availability and affordability. The collection and use of big data that is relevant for generation, storage, distribution and consumption is crucial in this. Furthermore, ICT can stimulate users to make sustainable use of energy and can be used to achieve energy savings. Critical design factors are public acceptance, ethical aspects, autonomy, robustness, privacy and cyber security.

From electricity to fuel and heat

Parts of the transport sector, such as aviation and freight transport, as well as industry, depend on fuels with a high energy density and on high-temperature heat (typically chemical processes at temperatures exceeding 100-120 °C). To increase the sustainability of these sectors, scalable, cheap and efficient chemical processes are required that convert electrical energy into fuel using biomass, captured CO_2, nitrogen or water. Technologies are also needed for the cheap and efficient conversion of electricity into high-temperature heat. This requires research into new, efficient electrocatalytic and electrochemical processes with a high product selectivity, including research into new catalysts based on abundant elements.

Dealing with variations

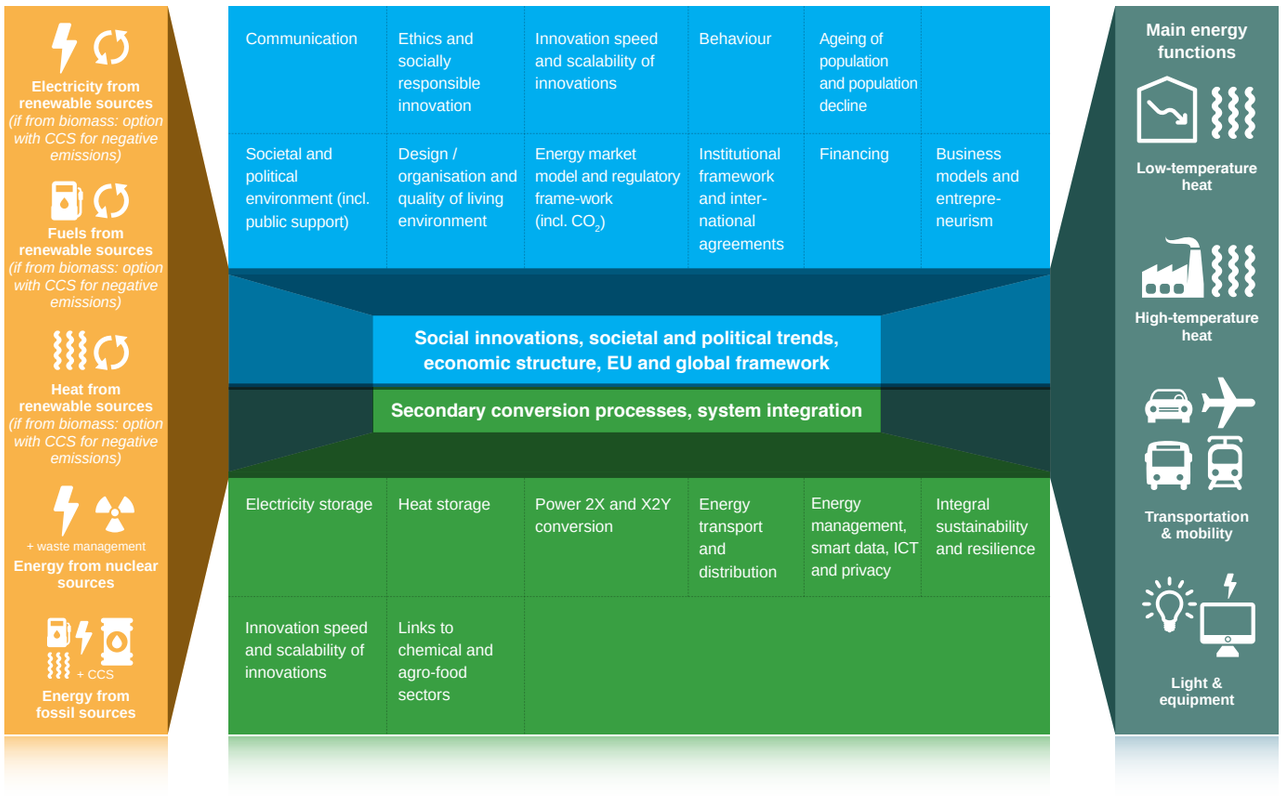
Energy supply and demand will vary in time and place in the future energy system. This therefore requires research and development on flexibility on the side of the energy consumers, with user behaviour and acceptation as important factors. Also important is the development of balancing, transport, distribution and storage technologies for electricity and other energy carriers. To create a society in which there is an ideal match between supply variations and different timescales of sustainable energy, we need to develop an effective economic plan and new governance models and legal frameworks.

Measure, analyse, adjust

It is crucial to measure the effect of the energy transition on emissions of CO_2 and other greenhouse gases and to analyse the impact of reduced emissions on climate change. We must keep analysing the greenhouse gas emissions of individual products in the product chain (CO_2 footprint). As well as greenhouse gas emissions, secondary effects will be measured, such as improvements in air quality. Such analyses can be used to optimise the pathway chosen. Conversely, we also need to learn more about the effects of climate change on the energy system and beyond so that we can be proactive in limiting the negative effects. Effective communication of the results with all stakeholders, including end users, is important as well.

Rapid switch to a CO_2-neutral society

A complete switch to a CO_2-neutral energy system within a few decades demands an unprecedented fast rate of innovation and social change. Social, economic and legal instruments that form the basis for very rapid innovation and the application of new practices will need to be developed. Attracting the investments needed for the transition to a sustainable energy



system also presents a big challenge. An important theme is how to generate effective incentives to stimulate efficient and sustainable energy use and to reduce emissions. Well-founded policy choices and effective interaction between the general public, the public sector and the private sector are crucial in this. Particular attention is required for the opportunities available to achieve negative CO_2 emissions in order to further accelerate the switch to a CO_2-neutral energy system.

A CO_2-neutral society will be different

A CO_2-neutral energy system will probably look very different from our current fossil fuel-based society. It is very important to properly understand the changes that will take place due to the transition to a CO_2-neutral energy society. Insight into the societal changes within and beyond the energy sector is important to be able to manage the transition process and to adjust it where necessary. Elements of this transition include a different spatial design, a transition to circular processes, new forms of transport, infrastructure for energy carriers (electricity, hydrogen, etc.) and changing lifestyles.

Public acceptance of certain solutions will also determine the resulting transition process and societal structure.

The Dutch transition in a global context

The transition to a sustainable energy system is a global process and therefore requires a global approach. It involves international research and policy efforts to learn from one another, to understand the conflicting interests that hinder a sustainable energy transition and why these exist, and to learn how to harmonise interests. It also requires a coherent approach in which the costs and benefits of the transition are evenly distributed. Another requirement is an understanding of cultural differences in preferences, behaviour and acceptance, as well as opportunities for guaranteeing global access to energy while maintaining national security of supply and reducing climate problems. Finally, a comprehensive, global chain analysis of energy and material flows and insight into the effects on people and the environment will enable a socially responsible energy transition to take place. ‘Think global, act local.’

Health care research, sickness prevention and treatment

By 2030, 7 million people in the Netherlands will suffer from one or more chronic disorders. That is 40 per cent of the Dutch population. The health care system will come under growing pressure as a result. Unless we intervene at short notice in a number of different domains, financial and staffing shortfalls will be inevitable. To ensure that our health care system is future- proof, we need a new perspective on health that acknowledges the differences between people and corresponds more closely to their personal experience.

This route has four game changers:

A new perspective, a new research paradigm
To begin with, we must come to regard health as a basic condition for doing what we find important: participating, playing a role in society, leading our own lives. That is a different and broader view than the prevailing biomedical model, which focuses on sickness. We must strive to promote the concept of 'positive health', in which actions are guided by the desires, values and preferences of the individual. Positive health means focusing not only on what someone with an illness is still capable of, but also on that person's perceived quality of life and the extent to which he or she can participate in society.

To implement the concept of positive health, we must be more aware than we are now of variations between individuals: variations in norms, values and goals, but also in lifestyle, behaviour, environment, genetic disposition, and above all in the body's response to healthy and pathogenic stimuli.

The biomedical definitions of ‘healthy’ and ‘sick’ only match with individual experience to a certain extent. For example, there are many people with known disorders who feel fine and simply participate in society. But there are also many others who feel sick even though no objective biomedical cause can be found.

To make this new approach possible, professionals need new and supplementary knowledge. The large-scale comparative studies that form the basis of medicine today are and will remain valuable, but they cannot provide all the information relevant for individuals. We also lack valid and sensitive measures for many disorders that allow us to track and predict outcomes. We need new research methods and outcome measures to supplement existing methodology. Where our current concepts of sickness and health are inadequate, we need new instruments to ‘measure what ought to be measured’. What is vital for future health research is a broad, interdisciplinary approach in which the public/patients, organisations and co-funding bodies also play an important role.

Investing in sickness prevention

For society to have a healthy future and affordable health care, effective sickness prevention is crucial. But our existing knowledge is not enough. For example, it remains difficult to reach groups at risk, like persons of low socioeconomic status and vulnerable elderly people.

We need to study the interaction between individual and environment in the broadest sense of the word. In addition to sickness prevention among groups and populations, we should also be studying and applying the concept of personalised prevention. It is also important to research how prevention can be integrated permanently into the social fabric. We can make substantial gains by applying a systems perspective that considers all the various factors, including social, psychological and economic ones.
Large-scale databases (big data) can help us develop targeted interventions for depression, anxiety and other disorders and for lifestyle-related diseases such as diabetes, cancer and cardiovascular illnesses. Prevention is not simply about avoiding the disorders themselves but also about promoting participation (in employment) and avoiding loneliness, immobility and all the other problems that keep people from leading their lives as they see fit.

A new perspective on treatment: personalised and regenerative

To ensure that the chronically ill continue to have access to affordable and feasible care, we need new approaches to treatment, such as personalised medicine and regenerative medicine. Personalised medicine should make safer, more effective care possible because it is based not on the ‘average’ patient but on the specific individual. Regenerative medicine – which involves the repair of damaged tissue by regrowth – holds the promise of actually curing some common chronic diseases, with potentially enormous gains in terms of quality of life but also in terms of cost and staffing efficiency.

Investigating care

We must specifically investigate health care and health care systems to ensure that findings in other countries can be applied in ways appropriate to the Dutch situation. The health care system of the future requires a new perspective on the role of care professionals, individuals, researchers and organisations. Positive health appears to depend in part on the amount of green foliage in a neighbourhood, social cohesion, not being in debt, the extent to which people are encouraged to cycle and take the stairs, and the layout of a supermarket or school building. There is still only limited scientific evidence for this, however.

Research must also reveal what is needed to implement and scale up interventions on a structural basis and how to make lasting improvements to care processes.

Data-related infrastructure, access, thinking and expertise

One very important and specific prerequisite for the developments described above is to have an advanced data infrastructure consisting of existing and new studies and documentation. However, sickness prevention and the promotion of positive health will require much more data from differing sources, ranging from local councils to building firms, from supermarkets to fitness centres, and from Facebook to health apps. This type of data allows researchers to look at individuals. That is not usually possible at the present time owing to privacy concerns, but also for reasons of prestige and a possessive attitude towards datasets. We must give considerable thought to data in the years ahead and study the technical, ethical, legal and societal aspects of data access and data use. Thinking about data also means developing new methods to derive the most reliable knowledge possible from the available data. However, the Netherlands has not acquired sufficient expertise in the field of data science. Recruiting and training data science experts should therefore be given top priority.

Technology and Health Technology Assessment

Regardless of how personalised medicine and prevention will be organised, technology will play an essential role. To some extent we can build on recent groundbreaking technological advances, specifically in IT. These include sensors and apps for smartphones. In other cases, targeted technology will need to be developed, for example intelligent measuring instruments, labs-on-a-chip, nanomedicine and technologies in such areas as genomics, metabolomics and proteomics.

Both science and enterprise must be involved in developing new technological applications. The human factor is vital for the successful implementation of technology; professionals and other users, such

as patients, must therefore be involved at an early stage. In addition, technical applications will need to be evaluated to guarantee their quality and to prevent their development from driving up costs unnecessarily. The methods that we use to evaluate technology and determine its effectiveness and cost-effectiveness – known as Health Technology Assessment or HTA – will need to be updated to keep up with changes in the supply of and demand for care.

New forms of cooperation

Who is better able to tackle the epidemic of diabetes, arthrosis and other comorbidities related to overweight: doctors, gym teachers, supermarket owners or urban planners? Can we compare and connect such diverse approaches? What we know for certain, in any case, is that original new forms of cooperation, research design and data analysis are required for truly effective prevention, for personalised and regenerative medicine, and for innovative health care research. Changes that are already taking place, for example cooperation between university medical centres, universities of technology, social sciences faculties, applied research institutions, and universities of applied sciences, must be extended and broadened. It is important to set up trans-institutional initiatives and teams composed of an unconventional combination of disciplines, and to break down obstructive conventional barriers between disciplines and sources of financing. We must explore the potential for co-creation with patients, enterprises and other stakeholders who are not normally invited to participate. Innovation also means parting with the old. Ineffective and even harmful forms of research should also be identified for that reason. And once we discover new paths, we must not put off bidding the old ways farewell.

Financing and new forms of financing

A major investment is required to future-proof our health care system, specifically with regard to sickness prevention. Investments in prevention-related research have traditionally been modest compared to the total cost of care. We must bring the two more into balance with one another. The new scientific outlook on prevention, treatment and care should impact the design and financing of research programmes. We can already begin experimenting with new forms in the years ahead by rewarding interdisciplinary cooperation and removing obstructive incentives. We must explore new forms of cooperation and integration between sources of financing. At times, that may require us to change the rules, for example so that insurers can also invest in research. New publishing paradigms and new methods for measuring research output can also help drive innovation in the pursuit of science.

On towards the future

This route advocates setting up an interdisciplinary taskforce made up of experts on prevention and treatment in the biomedical and social sciences as well as representatives of other disciplines and sectors, such as urban planning, data sciences, marketing and e-health. The taskforce will survey and connect existing initiatives and present arguments, details and an expenditure plan for the necessary investment.

Child and adolescent development, upbringing and education

The 21st century is throwing up challenges in such diverse areas as technology, the internet, relationships, ethnic-religious diversity, employment, sustainability, urbanisation and globalisation. All these challenges require a new perspective on how we are preparing children and adolescents for their future. By making them a priority, we invest in new research that can help create a healthy, safe and fair society for the next generation.

What do children and adolescents need in terms of upbringing, education and guidance to allow them to make a positive contribution to society in the 21st century, both now and in the future? That is the key question of this route. It reflects society's growing demand for proven, effective and equitable methods of promoting child and adolescent wellbeing and development, so that youngsters grow up to be adults who make a positive contribution to society in the future. A good education and effective prevention and interventions in upbringing and teaching are the keys to success in many areas of human endeavour. Together they can significantly reduce the cost to society of health care, social and economic deprivation, and crime. Conversely, a well-educated generation of critical and engaged citizens can contribute directly to building a safe, healthy and just society. The knowledge generated by this route is thus vital to creating a socially and economically successful society.

Game changers

This route promotes an innovative approach that puts children and adolescents at the centre of an integrative research agenda. This gives rise to at least three important issues that may well serve as game changers in future research.

Learning and development in different contexts

Youngsters learn and develop in different contexts, relationships and networks. The interaction between those contexts has largely been neglected by researchers. Research into the complex interaction between the various social contexts in which children and adolescents grow up may produce new insights about how today's younger generation is developing. How can schools make better use of what children learn at home, online or otherwise? How can parents be more effectively engaged in their child's education at school and support its cognitive and social development at home? What skills should teachers and other professionals master to put children's needs at the centre, to motivate them actively to learn and to integrate their different realms of experience? How can different forms of learning within and between contexts be used most effectively to optimise child and adolescent development and to prevent learning deficiencies or socio-emotional problems? And what does this require from schools and teacher training and from pedagogical organisations and training programmes? There are also key areas in development contexts that call for a more integrative approach to research, for example continuous learning pathways between preschool, primary, secondary and higher education, or different phases in family development and the relationships between various family members. This approach allows for the complexity of child and adolescent development in differing contexts and differing development phases.

Diversity and inequality

Children and adolescents come from different backgrounds and have different personalities. Too often, such diversity means inequality in their starting positions, in the opportunities available to them, and in the effectiveness of prevention and intervention. Research is needed into the factors that influence the intergenerational transmission of disadvantages and risks, from low literacy to child abuse.

We must also explore how to stop this transmission. Another requisite subject of study is inequality arising from existing and new structures and practices in education and upbringing, for example early selection, approaches to multilingualism, and the rise of homework classes paid by parents. Researching individual differences in development and learning and using that knowledge to devise personalised interventions and upbringing and learning environments will, in turn, produce other new insights. For example, how can testing and assessment be optimised to produce guidance and advice that does justice to a child's abilities? Finally, researchers must look into how we can recognise and encourage the power of diversity in child and adolescent development. What pedagogical and educational interventions offer an effective means of promoting social cohesion, so that diversity is a positive rather than an obstructive factor in communities, schools and cities? By studying diversity and inequality at all levels – from individual to policymaking – research on these issues will gain a new impetus and the results will find their way more directly into policy and practice.

Normativity of upbringing and education

What is the aim of upbringing and education? Proposals concerning the knowledge, skills and attitudes that the future will require, for example problem-solving ability, creative thinking, engaged citizenship or digital literacy, are always based on a specific point of view. However, the underlying norms and aims of upbringing and education are seldom an explicit topic of discussion or study in practice or research. Theoretical research is needed to provide a basis for new upbringing and educational aims. Empirical research is necessary to answer such questions as: What do parents, teachers and youth care professionals see as important to children in the 21st century, and what role do cultural and socio-economic factors play in those views? Are the interests and rights of children sufficiently well served by the policy and practice of upbringing, education and guidance? Do current pedagogical and educational contexts give parents, teachers and other professionals enough to go by? How can we involve children and adolescents in deciding what is important for their own future? Such questions can be traced back to key issues in pedagogy and are crucial to underpinning the type of research that will produce answers to the questions society faces.

Connections

In order to answer the key question addressed by this route, we require a combination of basic research, practice-based research and policy research. These different forms of research are linked by their explicit concern for applying evidence-based insights in the actual practice of upbringing, teaching, youth care and health care. Because child and adolescent development takes place in a myriad of contexts, a multidisciplinary approach is necessary. This route links the traditional disciplines of child and adolescent studies, for example pedagogy, developmental psychology and educational theory, to allied disciplines such as children and family law, sociology, cognitive psychology, the neurosciences, linguistics and communication science, medical science, philosophy and ethics. It also encompasses other disciplines generally less closely involved in child and adolescent matters but crucial to an integrative approach, for example public administration, change management and spatial planning.

This route explicitly aims to connect empirical research with the valuable experiences of children and adolescents and the practical knowledge of professionals – teachers, youth care workers and paediatricians – who work with them every day. The involvement of those who train these professionals is at least as important. Interaction between science and everyday practice can bring about a better match between research and society's needs and expertise. This route also emphasises the importance of researchers collaborating with local and national government, interest groups, regulatory bodies, enterprise, ICT and the media.

On towards the future

To effectuate the changes identified here, new multidisciplinary and interdisciplinary research programmes will be needed. A structural collaborative structure is indispensable for research activities arising from the questions posed by practice-based institutes and professionals, for example in the form of academic laboratories focusing on these game changers. To determine whether interventions developed by these alliances and in other contexts are actually effective, effects studies will also be necessary. This type of research will identify the operative factors that practitioners can also use, boosting the impact of this route considerably.

The activities outlined above can build on existing structures, but only after they have been fortified. One example would be to extend the partnerships entered into by research universities and universities of applied sciences to the local and regional level. The NWO and the NRO (national coordinating body for educational research) should furthermore assist in setting up a national infrastructure to facilitate national programme funding for interdisciplinary research and new forms of knowledge valorisation.

This route prioritises children and adolescents in all their development contexts. In doing so, it takes a coherent and integrative approach to the issues involved in education, upbringing and child and adolescent development that is entirely in line with the Dutch National Research Agenda. This is important because many of the major challenges facing society basically start in childhood and necessitate a more integrated perspective. In this way, we will come to understand what children and adolescents need from upbringing and education to optimise their development and make a positive contribution to society.

Art: research and innovation in the 21st century

The arts raise important questions about the meaning and impact of societal trends and new technologies. They not only play a key role in envisaging these trends, for example through narrative, images, film, games and installations, but also furnish scenarios that force us to think about the political or ethical implications. In addition, they challenge us to come up with new, innovative solutions.

This route aims to connect the practices and investigations undertaken by artists and designers, research in the humanities, social sciences and natural sciences, and creative firms and civil society organisations whose aim is to preserve and disseminate culture and take it forward. The underlying issues connect creativity research, cultural analyses, science and technology studies, and artistic and design experiments with pressing trends in technology, ethics, care and education. Connecting science and art enriches the scientific and public discourse, allowing us to question the ethical aspects of new trends, such as bio art and design. New connections between academies of arts, universities, heritage institutions, exhibition facilities, festivals and creative enterprises are hugely important to boosting the ecosystem of the arts and making a powerful and explicit contribution to society.

Game changers

This route is innovative mainly because it connects artists and designers, the social sciences, natural sciences and humanities, professional arts programmes, cultural enterprises and the creative industry and gets them working on a common research agenda. This alliance of the arts, science and society will address three questions.

The arts as the driver for innovation and reflection in a high-tech society

Creativity is essential for a knowledge-based society that is constantly reinventing itself. The arts and design practice already focus on creativity as a matter of course. The artistic experiment can serve as a model for the process of creation in other domains. In this way, the arts offer a different perspective on issues in such other domains as health care, management or politics. Applied arts and design practices can give us new and unsuspected views of societal, economic, political and technological issues. A knowledge-based society that is capable of exploiting this potential will be better able to respond to new contingencies as they arise.

This game changer also concerns the impact of technology and digitisation on the experience of being human. What does it mean to be human and how do we organise and continuously reinvent ourselves? These are age-old philosophical questions. The arts also ponder these questions and offer alternative forms of knowledge and insight that will grow more important as technology increasingly influences every aspect of being human, drives progress forward but also constantly introduces new and sometimes unpredictable issues.

Technology is fundamental to what it means to be human. Today's technology is becoming more invisible, however, and that makes it harder to grasp or comprehend. The arts are capable of illuminating, magnifying and exposing these invisible dimensions and raising them for discussion. The applied arts, design, fashion, performing arts, film and architecture are all needed to create new possibilities. These possibilities will become part of our dynamic living environment and help us accept changes, whose implications should, without exception, be subject to critical questioning. The arts take us out of our comfort zone. Given the rapid pace of technological progress, it can be said that human beings will constantly be taken out of their comfort zone. By offering us a critical, creative and investigative perspective, the arts can become one of the important training grounds for the 21st century.

The arts influence high-tech society in that they drive innovations by offering new perspectives on technological applications. They also utilise the design and creativity central to artistic practice to produce innovations in other domains of society.

Finally, they take technology out of the realm of the invisible and unmentionable, offering us food for thought and an understanding of its possible consequences.

The arts as an alternative form of knowledge generation

Besides developing theories, science is increasingly concerned with forms of knowing and understanding that are embodied and situated in practices and objects. Insights drawn from science theory, cognitive science, and cultural and human studies converge with insights that are the focus of practice-based research, especially artistic and design research: the methodological importance of what specifically occurs in the process of creation and the epistemological importance of what that process produces. The agenda for artistic or design research therefore corresponds to broader innovations in science and scholarship, specifically in the humanities.
This reinvigorating agenda has consequences for the way in which we think about any kind of research. We see that the focus is shifting towards other forms of knowledge generation; after all, we know more than we can express. Artefacts – images, designs, installations, compositions, performances and so on – are ideal for giving people a fuller, deeper understanding of who they are and how they relate to the world and to others. These alternative forms of knowledge generation merit specific attention precisely because they allow us to tackle the challenges that we are facing as a society. The arts and artistic investigation are the focal point in this context.

The arts influence the way we tackle societal challenges because the artistic process of creation produces a different type of knowledge than the knowledge gained through the traditional scientific approach.

The arts as a source of inspiration for education and lifelong learning

Although the importance of arts education is often acknowledged, the Dutch education system pays too little attention to artistic expression and creativity. Recent initiatives, for example the 'More music in the classroom' project, are meant to address this shortfall. The problem is deeper, however, and touches on the role of creativity in all school subjects and at every level of education. Insights gained in creativity research in social psychology, neurology and the humanities have little if any influence on educational theory and pedagogical and didactic practice.

There are opportunities here to work with professionals, educational institutions and researchers to extend the limited views held in education about 'cognitive skills' and to invest in creativity and in research on creativity across the entire spectrum of lifelong learning, from primary school to higher education. This issue corresponds with the international efforts to extend the focus on science, technology, engineering and mathematics (STEM) to the arts (STEAM) by recognising the importance of the arts in education and research and by subscribing to the expectation that future job-seekers will increasingly need to possess creativity as a core competence.

The issue goes beyond in-school education, however. Lifelong learning and the meaning of creativity in that context are equally relevant for small business owners, freelancers and line managers. New didactic methods and experiments, such as living labs, can be applied in a wide range of contexts. New materials and techniques, for example Massive Online Open Courses (MOOCs) or sensor networks, reach beyond the domain in which they were invented. The experimental practice of creation and co-creation in the arts offers a framework for investigating the subject of creativity in lifelong learning.

The arts impact education and lifelong learning because they offer guidelines for educating critically engaged and creative citizens and professionals, with the didactic methods of the arts academies and artistic practice serving as examples.

Research infrastructure

Universities and arts academies have recently started seeking to cooperate with a view to promoting research in and into the arts by means of cross-fertilisation. One of their aims is to give artists greater access to PhD programmes. Although it is clear that the arts are capable of producing outstanding quality on a limited budget, more must be invested in research in this sector, not only to act on the game changers described above but also to boost the international competitiveness of the Netherlands.

Compared with our neighbours in Europe, the Netherlands provides only a small amount of funding for R&D in the arts. Most arts programmes can be found in higher professional education. The research networks linked to these programmes, meant as laboratories for practice-based research, are limited in size. In addition, much of the research in the arts and culture is carried out by the humanities faculties at various universities, where funds are also limited.

This is the moment when we must reinforce the growing connections, alliances and innovation within the arts sector and related scientific disciplines. The main aim is to expand and extend their innovative impact on society and the economy. That is the only way to achieve the ideal: giving the arts maximum impact.

Quality of the living environment

A well-functioning living environment is vital to prosperity, wellbeing and health. Our environment is the source of clean air, healthy food, sufficient clean water and many other natural resources. It also creates opportunities for housing, work and leisure, and our experience of it contributes to health and happiness. To anticipate changes in our living environment, we must map out all these factors and how they interact and analyse how individuals and groups relate to their surroundings.

We can only maintain our current system of production and consumption – which increasingly involves transporting raw materials and products around the world – if we shift the problems caused by this system to other regions and future generations. This has worked for a long time, but it is making the socio-ecological system increasingly vulnerable.

Sustainable solutions need to be based on scientific evidence concerning the many factors that contribute to the quality of the living environment, how they are related, and their interdependencies. Linking all these factors therefore requires an innovative, integrated, transdisciplinary scientific approach in which researchers connect with the public, administrators and other stakeholders, for example civil society organisations and enterprise.

The core of this approach consists of a broad, integrative framework that combines all sorts of activities, processes and their interactions along various dimensions and the appropriate orders of scale. A framework of this kind must be constructed with input by experts in the natural, behavioural and social sciences. It should be tested directly and refined in realistic living labs. Living labs are knowledge-driven collectives in specific domains in which government, enterprises, NGOs, private parties and knowledge-based institutions work together to develop new, sustainable ways to use space that do not conflict with current environmental conditions. There are four potential game changers.

Nature-inclusive societies

It is and will remain a challenge to make sustainable use of our natural resources while protecting nature at the same time. How do we connect nature to the public and other stakeholders? If we want to change society, how do we guide enterprises and entire sectors towards a more sustainable utilisation of natural capital? How do we generate support for nature-based solutions among those who give shape to the living environment? What forms of governance and guidance are effective and legitimate? How do we adapt existing government policy to create more scope for synergy and societal innovation with the right amount of conservation land as part of the solution? How do we make policy more consistent at different orders of scale? And how do we measure progress and success? To answer all these questions about more sustainable, nature-inclusive societies, we need to carry out transdisciplinary research in which communication science plays a key role.

Landscape and sustainable use of space in a rapidly changing living environment

The landscape is the result of the dynamic interaction between nature and culture. It is part of our cultural heritage and, automatically, an arena for new interventions. Spatial challenges require research that not only focuses on survey and analysis, but also on designing and converting the potential of the landscape and the interaction between landscape, nature, wellbeing and health. It is vital that the public should be involved in landscape changes, for example through its input into

such themes as ‘landscape and identity’, but also by undertaking forms of citizen science. The research must concentrate on the aim of designing far-reaching spatial transitions in such a way that the landscape of the future will gain or maintain its outstanding quality and that we can build on existing features as much as possible.

Sometimes multiple ecosystem services can be obtained from the same location, for example biodiversity, water and food supply, and flood safety. In other cases, we need to make choices in order to secure specific ecological, cultural or economic core values. We can only determine which approach works best where if we undertake innovative research. We also need to connect resources that are now often regarded and managed as separate compartments: land and water, soil and substrata, culture, nature and health. We know too little about the interaction between ecosystem services, scale dependencies, resilience, the protection and recovery of species and functional biodiversity, communities and ecosystems, and how to link ecological, geological, sociological and economic approaches. Living labs can help us develop innovative solutions for the sustainable use of space. These living labs play a major role in ongoing data collection, monitoring and integration and can therefore complement the Landscape Observatory, in which various partners are cooperating to guarantee the quality of the landscape.

Living environment and health: the exposome

How does the combined exposure to multiple environmental factors – including air pollution, electromagnetic fields, noise, pesticides, hormone-disrupting substances and heat – affect an individual’s health? How do landscape factors influence health? And does that change from one life phase to the next? So far researchers have mainly investigated separate factors. Knowledge about combined exposure makes it possible for the first time to develop measures to avoid combined effects on health. The challenge for researchers is to integrate large quantities of different categories of data so that they can draw conclusions of practical value. The living environment has a major influence on our health. In the Netherlands, 12 per cent of mortality can be ascribed to environmental factors such as particulate matter. We know little about the effects of cumulative exposure and exposure to combinations of different environmental factors throughout an individual’s lifetime. To study this, the revolutionary concept of the ‘exposome’ has been introduced. This important and necessary innovation characterises the overall internal and external exposure of individuals to the totality of environmental factors throughout their entire lives. The exposome integrates all these factors. Thanks to new sensor technology with an extensive cover ratio, spatial modelling, apps and rapid advances in such disciplines as genomics, metabolomics and proteomics, we are increasingly able to apply this concept in practice. Various forms of citizen science can also contribute.

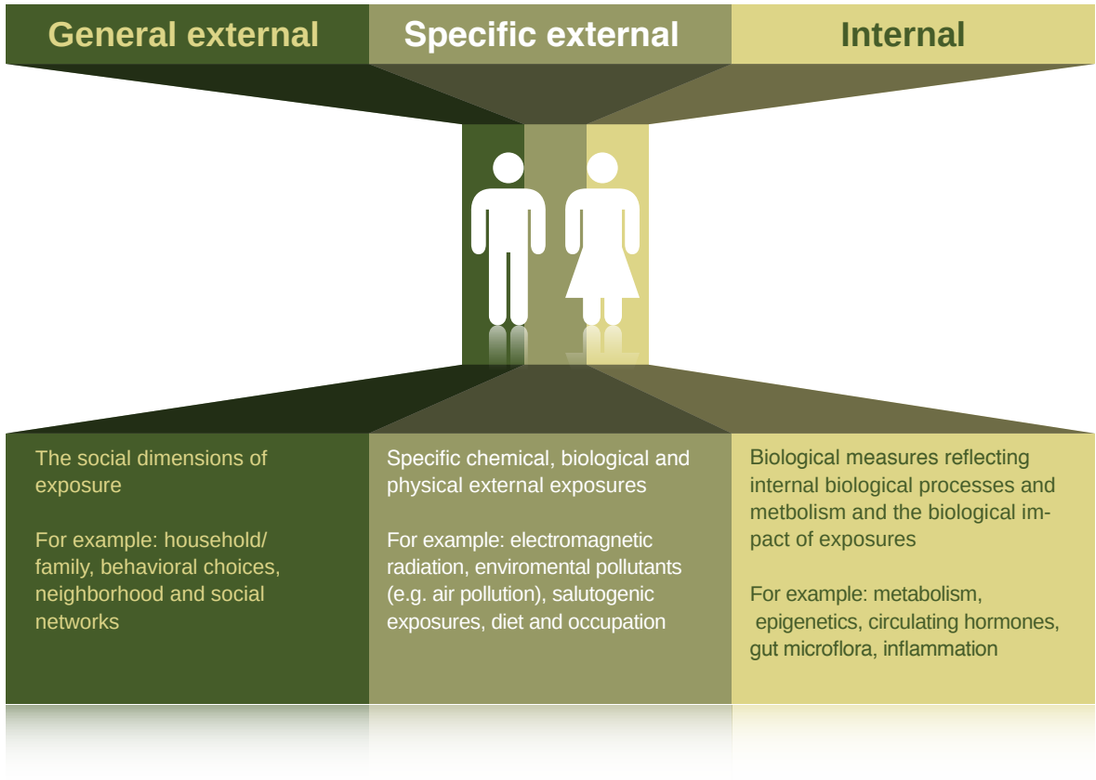
Resilience as a unifying concept for socio-ecological systems

The quality of the living environment is determined by ecological, social and economic factors and changes in those factors. These processes are closely related, both in their spatial distribution and in terms of the interaction between different factors. How do these systems recover and cope? And how do they transition into new systems? What are the consequences of natural and socio-economic changes and how can we anticipate them? We must develop a long-term systems approach based on a better understanding of how various processes and factors influence one another. The outcomes will help us design and develop a high-value living environment while preserving biodiversity, economic activity and liveability. This research is interdisciplinary and transdisciplinary in nature, and conducted in living labs. Besides scientists, civil society – for example authorities, civil society organisations, nature conservationists, industry associations and citizen initiatives – should help brainstorm about systems solutions consistent with their own practices.

Living labs

The Netherlands is located in a highly varied delta whose characteristic history has defined the appearance of many different landscapes. The Dutch landscape, including many areas of nature, is largely man-made. Its diversity means that the Netherlands can offer a broad spectrum of living labs, complemented by its overseas territories. These territories are diverse in terms of landscape and function, but also in how their inhabitants live, work and perceive their surroundings. In the Netherlands, moreover, intensive land use generally combines well with an attractive landscape and natural features.

These living labs give us an opportunity to carry out practice-based research into practical alternatives for specific problems. The value to society is immediate. Universities of applied sciences have an important role to play in such practice-based research. The livings labs therefore not only support innovation in professional practice but also offer students rewarding learning environments. In addition, living labs create opportunities for citizen science and allow consultants to contribute their specific knowledge of a region.



Innovative aspects

The integrated and transdisciplinary nature of the research we propose makes it highly innovative, with the involvement of the public and other stakeholders being central to the plan. The chosen method encourages technological innovation, for example in sensor technologies, sensor networks, citizen science, big data analysis methods, and new IT services. The living labs contribute to social innovation and themselves represent a form of social innovation.

The living environment is changing rapidly, along with the processes and interactions underpinning those changes, but society has been slow to respond. That is why we must gain a better understanding of these complex socio-ecological systems as quickly as possible. Quantitative modelling makes it possible to anticipate these changes. Modelling can also help us develop and test alternative solutions, pre-emptive measures and better regulations, quantify the impact of various alternatives, and take steps in good time. Combining traditional pioneering and design-driven research with public participation will undoubtedly contribute to the success of this research, boosting the level of support for it and perhaps also inducing NGOs and enterprise to provide additional funds.

Research into the living environment is, by its very nature, interdisciplinary and transdisciplinary. Theories and methods drawn from a broad spectrum of disciplines – the natural sciences, behavioural and social sciences and health sciences – are mutually reinforcing. We do need to take additional steps to learn and make use of one another's language and culture. We must continue to develop interdisciplinary and transdisciplinary competences of this kind, starting with the educational programmes in higher education. Research into the living environment is not regarded as a top economic sector, but it is vital to developing and implementing future policy on in this area.

Living history

The past is a source of inspiration and conflict. It is an anchor for personal and collective identity and awakens feelings of nostalgia. It also challenges us to come up with innovations. European society is facing major challenges. Studying the past can help us make the world more sustainable, inclusive and economically healthy in three ways: by affording us insights into our actions, by inspiring us to seek creative solutions to societal issues, and by creating connections.

To diagnose societal challenges correctly, we need to take the long view. A longitudinal approach will help us recognise patterns and illuminate the concepts from which we derive our research and policy insights. The Western world appears to have only a short-term memory, however. It will be impossible for us to understand or tackle financial crises adequately if we focus solely on the recent past. Climate change is not a recent phenomenon, and neither are migration and globalisation.

As a knowledge-based society, the Netherlands has become uniquely proficient at studying nature and culture from an historical perspective. We also have impressive longitudinal datasets on water management, the climate, population surveys, governance, the economy, finance, migration, linguistics and culture. These datasets have been digitised and made available in recent years and are interlinked. It is therefore the perfect moment to benefit from this extensive knowledge system.

The cultural value of heritage

Besides deepening our understanding, knowing about the past can also inspire us by shedding new light on historical solutions. Heritage consists of what people care about; it mobilises and stimulates public engagement in both a positive and negative sense (for example in stereotypes and exclusion). It is important that we learn to make better use of the cultural value of heritage – alongside the more dynamic, strategic deployment of the past that has evolved since the nineties – on behalf of society and as a source of innovation.

Understanding and coming to terms with the past allows us to take a broader view of issues, put matters into perspective, and use earlier experiences to tackle present and future challenges and to inform future generations.

Besides promoting interdisciplinary and even trans-disciplinary research, this route represents a dynamic, subject-driven approach to heritage. There is no objective, indisputable stock of heritage that must be protected by isolating it. Rather, heritage is about the continuous redefinition of objects in constant interaction with people. This approach to heritage is central to this route: the past is not dead; it is alive and is constantly being reinterpreted. Three game changers are pertinent at this point in time: issues related to sustainability and temporality; changes in governance; and the escalation and polarisation of public debate. The impact of this route is that it will lead to new instruments that can analyse our complex relationship with the past and make a greater contribution to the future.

Sustainability and temporality

Although the Club of Rome's alarming report (Limits to Growth) was issued almost 45 years ago, it is only relatively recently that society has shifted its focus towards sustainability. By studying the meaning of the

past within and for a sustainable society, this route aims to develop actual solutions to sustainability problems. Subjects of study include the recycling and reuse of data, objects, materials and buildings. But there is more to sustainability than recycling. Generally speaking, it is about dealing with the material and immaterial traces of the past with a view to the future, about questions of temporality: how do we deal with historical accumulations of art and craftsmanship, with places of remembrance, with archives, with traditions, in our rapidly changing world? We cannot keep everything. But how do we keep the things that we would rather not replace now, with a view to sustainability?

Knowledge retention

The durability of knowledge has both a cultural and an economic dimension. After all, it is expensive to keep reinventing the wheel. That is also true of research and data collection; not having a standardised, durable and acceptable method for storing historical data impedes the longitudinal analysis of patterns, monitoring and modelling. Digital durability is not only about data, then, but also about organisational structure. Important questions that we must ask as we refocus on durability, and that should lead us to develop new instruments and modes of action, are: how can historical knowledge help us achieve dramatic, innovative and sustainable landscape transformations? How can we effectuate the sustainable transformation of largescale ‘young’ (post-war) heritage sites despite the enormous pressure on space? How do we guarantee the endurance of historical objects and buildings that we would like to preserve, including objects made of modern materials such as plastics, sheet metal and concrete?

Expert citizens

Armed with better access to information, greater mobility, prosperity, leisure time and more education, well-informed, vocal and engaged citizens have claimed a major role for themselves in the discourse about how to deal with traces of the past and the role of the past in the present. This is true in the digital domain, where end users and heritage collections share the same data space, and it is increasingly true in the material domain as well. New knowledge about the past based on material vestiges preserved in the Dutch land-scape, archaeological remains, museums, archives and the built environment has traditionally

been regarded as the jurisdiction of academic and government institutions. What is new is the role of citizen science, with ordinary people contributing to our knowledge of the past through local initiatives and digital platforms. Citizen science has the potential not only to contribute significantly to research and datasets in archaeology as well museums and archives, but is also getting the public more involved in spatial planning. Ordinary people are increasingly taking responsibility for the durable production of, access to and storage of digitised and digital born heritage. The roles of heritage consumer and heritage producer, or of maker, curator and user, are converging.

Important issues raised by the rise of citizen science concern emancipation and democratisation. Experience is increasingly being regarded as knowledge. How do we go about evaluating such 'embodied knowledge'? What does the changing role of the public mean for that of professionals? How do we unite different sources of knowledge and use them to recognise patterns and trends and to develop scenarios?

Although challenging, the combination of scientific and citizen data collection, analysis and knowledge may lead to unexpected solutions that allow us to preserve our heritage and contribute to society's challenges of today.

Contested heritage

The dynamic nature of society is leading to growing diversity in our view of the past and to considerable variety in our affective engagement with it. Examples include the controversy surrounding the Dutch folklore figure 'Black Pete' *(Zwarte Piet)* and the Netherlands' involvement in the slave trade, as well as the changing role of religion and religious repertoires in our daily lives. How can a society engaged in emotionally charged processes of heritage-making foster social cohesion? How do we deal with increasingly polarised debates about individuality and identity, with so many different emotional claims being made on the past? It is precisely in this context that it seems important to invest in historical awareness and heritage wisdom.

But what does that mean in actual practice? What didactic or educational instruments do we have available? What role can the past play in a society in which many different groups bring their separate histories to bear and nurture conflicting heritage values?

In a context of societal polarisation and the politicisation of identity formation, research programmes draw attention not only to divergent voices and multiple perspectives but also to a more activist attitude, for example the struggle for decoloniality. The call for engagement has consequences for how we deal with the past. Those consequences also affect academic research, which does not take place in a vacuum. Researchers are facing new challenges, which this route intends to acknowledge by developing new instruments that allow us to deal with a myriad of changing realities.

Connection

Although heritage research is already interdisciplinary to a great extent, research projects in other domains would benefit by taking the historical dimension into account, an aspect that they often lack. The aim is to add a more holistic, transdisciplinary dimension to that research. The game changers listed above also require a more demand-driven form of research, in co-creation with the authorities and the public, by developing an even closer connection with societal sectors than already exists. It is precisely that connection that will produce benefits for knowledge accretion and for society.

Logistics and transport in an energetic, innovative and sustainable society

The aim of this route is to effectuate the transition to a reliable, efficient, safe and sustainable mobility, transport and logistics system inside and outside the Netherlands. Improving goods and passenger transport will promote prosperity in the broad sense of the word. It will not only generate added value and competitiveness in the Dutch logistics sector, but also promote the public prosperity associated with individual mobility.

A reliable, efficient, safe and sustainable transport system is a defining criterion for a well-functioning, modern society. Without trade and specialisation, we could never have achieved our present level of prosperity, and in many instances commerce simply requires the physical displacement of goods. Passenger mobility is at least as important. It allows us to live, work, and spend our leisure time in different locations. The passenger and goods transport system is complex, however, and must adapt constantly to demand. Increasingly, it must also meet stringent quality standards.

The growing level of worldwide urbanisation and spatial specialisation, the outcomes of globalisation, are driving up the demand for transport in and around cities. As yet we know too little about this trend. The demand for mobility, transport and logistics services is also growing as consumers order more goods online for delivery to their door, but also because of demographic and spatial trends. On average, people spend about an hour a day travelling, but the type of travel and its spatial distribution are undergoing enormous changes.

Sustainable transport and use of space

Society as a whole is making demands on sustainability. This includes a severe reduction in the use of fossil fuels and the associated carbon emissions, but also improvements in local air and water quality. The space available for the transport infrastructure is becoming scarcer as well, driving up its price. That is why there has been frequent discussion of double-decker or underground traffic and transport systems in urban areas, also meant to protect rare and valuable areas of nature.

Technology is advancing rapidly. Optimists expect great things from electric cars and automatic guided vehicles. The big data revolution offers unparalleled opportunities for more efficient real-time adjustments and information delivery to transport and logistics networks, for example by linking real-time traffic flows with data flows. The Netherlands is certainly not the only country facing such challenges. What is unique about it, however, is its ideal pole position as a living lab for studying the underlying issues and for designing, testing and implementing innovative solutions: it is densely populated and has an ideal location in terms of international transport routes, an internationally prestigious, innovative trade and transport sector, a broad, robust knowledge base, and four types of mainports (air, water, roads and data). All this makes the Netherlands a country where urgent, major and all-encompassing transport, logistics and mobility issues converge.

The Dutch transport and logistics sector is an economic powerhouse, with an added value of 55 billion euros a year and good for 813,000 jobs.

The Netherlands transports 3.7 per cent of all the goods traded in the world, although its inhabitants account for only 0.25 per cent of the world population and its manufacturing industry for only 1 per cent of global production.

Complex arena

Outcomes in transport and logistics systems emerge in an arena that is complex in many respects. The first complexity is the relationship and mutual influence between transport behaviour and spatial behaviour, for example where people live, work, shop and spend leisure time and where enterprises undertake production, storage and assembly activities.

The second complexity is the importance of dynamics and uncertainty for our understanding of traffic and transport systems. In the short term, this concerns the congestion dynamics and network uncertainty and unreliability, for example. In the long term, it concerns uncertainty about future technological advances and the fundamental dilemma of how to deal with them.

The third complexity concerns the significance of interactions between actors for the way traffic and transport systems operate. This is relevant for traffic congestion, for safety risks and accidents, for coordination within logistics chains, for optimising infrastructure management in relation to their use, and so on.

On top of these complexities is the fact that there are many different and relevant vantage points from which to consider traffic and transport systems in order to understand the outcomes properly. We need the very same vantage points to make informed strategic recommendations about optimising the system, whether from an individual, financial or societal perspective. Connections between these various vantage points often provide a frame of reference for developing urgent and innovative research in this field. One example will illustrate the significance of such connections. If we study how to make traffic and transport cleaner by means of technology without considering human behaviour as well as the acceptance of such technology, it will be difficult to predict the impact of new services and policy measures accurately.

An interdisciplinary approach is needed to understand logistics and mobility systems properly. That approach will consider the behaviour of enterprises and individuals, and therefore involves psychology, economics and other behavioural sciences. It will involve applied technological and practice-based research. It will involve the optimisation of complex dynamic processes and, therefore, operations research and mathematical approaches. It will automatically involve such disciplines as traffic science, spatial planning science and logistics. The importance of incentives and finance will require the involvement of business studies and economics. Given their mutual relationships, interdisciplinary cooperation between all these various disciplines will be necessary.

Fewer disruptions and delays in the transport system

The trends outlined above indicate that the transition to a reliable, efficient, safe and sustainable transport system is urgent but also raises questions that can be explored in high-value interdisciplinary research. A number of technical revolutions, including connectivity and big data, will have a powerful impact on our future transport system. The trends include:

- mode of transport: connected, cooperative and automatic guided driving
- transport guidance: real-time dynamic traffic management and routing
- impacts on mobility: real-time traffic information and intelligent incentives
- smart coordination of logistics chains and networks
- data-driven monitoring and supervision of international trade and transport.

We will be able to plan, guide and influence transport on roads, waterways, railways, in the air and across networks in a way that was unimaginable until recently. That applies for authorities and for enterprises active in these networks. In urban areas, new information systems will lead to closely interwoven passenger and goods transport systems. For example, the automatic guided vehicle that someone orders from the suburbs can stop on its way to the city centre at a distribution centre on the periphery to pick up a packet for that person's neighbour.

These and related technological advances will affect our behaviour and how we cooperate in ways that we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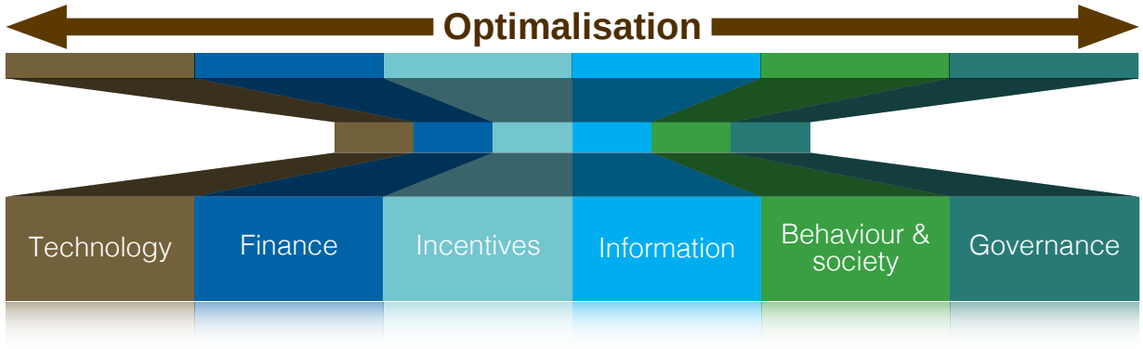


cannot yet imagine. Entirely new business models for service providers and new appealing services will emerge that will generate new activity.

Cooperation

Given the breadth and scale of this theme, achieving the aims of this route will require broad collaboration between knowledge-based institutions, research universities and universities of applied sciences, not to mention a large number of disciplines. These disciplines are well represented in the Netherlands, but there is still too little interaction between them. Another underexplored topic is how they might cooperate in a broad living lab. New connections and mechanisms are needed, with national policy and business strategies being based on public-private partnerships between government, enterprise and science. Cooperation between and with cities and regions is essential, along with alliances focusing on knowledge generation and business development between the different transport modalities (air, water, rail and road).

The best way to achieve the connections referred to here is through systems testing and cyclical improvement in living labs. The cooperative nodes and the national living labs will be sited at the mainports, where waterways, roads, railways and airways converge with smart data. Examples include the Port of Rotterdam and the Schiphol Airport-Zuidas-ArenA corridor. A national data lab is also needed to support these living labs. The major transport and logistics expertise centres can use these living labs and the data lab to study issues associated with international supply chains in relation to the challenges of urban logistics and mobility, and to come up with innovations.

Materials – Made in Holland

We are on the verge of a revolution: the development of tools to make custom new materials. Ultra-powerful microscopes allow us to see, manipulate and control individual atoms. Computers make it possible to calculate the properties of self-invented materials and design the ultimate in functional materials. All this is heralding in the era of custom materials – materials that we can program to have precisely the properties that we want.

The art of making materials do what we want them to do was instrumental in shaping our society. Materials are the ingredients that make up buildings, vehicles, devices, clothing and even food; they produce our energy, do our calculations, and allow us to communicate with one another.

Materials are made of atoms and molecules. The way in these building blocks are stacked and connected determines the properties of the materials they form. In recent decades, materials scientists have unravelled the relationship between the structure of materials and their properties. At the same time, new techniques have emerged for examining and manipulating atoms and molecules. That means that we are on the verge of a breakthrough that will give us absolute control over the building blocks for making entirely new custom materials.

Six game changers

3D-printing, designer materials and composites

Virtually all materials are made of multiple components. The combined properties of two or more materials are often better than the properties of just one. These composites, as they are called, are still created through a process of trial and error. As a result, their properties often fall far short of the theoretical ideal. In the decades ahead, we will continue to develop the techniques and concepts needed to design composites on the drawing board and then build them. That will make it possible to create designer materials that possess numerous revolutionary new properties. The new technology of 3D-printing is clearing a path towards the invention of new hybrid materials with controlled structures and superior properties. 3D-printing makes meta-materials possible, whose properties depend on the geometry of their composite materials. We can use 3D-printing to produce custom bone implants or ultralight but strong construction materials, or to develop entirely new production methods in industry. The ability to print soft materials will create unparalleled opportunities. Will it become possible to print food, textiles, drugs, bodily tissue – even organs?

These technologies are still in their infancy. We face major challenges when it comes to controlling the physio-chemical properties of the printing process, significantly increasing the resolution and speed of that process, and printing composites with contrasting properties. At the same time, we must develop computer simulations, models and instruments for the rational design of 3D-printed composites and meta-materials.

Biomaterials and self-assembly: nature as inspiration
Molecules arrange themselves spontaneously into cells, cells form tissues, tissues form organs, and organs form organisms. What are the natural laws and processes behind this self-assembly, and what potential does it hold? Molecular self-assembly makes it possible to produce smart materials on order, use natural resources more efficiently and create new materials that convert motion into energy, facilitate the controlled release of drugs, or respond to external signals.

In the natural world, living systems survive for a surprisingly long time, not because they are immune to damage but because they are capable of regeneration or self-repair. The Netherlands has captured a leading position in self-healing materials, for example concrete that uses bacteria to repair itself. Can we extend these concepts to other materials, such as ceramics and metal, and create self-repairing turbine engines, wind turbines, coatings or roadways? Can we develop self-healing biomaterials to speed up the repair of tissues and organs in the human body?

Materials for sustainable energy

The widespread use of solar panels offers a sustainable solution to society's looming energy shortage problem. To achieve that aim, we need to improve the energy performance of solar panels and lower their costs. That will require entirely new materials and designs that capture light and convert it into electricity. Suitable candidates are recently discovered perovskites, hybrid organic and inorganic materials, two-dimensional materials, new transparent conductors or materials as yet unknown to us. How can we improve the way we manage light in solar cells or even change its colour to improve performance and lower cost? Can we develop new, flexible materials that make it possible to integrate solar panels invisibly into building materials?

Besides generating solar energy efficiently, energy storage is also essential. One of the major challenges ahead is to develop new catalytic materials made of readily available metals. This would make it possible to use solar power to generate hydrogen from water or methanol from carbon dioxide and water. It is also vital to develop new sustainable, inexpensive, readily available materials to build higher-capacity, fast-charging, long-life batteries. They are essential to forcing a breakthrough in electric vehicles and the associated revolution in transport technology. New materials for heat storage also play an important role in the energy transition, along with materials for transmitting energy over long distances.

High-tech systems and smart materials

ICT has advanced at lightning speed in recent decades, driven by the increasing trend towards miniaturisation. We are reaching the physical limits of miniaturisation, however, and energy consumption is restricting our computing capacity. Without new breakthroughs in ICT, we will be unable to realise dreams like the Internet of Things or big data analysis.

New materials and concepts are therefore crucial. A revolutionary new approach has been conceived, inspired by the workings of the brain. Based on totally different components, it deals a million times more efficiently with energy than conventional electronics. We want to develop reconfigurable, neuromorphic materials with controllable and dynamically adaptable electrical or magnetic properties that mimic neurons and synapses. We aim to use molecular and cellular computing to develop logical switches based on biomolecules. At the same time, integrated nano-electronics, nano-optics and nanospintronics offer a unique opportunity to achieve energy-efficient data processing. All these techniques open the door to using quantum mechanics for the ultimate streamlining of information processing.

New discoveries in extreme energy efficiency allow devices to harvest energy from their surroundings. For example, body heat or movement will charge up mobile phones, medical implants will draw energy from the same biochemical source as cells, and the vibrations of cars on road surfaces will fuel streetlamps. A network of energy-harvesting devices will arise that can also communicate with one another.

Smart coatings, smart skins

Almost all industrially produced objects have functional coatings. They prevent metals from corroding, protect implants against the body's immune response, control the release of drugs in the body, reduce friction and make surfaces self-cleaning. It will be possible to develop responsive coatings whose properties adapt to their environment, such as light-responsive smart skins that can make buildings energy-neutral. Coatings can vastly improve catalytic efficiency. In the food technology sector, they improve the taste and shelf life of foods. The thinnest coating consists of a single layer of atoms. Graphene or layers of recently discovered chalcogenide may bring about a revolution in computer chips and solar cells. Super strong textile fibres will be used to create wearable computers that respond to environmental stimuli or can be integrated into sensors that monitor body functions. Completely new high-tech textiles will increasingly be used in agriculture and civil engineering.

Sustainable material life cycles

The stock of natural resources that we use to make materials is finite. We have almost exhausted that stock because of the careless way in which we often dispose of used materials. Right now closed-loop recycling exists for only a few materials, such as steel. The challenge that we face is to fabricate materials from renewable sources, create new cycles of use, decomposition and reuse, and replace scarce materials with more common alternatives. Only then can we continue to meet our demand for water, food and energy and make the Netherlands resource self-sufficient. This will require a design method that promotes sustainable use throughout the entire life cycle and the smart reuse of materials or their components. The transition to a full spectrum of recyclable materials requires a broad approach: not only do we have to produce materials sustainably; we also have to design responsible production, processing and recycling systems.

Connecting materials

Materials research encompasses physics, chemistry, biology, engineering and informatics and extends to such disciplines as medicine, architecture and industrial design. It is related directly to energy supply, medical care, food technology, building and landscape infrastructure, economics, the behavioural and social sciences, the environment and so on. Some applications raise questions about security, risk analysis, geopolitics, medical ethics and certification, and also touch on such disciplines as the humanities, the social sciences, and public administration.

Achieving the dreams by 2040

It is 2040. You're driving your electric car across town. Its wireless solar battery is fully charged. The city has undergone an amazing transformation: buildings and infrastructure are made of fully recycled, self-healing materials. At work, you use neuromorphic computers that are smarter than the human brain and much more energy efficient than old-fashioned models. You wear clothes with integrated sensors that monitor your body functions, for example your new heart valve, custom-made for you on a 3D printer. New materials will make this dream and so much more possible. Robust, long-term funding for basic materials research is vital to initiating outstanding, innovative research, improving research facilities, training the next generation of materials scientists, and creating innovations in close collaboration with technology institutes and industrial partners. Materials research connects researchers at research universities, research institutes, universities of applied sciences, enterprises, and civil society organisations. By 2040, we will have achieved the dreams of today and have produced an abundance of new and exceptional ideas and concepts beyond our wildest imaginings.

Measuring and detecting: anything, anytime, anywhere

‘Knowledge through measurement’. That is the idea behind our growing need for detailed information. This need sets requirements on the instruments we use to measure, on how we interpret their output, and on how we communicate, perceive and arrange ownership of the results. It is increasingly important to be able to measure complex systems and integrate the great wealth of measurement results. We also want to detect changes in those results with greater speed and precision, so that we can facilitate the transition from curative or reactive action to preventive or proactive forms.

Measurements are essential to science and innovation. To researchers and innovators, analytical science and technology function as senses. Since measuring and monitoring will increasingly become part of our everyday lives, for example as part of citizen science and personalised diagnostics, it will become more important to understand the significance and value of the output. People who work with measurements must be able to interpret the results and fluctuations therein and put them into the right context. They must also be aware of the value of their data for others. For reasons of privacy, society as a whole will have to draft or adapt a code of conduct and even legislation governing the ownership and use of measurement output and information. This route connects basic and applied research in the sciences with education, psychology, ethics, human behaviour, the law and other areas of the humanities.

This route has four *game changers*.

From point measurement to systems understanding

The ideal: an instrument that can conduct non-destructive tests to determine the entire elemental and molecular composition and dynamics of a living system, process or material as well as the chemical, physical and biological interactions at submicrometre level and on microsecond time scales. We can already measure many phenomena, either with advanced instruments in the lab or with sensors out in the field. However, we cannot answer such obvious questions as ‘Is this food healthy?’, or ‘Is the air I’m breathing right now hazardous to my health?’, even if we know the precise composition of the food or air in question. That is because we cannot fathom complex reality at a systems level. We can acquire the necessary understanding by considering material reality and its dynamics from different perspectives, and by studying how the whole system of components behaves. This requires complementary and, often, disparate measurements from different vantage points, at different levels of physical, chemical or biological detail, and at different length and time scales. These measurements must also be carried out in a way that does not influence the system. There are a number of ways to improve our understanding of systems. First of all, we must increase the level of detail of our measurements. We should also develop non-invasive and non-destructive monitoring methods. We must further develop, use and combine complementary techniques that analyse differing aspects of the object of study and its internal dynamics. Finally, we must develop generic methods for combining entirely different types of output, information and knowledge about complex systems or their elements.

Measuring where and when necessary

The ideal: In the future we will have an allergy sensor for personalised food safety; a refrigerator that tells us which food needs to be eaten as soon as possible; a robot that searches for earthquake victims; a toilet that keeps track of your health and warns you if something seems to be wrong; a factory that adapts its production parameters continuously based on the latest composition of raw materials; and a sensor in an automobile exhaust pipe that tracks emissions.

Detecting abnormalities as soon as they occur allows us to take precautions even without understanding the entire system. This, however, requires having enough data available and knowing what a significant or worrisome abnormality is. In the case of individuals, a sign of good health in one person may indicate a worrying turn of events for another.

To save time and make rapid intervention possible, we have to be able to measure, process the output and, in many cases, arrange feedback on transport of the results at the location of measurement. In fact, the laboratory should be brought to the object or person being measured, or even be inserted into them. The miniaturisation of high-tech instruments is therefore crucial. Because untrained users will increasingly be in charge of the measurements, extra demands will need to be made on robustness and effectiveness. Validation and standardisation are vital in this respect. It is important for users to have the result presented as reliably and unambiguously as possible. The questions ‘What should we measure?’ ‘How, where and how often should we measure?’ ‘Who should be getting feedback?’ and ‘Can we combine different measurements or results?’ call for communication between researchers in the relevant areas of application, in analytical science, in standardisation, and in design and systems integration.

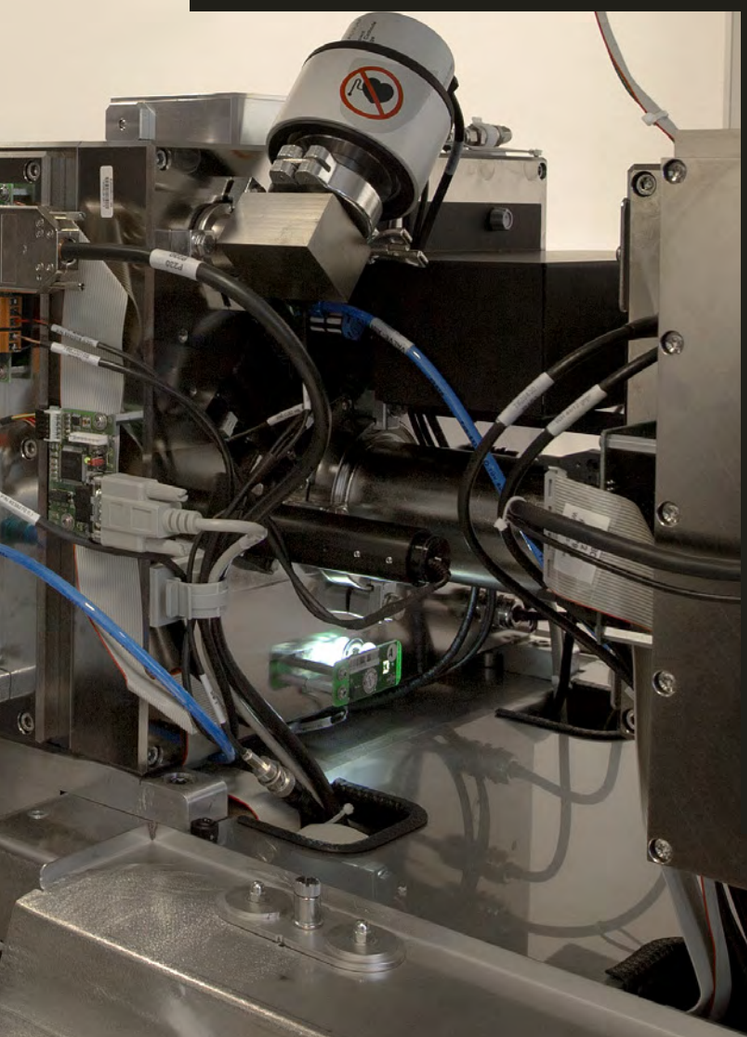
Understanding the relationship between structure, composition and function

The ideal: (a) An expert system that can predict the possible conformations of a chemical substance under variable circumstances based on structural information, and (b) an interdisciplinary platform for studying structure/property and structure/performance relationships.

The key to understanding systems is to comprehend the function or behaviour of the separate components of that system and how they interact with one another. This is of eminent importance in pharmacy, where we need to understand both the effects and side effects of drugs or identify toxicity levels without animal testing. The first

task is to get to understand a substance through and through by applying multiple techniques for structural analysis and by studying it under varying conditions. This type of practical research can be enhanced by chemical and physical conformational calculations.

The second step is to determine the compound's functional performance. In essence, this involves developing 'structure/performance relationships'. One key success factor is to have instruments for studying the behaviour of matter and the dynamics of its components while in use, without disrupting the system. There are a few examples in science and industry in which structure and property or performance are linked, but these are relatively limited and there is no generic scientific model available. Dutch public-private partnerships in the relevant fields would support the development of a platform for structure/performance relationships.

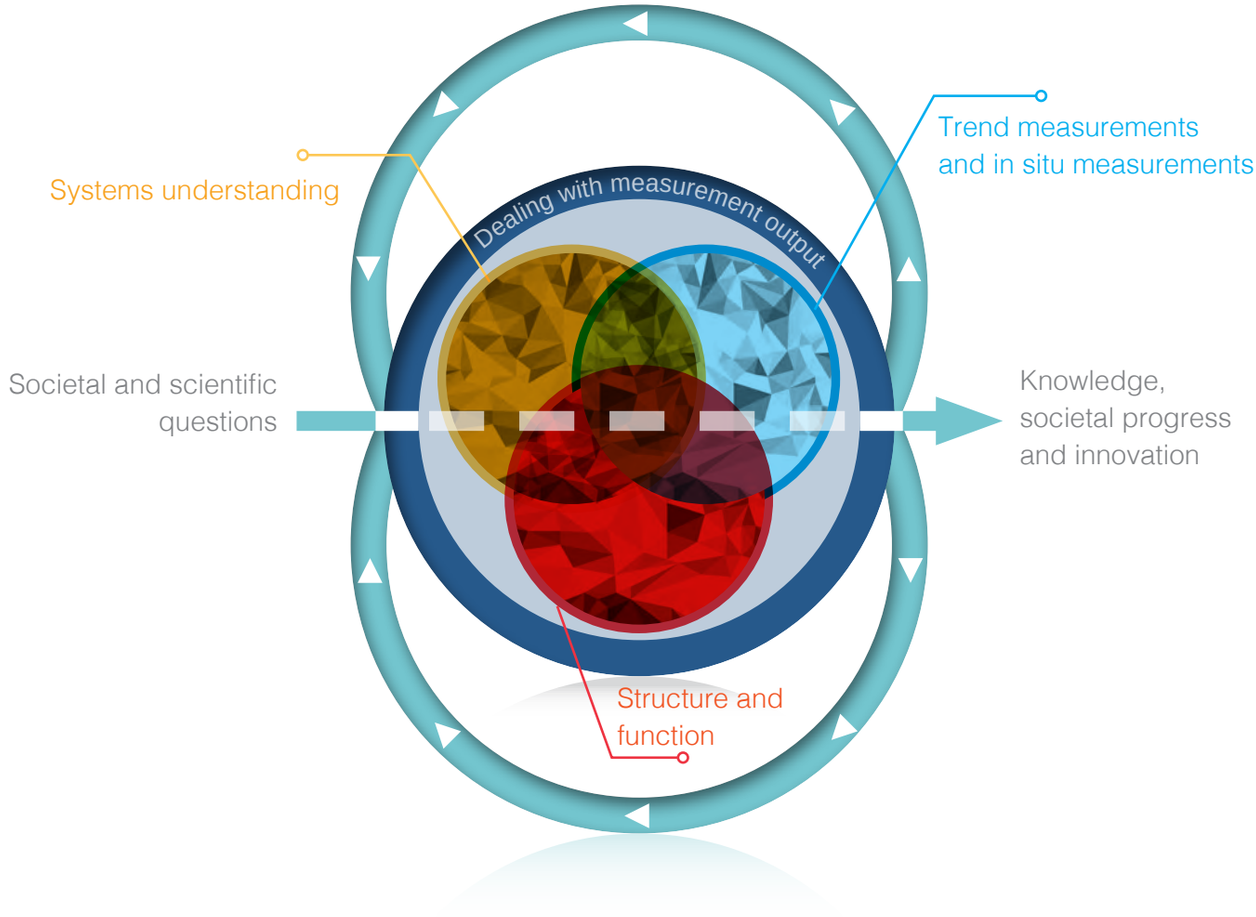


Learning to deal with output

The ideal: To move from analytical research to an analytical society; to link physics, chemistry, biology, statistics, ethics, law, psychology and design with growers, environmental experts, nutritionists, patients, physicians, civilians, operators and other users.

In only five years' time, we will be using more than 250 billion sensors worldwide in all sorts of applications, from monitoring the environment to monitoring patients, from monitoring plants to measuring the quality of the built environment. This is a factor of our society's growing need for certainty and risk avoidance, for example in terms of mental and physical health, nutrition, safety, and materials integrity. People will not only 'live in a sensorium' but become part of the team that measures and interprets the output. Untrained users will thus gain access to miniaturised equipment, with the risk that they will use it incorrectly at times. This trend will give rise to a growing need for validated and standardised methods to determine and guarantee the quality of the results.

Because such output will be used without expert intervention, for example in the Internet of Things, a new form of quality assurance is needed. While it can be based in part on existing quality assurance methods and techniques, a large dose of innovation will also be required. Education can also help both laypersons and researchers to avoid inaccurate measurements and the incorrect use of output. It is vital to know the strengths and weaknesses of the various methods, as well as the relevant levels of accuracy, selectivity and specificity. Training individuals in the basics of measurement is not the problem; the challenge lies in adapting the research to allow us to identify the most effective didactic methods. This calls for experts in instrument engineering, statistics and didactics to join forces and embark on joint research. By improving our understanding of systems, science will no doubt be able to reduce the margin of uncertainty, but uncertainty is inherent to measurement. We must make it clear to users what margins of uncertainty actually mean. This is especially relevant



when the measurement or monitoring results are bad news. That is why research with links to psychology is needed to study public perception and the best way to present results. The aforementioned link to didactics also plays a role here.

Sensors will not only tell us a lot about life and matter, but also about environments and even individuals. Progress in instrumentation will also give rise to discussions about intellectual property, public acceptance and privacy. Who owns the output data, the information and the knowledge, and what can and can't we do with it? What can we do with incidental discoveries? The answer may well lie in unique combinations of ethical and legal research, but not before we estimate the potential impact and risks of the data falling into 'the wrong hands'. Security experts must be involved to develop risk management solutions. Researchers must also consider how to raise public awareness of the value of measurement results.

It is more than obvious that we need to set up a multi-disciplinary platform focusing on the social, ethical and legal aspects of measurement and detection. An entirely new field, analytical logic, must be launched and coordinated through existing alliances in analytical science and technology and the other relevant disciplines mentioned above.

NeuroLabNL: the ultimate living lab for brain, cognition and behavioural research

The next ten years should bring major breakthroughs in our understanding of how the brain develops and changes during the life cycle. The living lab that we are proposing here, NeuroLabNL, will be the game changer that makes these neuroscientific breakthroughs possible. It will function as a 'University of the Netherlands' for the brain and serve as the ultimate laboratory that unites all brain, cognition and behavioural researchers and their partners in society. The results of new and recent research on the complex relationship between the brain, cognitive functions, behaviour and environment will lead to many innovations in health care, in education and in public safety.

Early detection of changes in the brain and the prevention of mental, developmental and health problems are high on the scientific and societal agenda. Integrated lab research – which combines the study of molecules, cells, nerve pathways and behaviour in humans and animals – can be combined with longitudinal population studies to take us a step closer to early detection and prevention.

NeuroLabNL can make a difference in at least three domains: health, public safety, and education. What the three domains have in common is that they involve research into early diagnosis and prevention. The power of NeuroLabNL lies in the mutual relationships between the three domains. For example, we know that children who live healthy lifestyles display less problem behaviour and perform better at school.

Health: a healthy lifestyle for the brain

The 24-hour economy requires flexible workers with fit brains. To be able to function regardless of age, people need a 'healthy lifestyle for the brain': enough sleep, nutritious food, the right amount of exercise, a social network, and a proper balance between stress and relaxation. This 'healthy lifestyle' also offers guidelines for brains that are less fit, for example the brains of those suffering psychiatric or psycho-social problems. Early diagnosis and intervention and a custom approach can help them live as independently as possible for as long as possible.

Not only is that more enjoyable for them, but it will also keep the cost of health care under control. Research in controlled laboratory settings and large-scale

population studies make a fit brain more likely for everyone. The combination of scientific methods and close collaboration with hospitals and care institutions can produce scientific breakthroughs and solutions to health problems. One example is research involving Brain Computer Interfaces (BCIs) in which those suffering from paralysis control artificial body parts with their thoughts. Another is the deep brain stimulation of specific areas of the brain in those suffering from serious forms of Parkinson's, depression or obsessive-compulsive disorders. Major progress is also being made in studying the potential of care robots, including for those suffering dementia.

Future: the Stress Passport

How do you know whether a psychotic patient is well enough to go home? Will your job end in burn-out or bore-out, or is it perfect for you? These are questions that the Stress Passport can answer. Countless physical and mental health problems can be attributed to too much stress. The Stress Passport has three components. The first consists of biological factors, for example cortisol levels and genetic and epigenetic variations in the stress system and how your brain responds to stress. The second is a person's environment, such as traumas they have been through and their support network. The third consists of psychological factors. How do you cope with stress? Are you optimistic or anxious by nature? Are you a worrier? You may be on the higher or lower end of the scale on all these points. Like your date of birth, place of residence and passport picture in your real passport, all these scores taken together produce a unique and individual profile that predicts how you will behave under stress: your Stress Passport. This makes it easier to identify interventions that will help people cope better with stress. It keeps them healthy and cuts down on the cost to society and the economy.

Public safety: preventing problem behaviour, encouraging resilience

A society based on self-reliance and citizen participation needs to know what conditions are needed for children and adolescents to grow up safely and in good health into adults who display these qualities. Conversely, it also needs to know what leads to problem and disruptive behaviour. Poor habits, self-harm and criminal behaviour, dependence and abuse can become ingrained pathways in the brain that are often difficult to change. Prevention, early intervention and personal monitoring can help prevent, temper or change the focus of such behaviour.

Research has shown that the areas of the brain where spontaneous feelings of empathy arise are much less responsive to activation in children and adolescents held in juvenile detention. By combining insights of this kind with research on the relationship between neurobiological factors and anti-social behaviour, we may be able to modify negative behaviour in children at an early stage of their development and develop personalised therapies for anti-social adults that teach them to cope with their disorder. In the latter case, wearable sensors that measure psycho-physiological processes are of enormous value because they make more effective treatment possible, as well as more accurate aggression risk assessments.

Practical example: the Prevention Intervention Team

The Prevention Intervention Team (PIT) is a collaborative project between Leiden University and the City of Amsterdam. It is meant for children who skip school a lot, exhibit transgressive behaviour, or come from the same family as a criminal who ranks as one of the top 600 Dutch criminals. The programme's origins lie in a profound basic scientific understanding of how the brain works and which vulnerabilities are the outcome of certain circumstances. These children receive neuropsychological screening at school in order to compose an individual profile of their social learning capability. A child's specific scores determine which assistance it receives. For example, to identify the right interventions, it is important to know whether a child responds aggressively to others from fear or because it derives pleasure from another person's

pain. This rapid, specialist and intensive assistance is a success: it has turned a negative development path into a positive one in two out of three children.

Education: motivated for lifelong learning

In a knowledge economy such as our own, it is vital to know how we acquire knowledge and skills, how and when we can optimise such acquisition for each individual; how we can help people of all ages find the intrinsic motivation to engage in lifelong learning; and what role technology and digital educational resources play. Brain research in education not only teaches us how people learn, but also brings personalised education for all a step closer.

Research on successful learning strategies and sensitive periods for learning, individual learning profiles, the role of language in the learning process, and the role of multimedia in learning has so far generated many valuable insights. Research using fMRI, which records brain activity in a scanner, shows how brain development can predict which children will make faster or slower progress in arithmetic, reading and writing, and other basic skills. The maths problems website *Rekentuin* has developed software that gives schoolchildren individual feedback on their sums so that they can improve their performance. An experiment using robots to support foreign-language acquisition may someday help refugee children learn Dutch and integrate more rapidly in primary and secondary school.

Practical example: brain-friendly lesson material

One of the most important areas in which our growing knowledge of the brain is being applied is in education. In the past five years, teachers, school boards and teacher training programmes have worked closely with neuroscientists to improve education. That has led to brain modules and brain-friendly lesson material developed by educational publishers and others. The integration of neuroscience and educational implementations is a forerunner of the direct application of brain and cognitive research in society.

Building with NeuroLabNL

Investing in brain, cognitive and behavioural research means investing in the foundations underpinning many of the routes set out in the Dutch National Research Agenda. NeuroLabNL would be well positioned from the start in terms of the exceptional quality of and close collaboration within Dutch research. The same is true of its potential impact on society. Unfortunately, all the important and large-scale programmes will soon come to an end.

NeuroLabNL can build on the success of such networks as BrainGain, the IT Innovation Platform Brain and Cognition and, above all, the National Initiative Brain and Cognition (NIHC). The NIHC has concentrated and revitalised brain research in the Netherlands. Its seventy partners have built a bridge between different scientific disciplines, but also between science, industry and society.

The new NeuroLabNL must be able to offer many different options for multidisciplinary and translational research. First of all, it would have to work on developing a multidisciplinary and interdisciplinary network in order to encourage integrative research and connect that research to practitioners in the field. In addition, it must offer scope for knowledge generation and product development and for promoting practical applications. NeuroLabNL should also identify which fundamental insights are still lacking and what we need to work on in future. Finally, it is both necessary and advantageous to explore the common need for a data infrastructure, new models and methods, international alliances and cooperation with other routes.

The origin of life – on earth and in the universe

A fundamental understanding of the origin, evolution and functioning of life in all its possible forms is crucial if we hope to detect and treat diseases, address the risk that constant environmental change poses to humans, animals and nature, and answer other societal challenges. We need new scientific and technological breakthroughs and an approach that transcends orders of scale and disciplines to discover where we come from and whether there is life beyond Earth.

Diseases are transmitted from animals to humans or evolve rapidly. Bacteria are becoming increasingly resistant to antibiotics. Biological systems possess an inherent variability that makes it difficult to comprehend how they function. Not all plant and animal life will be able to adapt sufficiently to the current rapid pace of climate change, leading to a loss of biodiversity on Earth.

To cope with these trends, we must comprehend the ability of life to adapt, from the molecular scale to the scale at which humankind and the biosphere must defend themselves against global natural disasters. The way to do this in the Netherlands is to set up an institute (for now, a virtual one) that will develop joint research plans.

Along this route, astronomy, earth sciences, biology, chemistry, physics, informatics and mathematics will join forces for the first time to initiate pioneering research into the fundamental questions of life. This innovative setup will make cross-fertilisation possible between research into life in the universe, Earth's formation and development, the origin and evolution of life, the production of synthetic cells, evolutionary scenarios going forward, and how to build and manipulate life at every conceivable scale.

Five interrelated themes will provide the basis for this scientific and cultural game changer:

Reconstructing Earth's origin and the beginnings of life

To reconstruct the early history of Earth and of life on our planet, we must first answer such questions as: how do earth-like planets arise and what are they made of? When and under what circumstances does life evolve from a cocktail of molecules? And how do complex multicellular organisms originate and function? We must also come to understand how the evolution of life changed the Earth's circumstances and how those changing circumstances went on to facilitate the growing complexity of life's building blocks and networks.

If we can truly fathom the origins of life and its growing complexity, we will gain a better set of tools to combat sickness, promote health and food production, and encourage sustainability.

Predicting how life will evolve

Evolution is a key mechanism in the origin and development of life and in the interaction between life and its surroundings.

We need to discover new, deep insights and connections and come up with new research methods and technologies not only to reconstruct and understand evolution retrospectively, but also to predict it. What we also need is more insight into extreme circumstances, for example the risk and nature of major

volcano eruptions, impact events, or the reversal of the geomagnetic field. If evolution can be predicted, we will have a better chance of preventing undesirable evolutionary effects, for example antimicrobial resistance, the rise of new diseases and pests, cancer cell plasticity, and perhaps even human conflicts.

Building and manipulating life, from molecule to biosphere

To understand how life functions, we must come to know more about the virtually unexplored domain of complex and dynamic interactions between the building blocks of life at a wide variety of levels, ranging from molecules and biomolecules, cells and organisms to ecosystems and biospheres. By mimicking life, we may finally gain a real understanding of how it functions. This will require modern technologies and mathematical models. If we can control life for specific purposes, it will become possible to restore life that has been disrupted, for example by creating new, synthetic cells, by reversing specific interactions, and by administering targeted therapies, or by developing new ecosystems in places where they do not yet exist, have been lost or are seriously damaged.

Finding alien life forms

Is there life beyond Earth? To answer that question, we must be able to recognise distinctive planetary circumstances and the associated indicators of extra-terrestrial life. If we should find traces of life on another planet, we would gain a better understanding of our own origins. A discovery of this kind would also have enormous philosophical, religious and political consequences. The search for alien life forms also informs our knowledge of the potential chemical and physical circumstances in which terrestrial and artificial life might exist.

Bridging major time and space scales

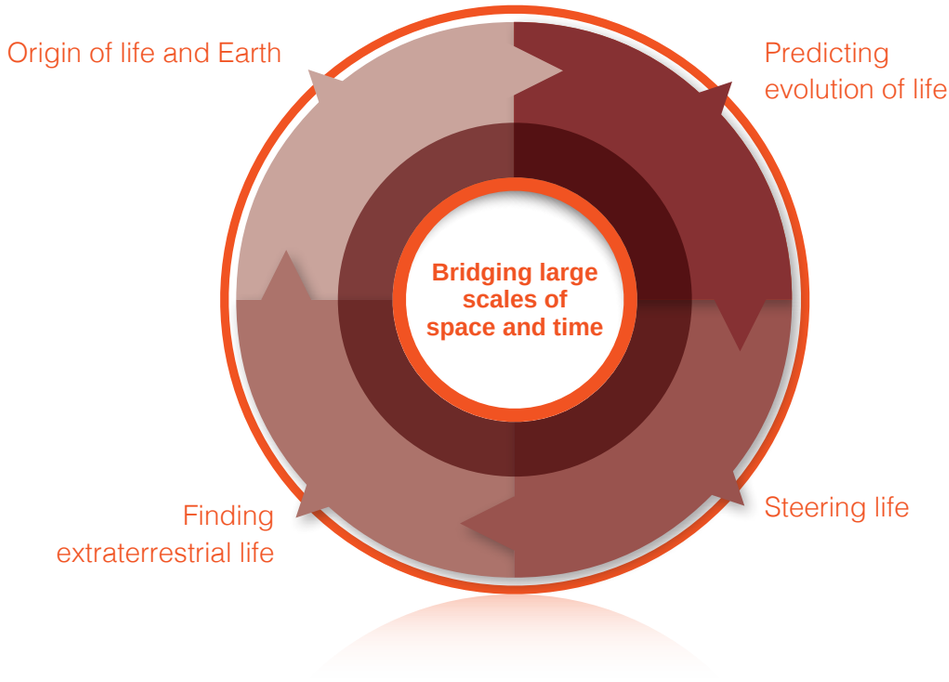
To answer all these questions, we must interpret interactions and causal connections between the components of cells and organisms and their surroundings by applying new conceptual, computational and mathematical methods. We must also combine huge volumes of numerical and experimental big data across the enormous range of time and space scales covered by this route. These range from the physical circumstances that make life possible to the scale of the universe, from the formation and evolution of planets to biospheres, ecosystems, organisms and cells and right down to individual molecules. Research in these areas will not only lead to a new understanding of the position of life in the cosmos but also spark huge changes in society. After all, extending our ability to intervene means we bear an enormous responsibility for our actions.

Impact: scientific, societal, economic

Fundamental questions about the origins of life have a wide appeal, from school children to top researchers. We must use this potential not only to answer these questions but also to attract new talent, so that the Netherlands becomes the knowledge-driven economy that it aims to be in 2030. We can do that with a long-term programme that fires the imagination of the rising generation. In addition, daring basic research generally leads to trendsetting technological innovations that can drive society and the economy forward. Humankind will only survive in the longer term if we come to understand how molecular and cellular networks of single and multiple cellular organisms operate, and if we can predict the basic principles of evolution in relation to environmental changes. This is especially pertinent at a time in which we can adapt living systems by means of genetic modification, geo-engineering or synthetic biological systems to reduce the risks associated with climate change.

Broad transdisciplinary programme

To showcase the Netherlands in Europe and beyond, we must reinforce existing international alliances by setting up wide-ranging, long-term research programmes. Much of the money currently being invested in this field is earmarked for disciplinary research crucial to extending the knowledge base of Dutch scientists. A dramatic expansion of this knowledge base across the breadth of science is vital if we are to implement our current research policy and maintain our leading edge in individual fields.



Alliances in the Netherlands today focus mainly on addressing issues of application. There is no broad programme that facilitates long-term, basic transdisciplinary research. Outstanding transdisciplinary research requires researchers trained and able to work in an integrated context. A virtual centre focusing on this theme therefore makes sense.

National centre

The Netherlands needs to set up a new national centre that concentrates the forces and ideas of this route and offers a new platform for developing the necessary equipment, infrastructure, IT and logistics for new transdisciplinary research and for pioneering projects. The centre will not employ researchers itself but consist solely of a support organisation. Researchers will participate in the centre while remaining with their own institution.

The centre will also apply for joint funding for the necessary large-scale equipment and facilities. This would also cover contributions to international physical facilities (telescopes, satellite instruments, computers) and distributed facilities for data analysis, ecosystem analysis and geoscientific observation.

At the moment, various research groups are already applying for small amounts of more or less separate funding to support the Netherlands' participation in the present and future European roadmap for infrastructure. An infrastructure facility linked to the centre would be extremely valuable in this regard and promote coherence. It will also make the Netherlands much more appealing to top researchers.

Towards resilient societies

Resilient societies are capable of absorbing shocks and challenges brought about by migration, climate change, new technologies, socio-cultural diversity, and shifts in the geopolitical landscape. In anticipating future challenges and researching long-term consequences of changes and developments at local, national and global level they can strike new balances, even in an unstable context. The route resilient societies will contribute to a more resilient and future-proof society.

Societies and their citizens are better able to anticipate and handle changes if they are able to adequately and timely adapt rules, patterns, organisations, and societal systems. In doing so, they must respect human rights and the principles of democracy and rules of law. Thus negative effects can be avoided and new inequalities, exclusion and contradictions can be prevented or mitigated. The legitimacy and the support for the way in which the changes and transformations must be dealt with, will be supported.

Such a transformation process requires close interaction between science and society. The public and civil society organisations as well as industry must interact with knowledge organisations in order to analyse the challenges they face and how these challenges interact, and to come up with responses to them. Only an integrated, joint approach will allow us to develop the innovations needed to make society as resilient, inclusive, and meaningful as possible. An integrated, comprehensive and joint effort on an unprecedented scale has to be started to develop the innovations to create a resilient, inclusive and meaningful society.

The resilient societies route will offer a systematic modus operandi with regard to our future society, economy and governance. This modus will be developed in interaction with societal, cultural and economic actors, thus acquiring the appropriate tools for policy-making and implementation. Building on the strength of society this route will help guide and support the transformation of society which is crucial to tackle ecological, technological and other challenges.

New connections

This route mobilises dynamics inherent to society. The Dutch polder model has a number of specific features that are unique in the world, for example a style of consultation and decision-making that emphasises equality, cooperation, pragmatism, and trust. In its long history, the polder model has offered many practical examples of local and national alliances that tried to respond to challenges, including international ones.

This route combines close cooperation between scientists and practice-based researchers with societal, cultural and economic partners across disciplines and institutes. In order to reach a better understanding of the challenges that we face the route ‘resilient societies ‘combines close cooperation between scientists and practice-based researchers with societal, cultural and economic partners across disciplines and institutes. Thus enabling us to develop and test scenarios. An evidence-based framework will be established to address specific issues that will make it possible to make rational decisions and to implement solutions based on knowledge and experience that will guide the transformation of society and boost its resilience. We could profit considerably by connecting science to government ministries, the Association of Netherlands Municipalities, community organisations and citizen initiatives.

The proposed model of co-creation is applied to three domains (political-administrative, socio-economic and cultural-societal) that together form the foundations of a resilient society.

For each of these domains a game changer has been formulated.

Towards new political-administrative arrangements

Politics, public administration and policymakers face a dual challenge of their legitimacy being at stake and diminishing trust in these institutions versus the globalisation and the blurring of borders which causes governance problems for the Netherlands and the world as a whole.

On the one hand, the public has lost trust in them and their legitimacy is being questioned. New political-administrative arrangements must be responsive to this trend. Experiments with direct democracy are not the balanced answer we are looking for. The challenge is to scale up small initiatives, enabling them to tackle global problems and, conversely, to make major problems manageable in a small-scale context.

Referendum

People often feel that government is not listening to them. A referendum may be a way to improve this, but can also have unintended negative effects. When should or shouldn't we call a referendum and are there any suitable alternatives?

These challenges do confront local and regional institutions with a bigger role to play than they are equipped to handle. Welfare state reform raises quality issues, the transition to sustainability requires greater flexibility, and cultural diversity issues are exceedingly complex in nature. In each case, resilience is thought to be found in new forms of participation, new political institutions and administrative practices, and in effective communication through new media and IT. Simultaneously the foundations of the democratic system of law must remain intact and participation must not give rise to new inequalities and forms

of exclusion.
Research and co-creation must result in new arrangements that build on the strengths of the polder model recalibrating it at the same time. The Netherlands dispose of an outstanding knowledge infrastructure in this area which for the moment is underutilised.

New forms of work and value creation

New technology and the robotisation and digitisation of production and 'knowledge work' change the way in which individuals and society deal with work. Growing levels of social inequality and cultural diversity, demographic shifts, and changing opinions about public service are affecting relationships in and around the workplace. Work functions as a place where people can gain experience and learn skills. Furthermore being part of the workforce is synonymous for participating in society.

The working population must be empowered to acquire new competences in order to be able to keep participating. Enterprises and organisations should have the desire to be inclusive, so that everyone can join in. Technology equally creates opportunities, for example by having a positive impact on the self-reliance of the elderly or by supporting the reintegration of people with a mental of physical limitation, increasing their ability to participate. As well as it is a potential reason for tensions putting pressure on employment relationships, social networks and safety nets.

Robots

Robots are taking over our work, leading to fears of job losses. But the rise of robots can also create new opportunities. How can we design organisations in the 21st century so that humans get the most out of machines?

Current changes require new forms of cooperation, new revenue models, learning organisations, and a new design for the labour market and the economy. New forms of work and training will also be needed facilitating lifelong learning and arming people with the 21st century competences they need to participate constructively in the learning economy. Basic premises are new scenarios for the way in which we earn income, share prosperity, and offer social security. We can develop these by experimenting, studying practical situations, initiating innovations and making societal considerations transparent. Through the scale and highly organised nature of Dutch society, the Netherlands are an ideal test laboratory.

New forms of inclusiveness and coherence

Migration, globalisation and technology underlie polarisation, conflicting cultures and socio-economic inequality. The idea of who we are and where we belong is changing. New networks and communities evolve demanding and offering new approaches at the same time. Organisations are being forced to reassess their ideas and practices in order to achieve their aims and connect with their target groups. At this crossroads of social continuity and change, competing and even conflicting interests and philosophies are emerging. Our perspective on the quick changing society requires us to revise our view and to take action at the same time.

Migration

Refugees and labour migrants are changing our society in vital ways. How do we support talent and give organisations the tools they need to get everyone to participate, regardless of their economic status, culture or identity?

A resilient society is based on the extent to which people are able to identification and participation. People will need to relate to cultural and religious contrasts, the changing role of families and new-style households. We must also find an answer to the gap between rich and poor.

Educational and cultural institutions must embrace new global and technological perspectives and include those of low literacy. Care institutions, ideological organisations and the public media need guidance on how to deal with normative and ideological questions and act accordingly. Community organisations, sports clubs and enterprises must be able to benefit from the power of diversity but also learn to deal with its more edgy sides.

A resilient society distinguishes itself by its power to improvise, its capacity to observe and reflect, its integrality and making sense of life as intrinsic reason for citizens to participate. Numerous societal initiatives and experiments are already under way in this area.

Combining these initiatives and experiments with the scientific analyses of processes of inclusion and socio-cultural diversity can be a driver to find answers to the above raised urgent societal questions.

Long-term investment

This route focuses on the process of co-creation, i.e. close interaction between actors in science and society. So far there has been very little systematic research into what makes a resilient society, but such research is necessary given the challenges we are facing. We need financial resources and an infrastructure to develop an ecosystem in which research and knowledge-based institutions in society and enterprise can play to one another's strengths in this domain.

Personalised medicine: the individual at the centre

Giving each and every patient precisely the right kind of care in the right amount to achieve maximum results with a minimum of side effects, and doing this at minimum cost and as close to home as possible: that is, briefly, the aim of personalised medicine. Making this possible for the growing number of patients with chronic disorders requires a revolution in knowledge acquisition and in how we organise care. Besides a major investment in a solid data infrastructure and technological and methodological advances, new knowledge coalitions and close contact with society are also critical.

Every patient has unique traits that may have important consequences for his or her course of treatment and for its effects. The same is true of every illness or disorder. Environmental factors also vary greatly. These variations give rise to major differences between patients who appear to have the same disorder. Personalised medicine requires insight into the variation between individuals and their disorders so that every patient and physician can choose the best treatment with the fewest side effects.

The ideal

Health care places the individual at the centre. In future, our growing knowledge of sickness mechanisms, based on survey data, laboratory research and diagnostics, means that we will be able to establish a person's state of health at any given moment and how it will evolve in the years to come. Is he or she at risk of depression? A heart attack? Cancer? Later on in life, that person may fall in fact ill. He or she will be told which treatment is most effective given the diagnosis but also given his or her genetic profile, lifestyle, diet, medical history, and so on.

Personalised medicine thus starts with prevention, provides targeted interventions where needed, and continues up to and including personalised terminal care. The importance of personalised medicine is generally recognised and acknowledged; 21 of the 140 cluster questions in the Dutch National Research Agenda are related directly to personalised medicine.

Game changers

Personalised medicine is important for all disorders and plays a role in every facet of health care, from prevention to terminal care. The main point of investment will therefore be to fund infrastructure and advances of broad applicability. Important game changers are:

- a new perspective on health
- a strong Personalised Medicine & Health Research infrastructure based on reliable findable, accessible, interoperable and re-usable data
- new methodologies and technological applications that make it easier to predict outcomes in individual cases, align treatment with those predictions, and administer reliable tests to determine the success of that treatment
- good communication and education focusing on the changes that personalised medicine will bring
- closer cooperation between basic, translational and clinical researchers and between knowledge-based institutions and enterprises.

Focus on variation

Personalised medicine requires us to look at diseases, patients and data in an entirely new way. We must begin by shifting our focus away from the largest common denominator and instead be curious about

differences between patients. This is the essence of systems biology as an approach. Why does the same drug work for some patients and not for others? Why does one patient with tumour metastasis die within six months while another with the same tumour at the same stage live for another ten years?

Connections needed

Individuals differ from one another in many different ways, but that is not all: illnesses that appear to be the same at face value often differ considerably in their molecular properties. This affects how aggressive they are and how responsive to treatment. Which of these differences is responsible for the variation in treatment outcomes for the same disease? To answer this question, we need enormous quantities of data about huge numbers of people and illnesses. Big data, in other words. We also need frequent longitudinal studies of individuals and their disorders. Initiatives such as the NFU project Registratie aan de Bron [Recording patient information at source] and a national electronic patient dossier (EPD) are absolutely crucial in that regard. There has already been a considerable investment in setting up data infrastructures and bio-banks in recent years. The various data sources will need to be combined in the years ahead. The Personalised Medicine & Health Research infrastructure initiative corresponds closely with these efforts, but it will naturally require special precautions in the interests of privacy.

Besides access to large volumes of data, data quality is also important. Data collected for purposes other than research (such as care, services or marketing) may not all be generated in the same way or be recorded with the same degree of reliability.

Targeted research

Researchers who concentrate on pure science will need to work with translational researchers, clinicians and epidemiologists in the years ahead to refine our knowledge of sickness processes and interventions. New methods, for example stem cells (iPS cells) generated directly from a patient's adult cells, personalised microbiome analysis, organs-on-a-chip and technology that makes genome editing possible (CRISPR-CAS9), will speed up the pipeline between laboratory and clinic.

We will also need to invest in techniques for harvesting treatment-relevant information from patients in the least invasive way possible. Examples are liquid biopsies for cancer patients, imaging techniques, and methods that measure whether a particular dosage of a given drug is sufficient.

It is also important to upgrade research methodology to determine the value of an intervention for small numbers of patients, and perhaps even for individuals. The evaluation of new interventions deserves special consideration.

Good communication and education

Physicians and other care professionals must learn to deal with new decision support systems and a broad range of communication tools. They must inform and support patients in their direct contact with them but also by using a variety of e-health applications, and decide about possible courses of treatment together with them. Education and post-graduate training are therefore important prerequisites for the success of personalised medicine. Perhaps the most important criterion in practical situations is the ability to communicate effectively with individuals. Health information should be presented in a way that invites people to take specific actions and decisions, and it must be geared to the patient's level of understanding. Mass communication and education should ensure that all present and future patients are properly informed about advances and alternatives in personalised medicine. The new model sometimes requires patients to play an active role as the coordinator and member of a team that monitors their health.

New alliances

Attaining the aims described here will require not only a great deal of research but also the development of new products and new forms of care. To close the innovation gap between laboratory and clinic, we need cooperation between partners who do not always move in the same circles. In biomedical research, there is a need for even closer cooperation between basic, translational and clinical researchers. In addition, researchers at universities of technology, in the social sciences and in informatics will also need to contribute. To achieve real innovation in clinical practice, enterprises must continue to develop new knowledge into useful products and standards. Finally, the rise of e-health and ‘domo-medicine’ (home automation for medical purposes) will bring about a change in how care is designed and organised.

Broader dialogue

These far-reaching changes in medical research and in the practice of prevention, treatment and care will not be possible without patients, or rather the Dutch people. Besides individual communication, a broader dialogue will be needed with larger groups in society. Ethics and legislation will be important issues in that dialogue. There are significant ethical and legal implications associated with the collection, storage, sharing and linking and use of large datasets containing privacy-sensitive data. For example, who owns that data? Under current rules, there are major barriers to collecting and sharing data, even if it is done in the interests of scientific research. Any solutions to this problem must allow for the importance of both privacy and better care through personalised medicine. New research methodologies also have ethical implications. If an individual’s data is entered into an astronomically large dataset, it can be difficult to enforce the theoretical right of that person to withdraw from the associated study at any given time. These and other issues demand timely dialogue and thorough research that includes a critical evaluation of good and bad practices abroad.

Transparent financing and reimbursement

Personalised medicine is not only desirable because it will deliver better care; it is also an absolutely necessity due to the ageing of the population and the growing number of patients suffering one or more chronic disorders. Ultimately, the advances described above will make care more cost-effective and affordable and less labour-intensive.

But there are various questions that must be answered first. For example, how will we finance the necessary research? What can public-private partnerships do in terms of financing? And what reimbursement system will ultimately be put into place in a care system that is so different from todays?

For example, it is important to test out reimbursement arrangements when developing personalised medicine at trial sites and in pilot projects. Medical insurers and other enterprises such as e-health developers will need to be actively involved so that they invest as well and reap some of the benefits later on.

En route to personalised medicine

The picture we have presented here of personalised medicine is ambitious but by no means unfeasible. We already know a great deal about biomarkers that indicate a person's state of health and possible sickness processes. Our understanding of the underlying biological mechanisms is growing day by day. And unexpected connections are already developing between the various parties involved.

The ultimate aim is for this health care trend to benefit Dutch patients, Dutch enterprises, and our society as a whole.

The quantum / nano-revolution

We are on the eve of a new technological and industrial revolution, brought about by the latest advances in quantum and nanotechnology. Thanks to nanotechnology, we can study and also manipulate individual atoms and molecules of matter. The laws of quantum mechanics play an important role at this scale. New quantum and nanotechnological applications can and will bring about a dramatic change in society.

Nanotechnology has already led to explosive technological advances. Examples include processors in smartphones, where the smallest electrical wiring is only a few dozens of atoms wide. The laws of quantum mechanics become more important at this scale, producing odd properties: widely separated atomic particles can interact with each other, be teleported, spin left and right at the same time, and be in different places at one and the same time.

We can now control the nanoscale to such an extent that we can test and apply quantum phenomena in experiments. Quantum technology and nanotechnology are set to enter a new, revolutionary phase in the decades ahead, giving rise to changes in IT and software development, materials for energy, medical diagnostics and sensors, and much more.

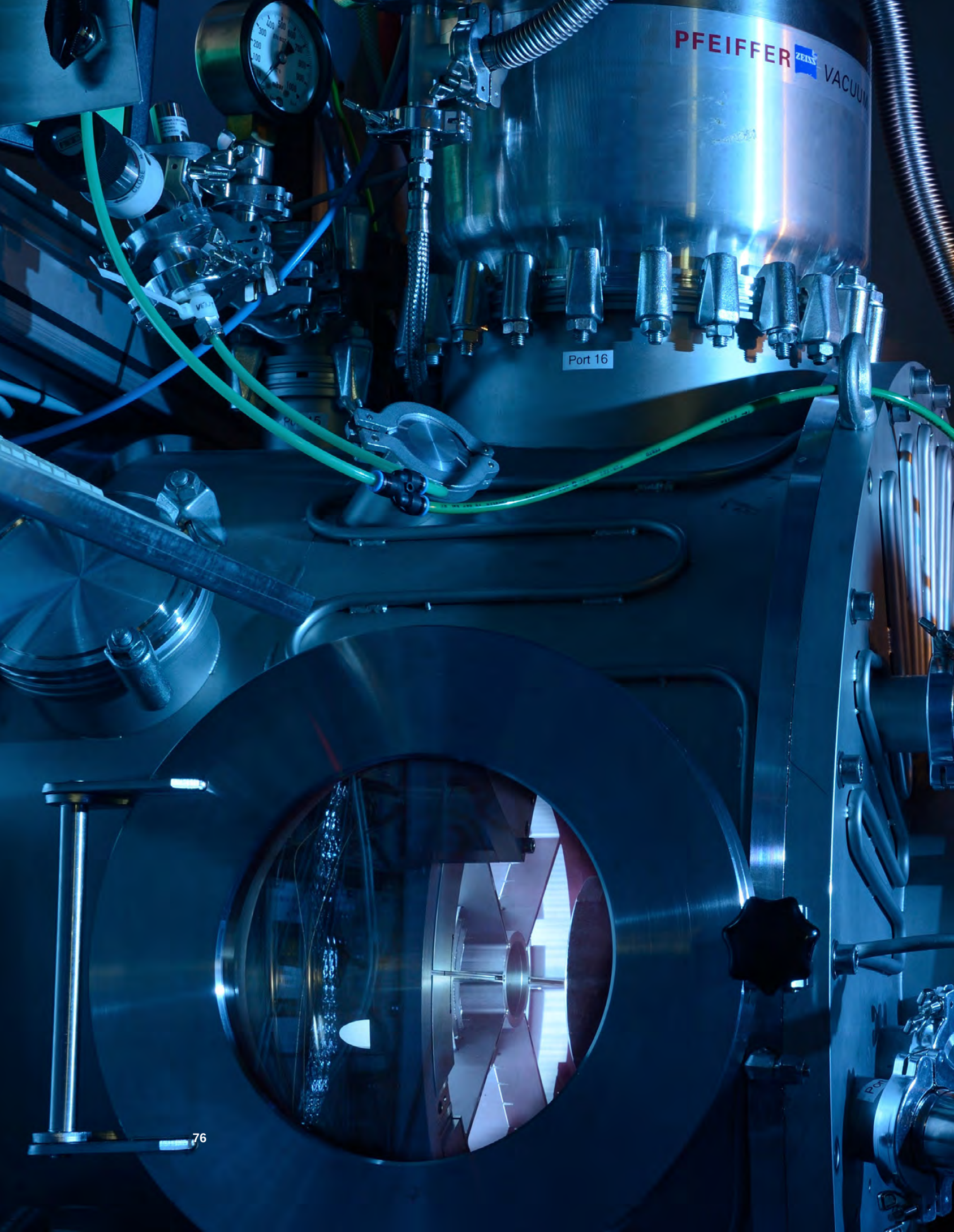
At times, technology will be so radically innovative that we will be unable to imagine all the many different ways that we can use it. One example is the quantum computer, which has such enormous processing power that it will be able to tackle problems that seem unsolvable today. Traditional technology will be reaching its physical limits. In nanoelectronics, for example, the curtain will fall on Moore's Law, which states that the number of transistors on a chip will double every two years. If we continue to reduce the size of structures, both quantum phenomena and temperature control become limiting factors. It is essential to develop ways to compute while conserving energy, thereby lowering heat production. Because quantum technology/nanotechnology could very well have a major impact on our society, this discipline will have to engage more often with areas of application in industrial sectors, and with the behavioural, social and health sciences.

The Netherlands has an excellent foundation for making a difference on a global scale in this revolution. Dutch research on quantum IT and nanotechnology, including nanobiophysics, nanomaterials, nanophotonics and nanomedicine, is world class. The Dutch have captured this position by investing in major public-private investment programmes early on, leading to an extensive scientific network that has an excellent relationship with industry.

Three game changers can force breakthroughs, provided that disciplines and industrial sectors, that still operate more or less separately, agree to join forces and rise to the challenge:

Quantum computing and the quantum internet

The unparalleled power of quantum computing makes it possible to predict and improve the properties of materials, chemical processes and drugs. At the end of the 1990s, we managed to raise the temperature of superconductors by a hundred degrees, more or less by accident. However, we are still two hundred degrees below room temperature. A quantum computer can eliminate serendipity from our quest by calculating which materials need to be combined to make room-temperature superconducting possible. Within the next ten years, we may be able to use relatively simple quantum computers to compute the right combination of smaller molecules, for example to produce more environmentally friendly fertilisers or for artificial photosynthesis. As we continue working to build the quantum computer, we will have to develop many new technologies. These include quantum sensors with a revolutionary level of sensitivity, quantum algorithms and software, and secure data communication systems. By linking quantum computers with each other and other quantum systems, we can create a quantum internet in which data communication is inherently secure and where we can utilise quantum entanglement to build highly sensitive sensor networks. As quantum mechanics goes against our intuition, we must also make public acceptance top priority from the very start.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The development of a quantum computer will require a great deal of basic, interdisciplinary and applied research. IT experts, telematicians, electrical engineers, software engineers, informaticians, chemists and physicists are already working together in various research institutes. But other important new connections are needed with experts in software architecture, cryptography and cybersecurity. Closer cooperation with Dutch industry would also be a positive development, so that researchers can work on specific initial applications and demonstrators, for example for the Aerospace or AgriFood sector. No less important is for social scientists, legal specialists and economists to consider the implications of quantum computing. How do we regulate a quantum internet, what will the economic consequences be, and how will it influence communication? As soon as the first quantum computers are used to develop new biochemical molecules, the biomedical sciences and industry will also be involved.

Green IT

Progress towards revolutionary energy efficiency in data storage, data communication and data processing will make a major contribution towards creating a more sustainable society. The aim is to develop ultra-efficient alternatives for electronic switches, based on integrated photonic or electronic quantum circuits that have a very high information density and sharply reduced energy consumption and which do not require the use of scarce natural resources. We anticipate important breakthroughs in this area. IT accounts for approximately ten per cent of total electricity consumption in developed countries. By making full use of quantum effects, energy losses can be limited and computers may operate millions of times more efficiently. Research is focusing on new nanomaterials and nanophotonics that should be capable of interacting closely. Other advances, such as spintronics – with magnetic instead of electrical information processing – will generate enormous energy savings. Another promising development is the introduction of neuromorphic systems. The brain serves as inspiration in this case, as well as a modelling system for new ways of designing powerful, energy efficient computers.

The development of Green IT will only be possible if researchers in a wide range of different areas – including materials research, informatics, electrical engineering, physics and chemistry – work closely together. This calls for an interdisciplinary approach that starts at the atomic scale and goes on to complete internet systems that span the globe.

Nanomedicine: new medical applications

Nanomedicine will bring about a revolution in health and wellbeing, with an unparalleled potential in terms of diagnosis and the fight against diseases. Examples of applications include nanotweezers for grasping, studying and manipulating biomolecules, and injectable and implantable nanosensors that can detect and localise diseases at a very early stage. Because diseases are often the result of molecular defects, nanotechnology can make an important contribution to our understanding of their origin.

Knowledge of nanometers is also vital to the diagnosis and treatment of diseases. For example, there are clinical trials involving genetically engineered DNA origami boxes that can find their own way to a target in the body and, upon arrival, unfold spontaneously to deliver the drug that they are carrying. Besides this type of nanotherapy, major progress is being made developing intelligent biomaterials – including nanostructures made of self-assembling proteins – that urge the immune system to destroy cancer cells throughout the body.

Minuscule chip implants and injectable nanorobots would be able to monitor important biological markers in our blood and detect the early onset of a disease in this way. These robots would also help our immune system by fighting bacteria or cancer-forming cells. It is also interesting to contemplate the use of biological nanostructures in this context, for example viruses and genetic complexes, in order to understand interactions between cells and pathogens, or to use these nanostructures in the aforementioned therapy and diagnostics.

Nanomedicine is already a highly multidisciplinary field that unites biochemists, chemists, biologists, physicists and mathematicians. Even so, more new connections are needed to improve the impact of bionanotechnology in helping us improve our understanding of diseases and their diagnosis and treatment. One important new connection is that between bionanotechnology and the biomedical and pharmaceutical sciences. Another essential relationship is with risk analysis and technology assessment.

Relationship between game changers

The three proposed game changers have their origins in advances in the field of nanotechnology. The relationship comes down to the possibility (or impossibility) of building and manipulating nanostructures and nano-objects. There can be no quantum computer without new advances in functional materials. The quantum computer, in turn, will lead to the discovery of new functional materials. Bionanomaterials will be integrated into nanosensors produced by big data. Nanosensors, in turn, would benefit from a quantum internet. Nanophotonics and spintronics will bring about revolutionary advances in energy efficiency in data storage and data processing, making an important contribution towards creating a more sustainable society. Nanophotonics will also play an important role in secure data transmission, and will also lead to more efficient sources of light, solar panels, and the production of solar fuels. The actual equipment forms a vital link between concept and reality, and equipment engineering is something at which the Netherlands excels.

Bionanomaterials designed specifically for diagnostics and treatment and personalised for the individual patient will spark a revolution in healthy ageing. New generations of supersensitive, energy-efficient, minuscule nanosensors and bionanosensors will be omnipresent and fully integrated, giving rise to smart cities, intelligent medicine and the Internet of Things.

A shared Dutch infrastructure, like NanoLabNL, is indispensable in this context. Previous research programmes gave researchers the chance to amass a vast amount of experience in technology assessment for research purposes and the commercialisation that it generated. Together, these legacies of the past offer a solid basis for achieving real changes in science and for implementing new applications that will help us address major societal challenges and secure our future revenue-generating capacity.

Regenerative medicine: game changer moving to broad areas of application

Regenerative medicine offers those suffering a chronic illness the prospect of recovery, instead of expensive relief from symptoms. It means being able to repair damaged tissue and organs without resorting to a transplant. Drugs can then be tested on organs-on-a-chip, without using laboratory animals and customised to the specific patient where necessary. Work is advancing on connecting the brain and electronics in new ways, for example in bionic limbs. This is a fascinating picture of the future, with regenerative medicine representing an enormous opportunity for health care and the economy.

Our population (and thus our workforce) is ageing, and it can be quite a challenge for people to remain robust and continue participating. After all, old age leads to deterioration in tissues and organs in everyone, but this process may be accelerated by arthritis, cardiovascular diseases, diabetes, neurodegenerative disorders or other illnesses. Fortunately, we are learning more about natural tissue recovery all the time, and there is a growing range of biological and technical methods available for repairing tissue and organs.

Interdisciplinary research in regenerative medicine is based on a growing knowledge of stem cells, growth factors, tissue architecture, biomaterials, and refined testing techniques. Thanks to earlier programme-based investment in large-scale alliances, the Netherlands has built up an enormous potential for valorisation. Unfortunately, very few patients have thus far been able to benefit from specific therapies.

From the lab to the clinic

The time has come to expand this basis and make the transition to broader clinical application. Regenerative medicine is already a billion-dollar industry, with more than 700 enterprises worldwide representing a shared market value in 2013 of USD 16.4 billion, expected to grow to USD 67.5 billion by 2020 (Proteus Data, 2014). The Dutch economy can benefit as well, but that will require ongoing investment in public-private partnerships to cross the infamous ‘Valley of Death’, i.e. the period between proof of principle and the large-scale, long-term manufacture of the final product.

The biggest game changer

Regenerative medicine is one of the most significant game changers in medicine today, although it will take a huge effort to capitalise on its promise.

Investing in training and talent

Various disciplines are currently working on regenerative medicine, e.g. electrophysics, bioelectronics and medicine. Each one is working to come up with new tissue and organ solutions in its own area of expertise. In future, however, we need scientists whose expertise lies at the interface between technology and medicine. A targeted programme of career incentives in this area could increase the impact.

Consolidating alliances

BMM, TeRM, NeuroDelta, NIRM and other examples of major, successful public-private partnerships in re-

generative medicine paid for largely from the Economic Structure Enhancing Fund (FES) have come to an end. Thanks to the foresight of prior governments, which co-financed these partnerships, the Netherlands has a strong research platform in regenerative medicine. What is of the utmost importance now is to invest in consolidating these connections. Large-scale partnerships are now often funded by the European Union, given that Dutch funding falls far short compared to that in other developed countries. Researchers, enterprises and ministries recognise the importance of such consolidation and have already started taking steps in that direction. Two examples are the Institute for human Organ and Disease Model Technologies (hDMT) and Regenerative Medicine Across Borders (RegMed XB), both aimed at conducting pre-competitive research in cooperation with enterprises. These vital alliances will help bridge the gap between scientific concepts and patient care.

Investing in infrastructure and research (basic and translational)

Encouraging a joint research agenda makes synergies between programmes (e.g. by government, health funds, top sectors) possible that will drive regenerative medicine forward. Both hDMT and RegMed XB are interesting initiatives in that respect because they use multidisciplinary knowledge and expertise to create critical mass in relation to specific research themes. At the same time, shared use is also being made of expensive infrastructure (Good Manufacturing Practice clean rooms, microfluidics production).

Major national alliances and infrastructures of this kind make it possible to develop the conditions for taking the next step from basic concepts to specific solutions for patients, e.g. by studying the genome, new technologies and interactions between biomaterials and cells, and by investing in advanced imaging platforms. These investments also line up with the investment agenda of the Netherlands Federation of University Hospitals (NFU), as described in the paper Sustainable health.

Responsible Research and Innovation (RRI)

For applications to catch on, it is important to inform the public properly and to involve it in a dialogue about the social, legal and ethical consequences of regenerative medicine. An open discourse of this kind can ensure that new applications actually meet the needs of the Dutch people and are widely accepted. These new care products also need to be sustainable

and profitable, so that they help manage the costs of health care.

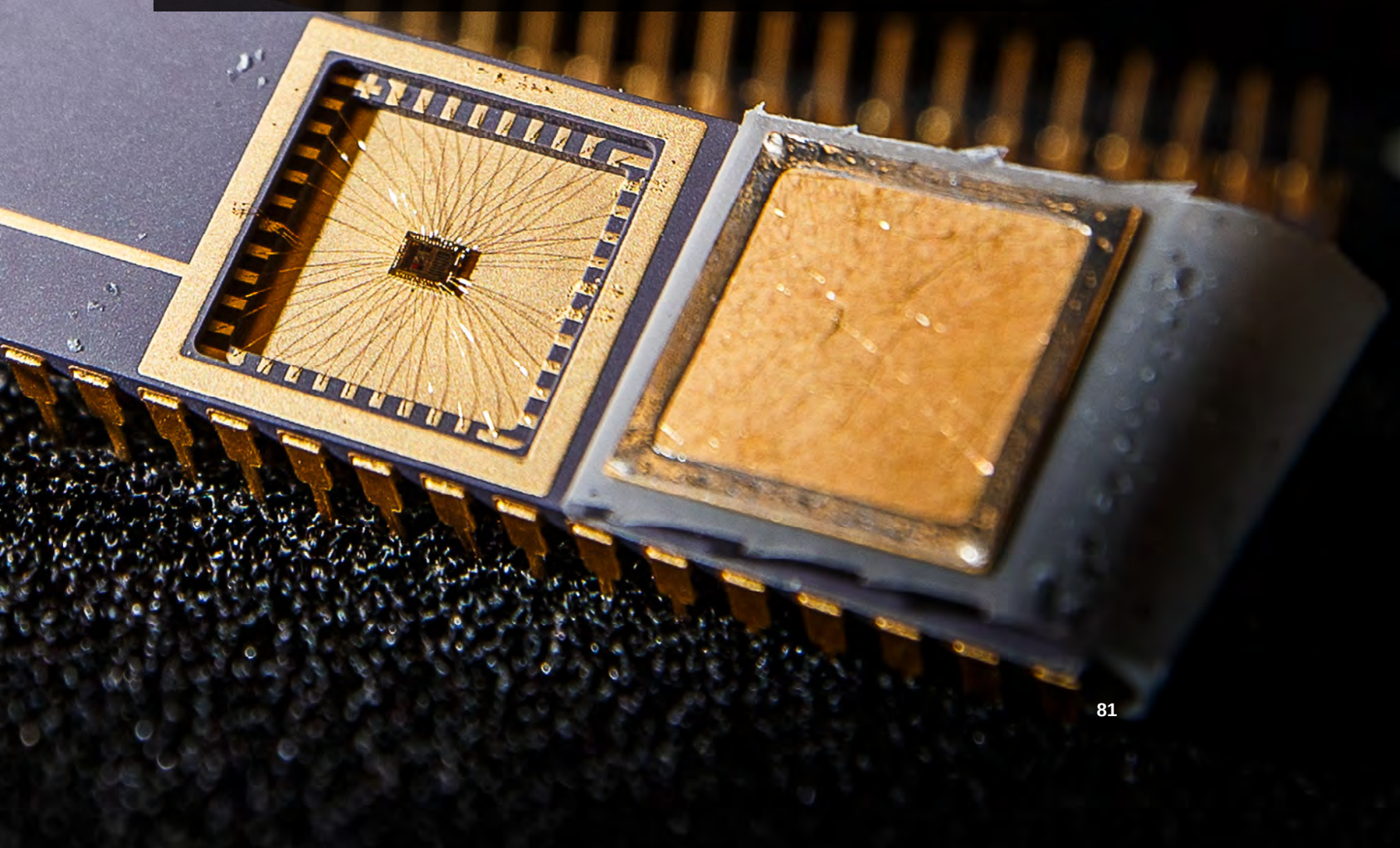
Besides the financial support of long-term alliances, government must also invest in making the Netherlands an interesting place for enterprises specialising in regenerative medicine. Theme-based Regenerative Medicine Technology Transfer Offices (TTOs) are needed to accrue and share a specific knowledge of intellectual property rights, market authorisation and production processes for this new industry. Researchers must be guided by such TTOs at the earliest possible stage, ensuring that they receive timely information about implementing their knowledge and taking market-appropriate action, increasing the chance that their knowledge can be commercialised and utilised.

Position in regenerative medicine research

The Netherlands is among the top five countries in the world in regenerative medicine research, and number 1 when it comes to the impact of published papers (Pubmed analysis). Although much has been achieved, very few patients have actually benefitted from specific products. We have yet to take the step from the lab to the clinic and from experiment to widespread application. That is in part owing to insufficient funding for translational research and the limited production facilities available. At the moment, the Netherlands' research advantage has not yet translated into greater economic value in domestic terms. It would be a waste of capital if all the investment previously poured into this promising area, with an anticipated market value of USD 67.5 billion by 2020, would ultimately only produce economic profits abroad. Governments in other countries are providing powerful incentives to drive the necessary technological advances. Examples include Catapult Cell Therapy in the UK and the Centre for the Commercialization of Stem Cell Research in Canada (ranging from 15 to 100 million euros a year). It is absolutely vital for the Dutch government to invest at least a comparable sum if the Netherlands is to hold on to its current position in science. This will also guarantee the Netherlands' appeal for enterprise. One crucial condition is to acquire specific expertise concerning the valorisation of regenerative medicine.

Impact

In 2011, diseases for which curative therapies are now being developed based on regenerative medicine cost the Netherlands 18.2 billion euros. The burden



of mortality and living with these diseases comes to an annual 1.4 million Disability-Adjusted Life Years (DALYs). A relatively small investment in regenerative medicine research could therefore have a huge impact in the Netherlands. Regenerative therapies are already being developed for most of these diseases.

Health care innovation is needed if the Dutch are to have access to the best and most up-to-date therapies, which will boost prosperity and the quality of life. It has been shown repeatedly that innovation can cut health care costs: every euro invested in improving the effectiveness of treatment produces a long-term annual savings of 3 euros. This makes innovation interesting not only to government but also to medical insurers.

Investment needs

Regenerative medicine takes a very different approach to healing, with the recovery of organ function in the chronically ill being central. This branch of medical science would benefit enormously from a national, cross-disciplinary, large-scale, long-term research infrastructure that is embedded in an international context. The future position of the Netherlands in this international context will depend largely on the country's ability to keep up with the new technologies that drive the field. The Dutch investment in infrastructure must keep pace with competing investments by foreign governments. The NFU's efforts in this regard will have a multiplier effect on these investments. In addition, it may be possible to use current programmes to speed up implementation. The investment required to develop shared research agendas can be obtained by matching funds (local government and Top Sector Consortia health funds).

In ten years' time, an extra investment will mean that patients will benefit much sooner from improved, innovative therapies. Ultimately, this will lead to patients participating fully in society and to a reduction in symptom-alleviating treatments. This investment will also produce new, trained talent that will make the Netherlands a more appealing place for pharmaceutical and biotechnology firms, and lead to major cost savings in health care.

Smart industry

Perfect, lot size 1, custom items made for the price of a mass-produced product. That is the speck on the time horizon of industry. To make this possible, science will have to take action. We must develop smart products and services, design flexible production systems, and develop the technologies that we need to create new products, services and manufacturing methods. We must also explore the impact that this new 'smart industry' will have on society.

Industry is becoming digitised and automated. A combination of digitisation, linked intelligent systems and new technologies is not only altering production processes in industry but also business models, jobs and patterns of consumption. Production is set to return to the Netherlands from low-wage countries. It used to be profitable to purchase inexpensive parts from China and keep them in stock, but nowadays customers can upload a drawing of a part online and then have a 3D printer turn out the part and delivery get it delivered in hours, for example.

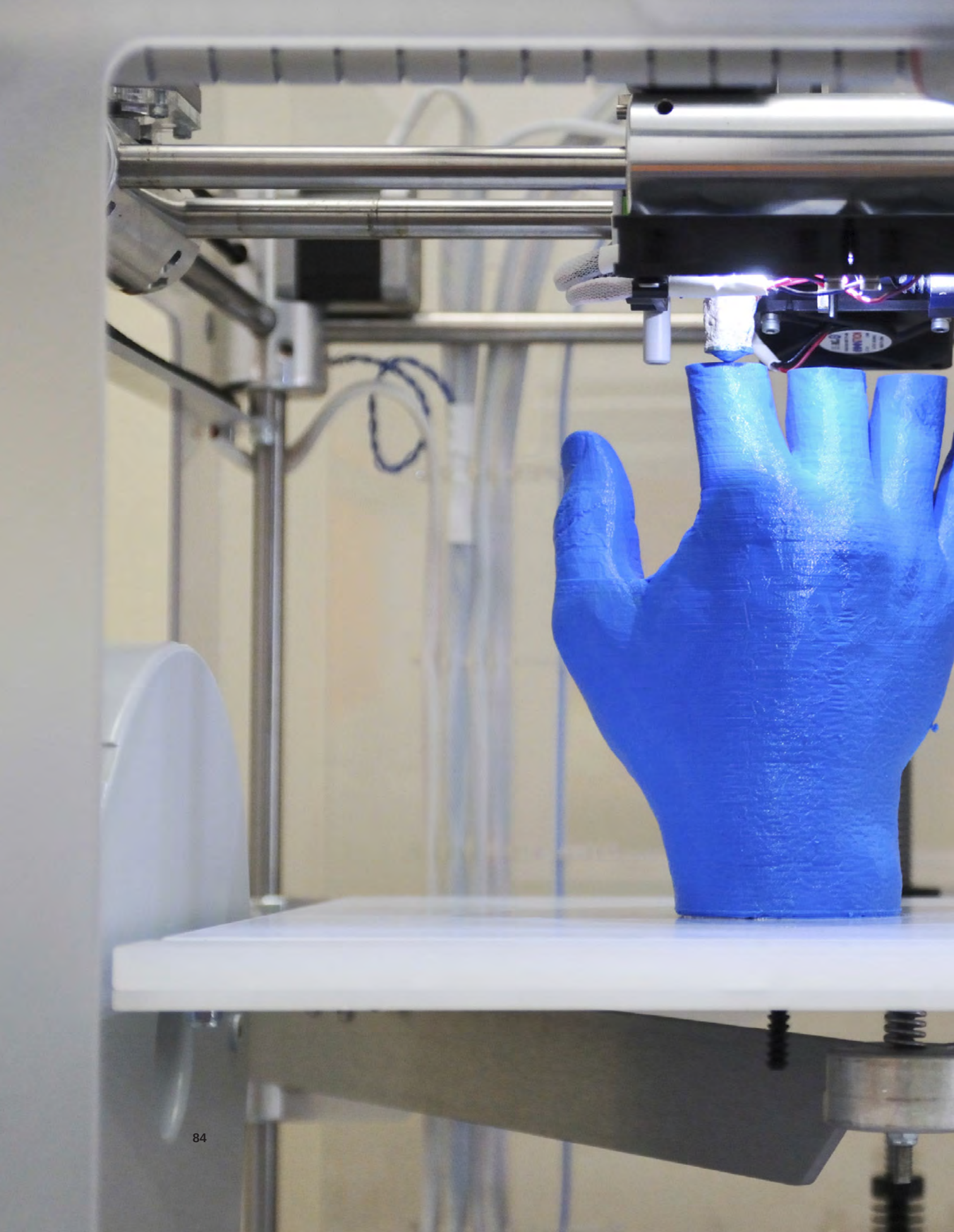
At the same time, we are witnessing the rise of personalisation and 'servitization', with service provision underpinning production firms. Customers pay to use a product rather than to own it. Enterprises that used to focus mainly on manufacturing physical products are now turning into customer-specific service providers. In digital marketplaces, they offer customers solutions and service first and foremost but also make the associated hardware product available to deliver the solution. They no longer manufacture that product themselves; their suppliers have taken over the entire production process.

Industry 4.0

The future of industry – sometimes referred to in Germany as 'Industry 4.0' – is linked to digital technologies. In the Netherlands we use the English term 'smart industry'. This concept includes the digitisation and servitization of value creation. 'Industry' refers to all the processes that lead to value creation. This is broader than the traditional concept of industry in the Netherlands, which describes traditional brick-and-mortar factories. Because it includes the concept of servitization, smart industry also means the service sector, ranging from maintenance, logistics, product design and distribution to commercial, banking and insurance services. In economic terms, the broad definition of smart industry encompasses all exports and a large share of our gross national product.

Smart industry uses IT to optimise production. Smart machinery and robots communicate with one another, track down non-compliances, and repair them. Guiding these processes is powerful software that is working continuously to combine, analyse and interpret enormous quantities of data fed into the system by sensors and customer demands. Production is consequently much more efficient. The processes are faster, more sustainable, and less expensive. That is not only the case for factories, but also for hospitals and any other process based on production and logistics.

Smart industry thus has an impact on our entire economy and consequences for our society and for employment. If the Netherlands is smart and jumps on the bandwagon in time, this trend will be a jobs generator in the future. Four game changers will make this possible. Each one will have an impact, on new business, new jobs, new science, and new forms of education, respectively. And each game changer will require cooperation between enterprises, knowledge-based institutions, and government.



Smart products (personalization) and services (servitization)

This game changer explores innovations in products, product-service systems and business models made possible by applying smart industry technologies. The specific focus of attention is the interaction between people, product and content. One special area of concern is to make life easier for people living in complex environments. This game changer has an impact on manufacturing, the IT sector and the creative and financial industries, especially those areas that derive profit from value creation. What we need are intensive, short-cycle, multisector experiments undertaken by all sorts of alliances, in the form of trial sites, living labs and field labs. This will involve developing servitization into a fully-fledged science alongside traditional product design, and extending Dutch Design to services and content. Service creation is also related to economics and the social sciences and associated with changing legal aspects. Consumers want custom, personalized products and fast delivery, and producers can no longer afford to spend years getting a new product to the market. That has implications for plant logistics and planning. How can we design production lines so that a small change in a product specification no longer shuts down an entire line for several hours?

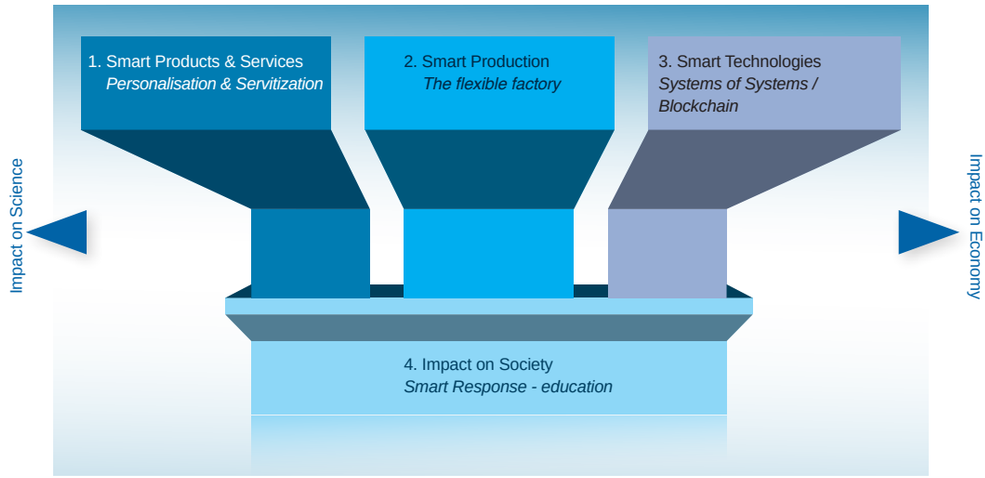
Service and maintenance also need to be overhauled. For example, we can imagine machines that report on their own performance online. The maintenance crew will no longer turn up according to a predetermined schedule, but only if a problem is looming. This type of model raises other questions, however. Who is responsible if a piece of machinery becomes dangerous to operate but the machine itself does not detect the problem?

Smart Production – Flexible factories thanks to digitisation

This section involves researching the changes needed to enable the automated production of limited series and one-off items. The game changer in this case is the flexible factory, with metropolitan manufacturing as the ideal: small, universal, flexible factories in or near cities that can produce a variety of product types to customer around the corner. Having it manufactured it locally it can later be disassembled too. The Netherlands industry players are already specialised in making limited series of such high-value production systems for niche markets. It can even boost its position in this value chain and supply new machinery for producing lot size 1 items created by means of 3D printing and limited series of flexible electronics, for example. We will go from economies-of-scale in production, which lead to mass production in low-wage countries, to economies-of-networking, in which enterprises are more likely to share the responsibility for a product or service, whether large companies or SMEs in a regional network of companies. Old-style industry is evaporating, but new parties and change-driven entrepreneurs will create jobs and maintain employment. By supporting applied research, the Netherlands can lead the way in flexible factories and the high-tech instruments they require.

Smart Technologies – Systems of systems & blockchain

This game changer concerns innovation in the technological basis that underpins smart industry, i.e. the IT infrastructure, data-sharing, software, new sensors, and precision and process technology. This is the hard technological grounding needed to make smart industry a success. The Netherlands can expand on its unique position in this area by collaborating with international data platforms and participating in international value chains. The international component is especially important. This game changer addresses multiple scientific challenges and is an enabler for a later economic impact. It requires international networks and decisions as to what the Netherlands wants to excel at. The implications and implementation of the Internet of Things – in which hardware and software are connected through a network – and the blockchain – a distributed database that maintains a continuously-growing list of records (called blocks) secured from tampering and revision – are important topics of research.



Research topics in which the Netherlands should also maintain a pivotal position include complex software, embedded systems, mechatronics, precision technology and material modelling and simulation.

Smart Response – Societal impact on smart jobs & skills

This game changer concerns the broader societal impact of accelerating digitisation and the ability of society and individuals to anticipate that impact and to deal with it intelligently and safely. Smart education is the main factor in this game changer. How do the concepts made possible by smart industry filter through to society and how are consumers, employees, politics and the media responding?

Besides identifying these societal effects, we will also have to choose which fields the Netherlands can develop a unique position in and how it can achieve its ambitions. How do we improve the digital skills of the entire Dutch population? What new jobs will emerge and how many, and which new skills will they require? And how will initial education and lifelong learning change?

Skilled workers in manufacturing will come to occupy a new role thanks to advances in automation. They will spend more time looking at screens to determine how well a machine is operating. Robots that take over the original manual labour will need to be monitored by experienced skilled workers. That means that many of these workers will need to be retrained.

Finally, the new way of working requires knowledge of cybersecurity. The more sensors, machines and factories are linked to one another online, the more risk there is of hackers interfering with production processes.

Smart, liveable cities

In 2050, seventy per cent of the world population will live in urban environments, which will account for almost eighty per cent of the gross world product. Cities need to function well: not only for their own inhabitants but also for the people living in the suburbs and in rural areas. The city of the future will require an integrated, multidimensional approach that addresses urban opportunities and challenges. New alliances are needed to sketch the contours of a city where people can live well and safely.

Cities function on an order of scale where crucial societal, ecological and digital challenges become manifest. Making cities and their environments futu-reproof requires a new, inspiring form of engagement on the part of citizens and enterprises, changes in governance models, and the circular use of energy and resources. Climate change adaptation, digitisation in the service of safe, well-functioning and healthy cities, and the improvement of urban ecosystems are all important factors.

Five game changers

Science faces interesting and complex challenges in the transition to a resilient, liveable, smart city. Smart, liveable cities are the result of societal and technological changes that are occurring more and more often and on an exponential scale. How can we apply new perspectives, alliances and paradigms in cities? What works and what doesn't? Solutions will have to come from multidisciplinary research. That will require a radical new approach, one that involves dialogue and cooperation between existing and new disciplines. Our approach to smart, liveable cities will need to be based on four parallel, contingent perspectives or lenses: the tangible city, the human city, the organised city, and the invisible city. Five game changers have been identified.

Safe Big Data Cities

Society is digitising. Technological advances in IT, sensors, e-health, apps, the Internet of Things and the digital revolution are increasing the level of digitisation in cities. How can we organise a platform of data and information that makes city-wide governance possible? The question is not whether our cities will be transformed into smart cities, but rather how we can optimise the way this new digital city functions. Can we manage digitisation in such a way that it promotes the liveability, economy, health and safety of society? The reliability of data is a growing point of concern. How do we ensure that the data we use in public life is available and reliable, and how can we involve the public in this? The digital city must allow for the many different needs of its inhabitants and will have to anticipate changes in society and technological advances. One important accountability issue is vulnerability to cybercrime, terrorism, hacking and spam. There is a growing demand by both the authorities and society for information, including for security purposes. For commercial reasons, the need for more information will be enormous. That makes privacy the second key accountability issue. It is becoming increasingly important to ensure privacy in general and, more specifically, to define and establish a minimum level of privacy.

Smart polder model

Today's technological and societal trends will have far-reaching implications for the way cities are organised and for their institutions. They make new forms of participation possible in decision-making, self-governance and networking, as well as different forms of communication and cooperation between

administrative bodies. It is therefore crucial to understand the organisational and political structure of cities, how they develop, and what impact new technology has on them and on social and human interaction. We still know too little about how decision-making comes about at various levels in a city. That is in part because we know little about the effect of new technological advances, decentralisation and citizen participation. Research is crucial. New technology makes organising and decision-making faster and more efficient, but there are other unavoidable, mainly indirect effects that are impossible to predict without research. Cities vary widely in terms of governance and organisation, and those variations are decisive for their structure, identity and quality of life. The effects of new technology, communication and data use are unknown. It is also important to explore the impact on more undefined forms of governance, for example temporary consortia of institutions, enterprises and people in individual projects.

The vibrancy of a city also depends on organic processes to a great extent, for example community self-organisation, the procurement of services, and transport. This vibrancy is also generated by activities on the fringes of urban life that are concealed from formal decision-making processes. Such forms of organisation are often a poor match with current rules and the timescales that they involve. Once again, new technologies can facilitate governance, but we must first identify the potential consequences.

New forms of communication can increase citizen participation, but it is obvious that their use should not exclude people who are unfamiliar with the new routes. Differences in access can lead to disruptions in the democratic decision-making process even in a less absolute sense. A well-functioning urban society must have confidence in government services and in its communication with government.

Citizen empowerment

Engaged citizens living in harmony in the city: when there are no conflicts or tensions between individuals

or groups, cities are much more liveable. Smart data and smart technologies can create new reasons for city-dwellers and businesses to connect.

Self-empowerment is also important from an economic perspective. Increasing the level of participation is one of the defining conditions for mobilising human capital. How do we create paid and unpaid work by getting the urban population to participate and engage more? Little is known about how the rise of mobility and digital communication is influencing encounters between people in cities. Digital platforms, serious gaming and sharing-technology can help people to organise, share services and together improve life in the city. The degree to which people and organisations arrange such activities reflects the smartness of the city. Research should deepen our understanding of how to empower citizens and increase their social, economic and emotional engagement with one another and the city.

Urban technologies

The changes that built urban environments are facing are considerable and require an integrated approach. New technological solutions are in demand to deal with changing demographic circumstances, to concentrate energy use, generation and storage, to introduce climate adaptation measures, and to prepare cities for new forms of mobility. New technologies are needed to embed these technological advances in the existing urban landscape, where space is at a premium and acceptance is vital.

Many of the issues and challenges that society is facing will have a huge impact on built urban environments, and some of the solutions to these issues will need to be created in those environments. These are issues and challenges that cities must acknowledge and address, and they include urban expansion, ageing populations, new industrial processes, the energy transition, climate change, changing patterns of mobility, data communication, and the digitisation of the built environment. To key into these trends and developments, we need new solutions and technologies

that can be applied in the built environment. Recycling and reuse are essential, both in terms of solid building materials and organic waste.

Research is focusing on the changing relationship between humans, health, infrastructure, energy, the environment, light, noise, buildings and green landscaping in smart cities, with a convergence between architecture, environmental psychology, health care, spatial planning and urban design.

Resilience

A smart, liveable city is one in which the built environment is flexible in facilitating a broad range of constantly changing activities and interactions; it is also one in which public space plays an important role in the social fabric. The city of the future must be resilient, flexible, and driven by faster, better design processes, but it must also preserve its existing qualities and cultural heritage. The city's physical structure must allow it to absorb new functions, easily alter existing functions, and cope with disasters and major disruptions in processes. These are all factors in what is known as 'resilience engineering'. Research is needed into new spatial design and planning concepts, interventions and maintenance without inconveniencing residents, so that processes in the smart, physical city can be optimised with the limited space available, and use of that space can be more intensive and multi-purpose.

Approach

This route requires research in the humanities, science and technology, and the social and behavioural sciences, often in close coordination and cooperation. New alliances are necessary to address the four perspectives: the tangible city, the human city, the organised city, and the invisible city.

This route is highly international in outlook; Dutch cities are renowned internationally for their successful planning mechanisms, their experimental nature and their propensity for change.

The route challenges us to develop new research methods, from participative action research, sensor-based data research, living labs and app-based citizen science to research on the acceptance of technological change. Innovation, creativity and an undogmatic attitude towards new research methods are both necessary for research on smart, liveable cities and widely recognised qualities of Dutch research culture.

Sport and exercise

Exercise and sport are important throughout the entire life cycle. Babies learn by moving about; children need to run and play for their physical and mental development; adults need exercise to stay fit and keep the diseases of prosperity at bay; the elderly must remain physically active to maintain vitality so that they can take care of themselves and live on their own for longer. And some people can parlay their physical skill into a career as a professional athlete. Sport and exercise bring people together and contribute to social cohesion.

Research on sport and exercise is set to make a huge difference in the years ahead. That is because we will no longer need to base our studies on group averages, but instead will have access to individualised data that allows us to produce custom exercise and sports programmes for everyone, even non-professionals. The game changer for this route is personalised exercise, for everyone, at every age.

To achieve this, we need to help every individual fulfil his or her physical potential. We will not only study what every person needs and is capable of, but also their social and physical environment. After all, the desire and ability to exercise depends on our personal traits and contextual factors. Even professional athletes need to optimise their individual training plans to get the best out of themselves and deliver a peak performance.

Personalised exercise for everyone

Each of the three themes – ‘Learning (and) physical fitness’, ‘Healthy exercise’ and ‘(Peak) performance’ – is valuable in and of itself, but all three are also closely connected. The game changer will only succeed if we act on all three. For example, what we learn by studying professional athletes has practical value for healthy exercise and learning (and) physical fitness, and vice versa. To assess the merits of each theme, we need to view each one in context with the other two.

Learning (and) physical fitness

Every individual needs something different to fulfil his or her physical potential. Good physical fitness increases our enjoyment of exercise, improves our skills, supports our personal growth, and reduces the risk of physical or mental illness. It is the basis for a healthy and happy life. Good physical fitness and a healthy diet together can prevent overweight, one of the biggest public health problems of our time. They are also essential factors in healthy parenting. By studying retroactively when and how adults learned healthy fitness habits, we come to understand the turning points along the spectrum of learning physical fitness and neglecting it.

Children start to learn about physical fitness at school. A four-year longitudinal study of children will allow us to build the foundations of a fitness tracking system and integrate it with existing pupil information systems. That way we can detect patterns in how children learn physical fitness, allowing us to develop and test specific interventions for specific children. Such interventions would focus not only on the individual child, but also on social or group learning, cultural aspects, and spotting talented athletes. Ultimately, we want to chart individual learning strategies so that we can identify the life phases in which exercise has the biggest impact on individuals.

Research must also demonstrate which combination of learning, exercise, and learning through exercise has a positive effect on learning and pupil performance.

The research described above will require cooperation between the fields of pedagogy, educational theory, human movement science, neuroscience and data science. Research on implementation and structural incorporation into education is being carried out by cooperating primary schools, secondary schools, associations of teachers, local government, research universities and universities of applied science, sports clubs, and local sports providers.

Healthy exercise

If we want people to be physically fit, we have to consider not only the personal aspects but also the social and societal factors. By collecting data systematically at all these levels, we will learn which policy interventions are best for encouraging people to exercise. In four years' time, this approach will make it possible to match local sport and exercise facilities with individual citizens, based on their needs and potential.

Large-scale cohort studies will allow researchers to investigate in which communities people get too little or just enough exercise. They can then combine that data with the traits of these communities, for example demographic composition, social class, physical surroundings, degree of mobility, or presence of sports facilities and clubs.

Sport and exercise are often more effective than drugs when it comes to lifestyle-related health problems. In addition, physical exercise is cheaper and has almost no side effects. Based on data collection and analysis, we know which health problems are best served by exercise interventions and how they can be integrated into individual treatment plans.

To achieve all this, we need to forge new alliances that combine policy and prevention research, or that integrate local data collection and socio-psychological research and policymaking, and medical research and socio-psychological insights in the behavioural sciences. Also necessary is cooperation between local government and local social welfare and health care organisations, local sports providers and associations, research universities and universities of applied sciences, hospitals, research institutes and insurers.

(Peak) performance

By preventing sports injuries, we can avoid much personal suffering and economic costs and keep people exercising longer and with better results. In professional sports, this means the ability to perform steadily and for longer periods at peak levels. Prevention is thus part of performance. In the next four years, we will use implementation research to put effective injury-prevention techniques into practice.

Major advances in training efficiency are also possible. Right now, a person has to practice 10,000 hours

before he or she masters a new skill. We can cut that amount of time by half. In the next four years, we will use data science techniques and technology to track down the relevant training data on talented and pro athletes. Based on that data, we can then develop guidelines for personal monitoring and feedback.
We will also be looking at fair play issues and FAIR (findable, accessible, interoperable and reusable) data. Unusual patterns in an athlete's individual data may indicate a doping problem. Competition data can provide evidence of match fixing. The explosive growth of sport-related data makes fair play a realistic goal. What is especially new here is the connection between data science and movement science. Sports federations, sports associations, professional athletes, enterprises, research universities and universities of applied sciences are cooperating in this area.

Cooperation and partnership

Theory and practice are already closely intertwined in sport and exercise. We want to boost that relationship even more in the years ahead. Funding bodies have already joined forces and agreed to develop joint programmes. That will lead to prioritisation and focus, and thus to greater mass, impact and benefits.
We will follow the example of the Olympic Games by reviewing what is needed in four-year cycles. We will

also look beyond our national borders and seek out international support and enrichment.

Applying knowledge in the field

How can the knowledge we have gained in the lab and in experiments be used most effectively to meet needs and requirements in the field? To answer that question, we need to study how best to implement and embed that knowledge permanently in policy-making and in practical situations. In professional sports, scientists are already working alongside and as coaches to analyse training data and offer advice. In the future, we want to extend this by getting sports practitioners involved in research in order to improve the way that we apply knowledge.

We also want to explore how knowledge obtained in other sectors, such as health care, education or spatial planning, can heighten the impact of sports and movement research. It is important that this knowledge filters through to the pursuit of sport, to schools and enterprises, and to local government policy, and that educators, researchers, policymakers and practitioners work together. In applying what we have learned, we will look explicitly at those groups who might be left behind when turning theory into practice, for example people with a low socio-economic status and poor health skills, or migrants and refugees.

Data science

Efforts have recently gone into building an infrastructure that will allow data to be shared and analysed by many different parties by making component datasets widely accessible and available to specific experts. Their analyses will produce new insights in many different domains, from haemogram analysis to talent scouting and discovering why people do or do not engage in sport.

Data mining, text and image analysis, machine learning, visual analytics and other methods will help us discover robust and interesting patterns in data. We can also use sensor technology and other data-generating techniques. This will make it possible to analyse and make predictions at individual level. Thanks to data science, it will also be possible to analyse the environmental factors that influence sport and exercise in individuals. That means that the data must comply with stringent quality and quantity standards. An advanced data infrastructure is a crucial criterion. We must also consider the ethical, legal and societal aspects of big data.

Making a difference

We will create an ecosystem for research and sport innovation in which researchers, enterprises, government, and sports organisations can work together on sport and exercise interventions and innovations. Our aim is for local governments and enterprises to commit into this infrastructure so as to increase its impact and generate economic benefits. Personalised exercise, for everyone, at every age, is now within reach!

Sustainable development goals for inclusive global development

How can we promote inclusive global development and improve sustainable global well-being? That is the main question of this route. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their needs. Inclusive development means improving wellbeing while ensuring that it is equally distributed across and within (global) societies. In addition, it refers to the involvement of excluded, disadvantaged and poor groups in society and politics.

Sustainable development is about striking a balance between ecological, economic and social interests. Development differs from growth because it embraces other dimensions of wellbeing than economic ones. Poverty functions as an impediment to sustainable development, however. Climate change, security and migration, food security, green energy, gender inequality and many other global challenges are not only sources of poverty, but poverty also hinders tackling them effectively. The gap between rich and poor reinforces poverty.

When solutions to global challenges fail to take the interests of every population group or country into account, they can never be sustainable. Being attentive of the relationship between poverty and sustainable development, the United Nations decided to focus on combatting poverty in developing countries in its Millennium Development Goals.

The UN's Sustainable Development Goals (SDGs) go much further and are of universal relevance in every country. They set out seventeen focus areas that go beyond combatting poverty in developing countries, that reflect the complexity and global and interactive aspects of sustainable development. To achieve inclusive global development, we need to integrate ecological, social and economic dimensions of development. This turns inclusive global development into a more complicated problem than it already was, one that requires new evidence-based knowledge about the mutual interaction between the components of the SDG system and between domestic and global effects.

Added value for society

The existing strong levels of inequality by pursuing inclusive development ask for a policy that favours coherence aiming at interrelationships and possible synergies, preventing possible contrasts or bartering between different policy domains. A research agenda based on the Sustainable Development Goals offers the Dutch Government an ideal chance to improve horizontal policy coherence between development and trade policy and policies in areas such as economy, security, infrastructure, environment, and research and innovation. The same holds for vertical policy coherence – i.e. the relationship between national, regional and global policies – with a view to the effects of Dutch policy, for example on poverty in developing countries.

An inequitable distribution of prosperity and wellbeing undermines social cohesion and increases the risk of conflicts. Conversely, extreme poverty tends to concentrate in places dominated by anarchy, exclusion and violence. The absence of peace, security and opportunities for economic development is a key cause of migration. Investing in inclusive development contributes to global ánd Dutch security.

Added value for the economy

A wide wealth gap is harmful to economic development. Raising the income of the lowest income groups has a relatively strong positive effect on a country's economic growth as a whole. Various developing countries that have received long-term aid from the Netherlands experienced rapid growth. But also the Netherlands benefits because Dutch exports to these

countries is increasing sharply. In other words, it is economically sensible to invest in disadvantaged groups and developing countries.

Added value for science

At the moment, there is hardly room for studying the complex problem of inclusive development at global level. The complexity theory, the availability of big data, technical tools for open knowledge generation and open access to knowledge provide opportunities to study global inequality in all its interrelated aspects. For this, a systems approach that combines both western and southern perspectives and that transcends relevant sectors and disciplines is needed. The inclusive global perspective, based on intercultural perspectives and in cooperation with non-western cultures, also offers Dutch science access to a broad spectrum of new scientific approaches, and tools and methods for knowledge creation, research material, and expertise in non-western societies. This clears the path to innovative insights and breakthroughs that would otherwise be beyond the reach of Dutch science.

Game changers

The new approach promoted by the Sustainable Development Goals requires new, evidence-based insights into the mutual relationship between the three component systems into which these goals are grouped. In addition, a knowledge infrastructure is needed that can accommodate multifaceted value and knowledge systems in order to develop, manage and share new scientific insights, technology and practical experience.

Systems science

Until now, research on inclusive global development mainly looked at the individual component systems, i.e. the natural environment, the infrastructure and wellbeing. However, it is difficult to promote global inclusiveness, leaving out specific uncertainties, conflicting values, changing criteria and interdependencies. Partial solutions only give rise to new problems as a result. Systems science attempts to consider the whole picture instead of concentrating on separate component systems. Systems behaviour is not simply a matter of cause-and-effect, but the combined action of reciprocating component systems in which feedback plays an important role. How do interventions within a component system influence the inclusive development of the whole?

Systems science has already come a long way in the social, natural, technical and medical sciences. To function as a real game changer, these separate systems science approaches must now be combined. Applying comprehensive systems science in research would endorse horizontal and vertical policy coherence.

It is a characteristic of complex problems that interventions have unpredictable consequences that are difficult to quantify. Therefore, this game changer must absolutely integrate scientific monitoring of inclusive development and quantification of impacts. This requires an easily applicable definition of goals and of quantifiable progress indicators. The major task of defining and elaborating verifiable indicators and a quantification procedure at global scale represents a scientific and political challenge that fits in well with the game-changing nature of systems science. Open access to big data can be of major help. Having a sound scientific basis for impact will improve transparency and reflection, support interim adaptations, and promote greater effectiveness.

Knowledge infrastructure for value and knowledge pluralism

Research on global inclusiveness often angles the western view, with the western model of modernisation serving as a blueprint. This approach does not bring in strengths from the values, structures and development models that non-western societies

inhibit. The ‘uncertainty’ paradigm is a good example. Where western society views economic uncertainty as a factor that must be anticipated, sharia law forbids this approach; since deliberately avoiding uncertainty implies failure to trust in Allah. To study inclusiveness at a global scale, we must recognise and practice a wider spectrum of knowledge types and innovation styles than is customary in regular western science. This requires cooperation between different knowledge systems, with new knowledge being co-created thanks to the integration of scientific and experiential knowledge (including enterprises) of western and non-western partners.

Cooperation between differing normative and instrumental knowledge systems will benefit from horizontal knowledge generation and knowledge that is available to everyone. Digital technologies can provide infrastructures that support this shift from vertical to horizontal organisation of knowledge. In that way, IT can facilitate universal, open access to data and support the global, open source generation of knowledge and innovation.

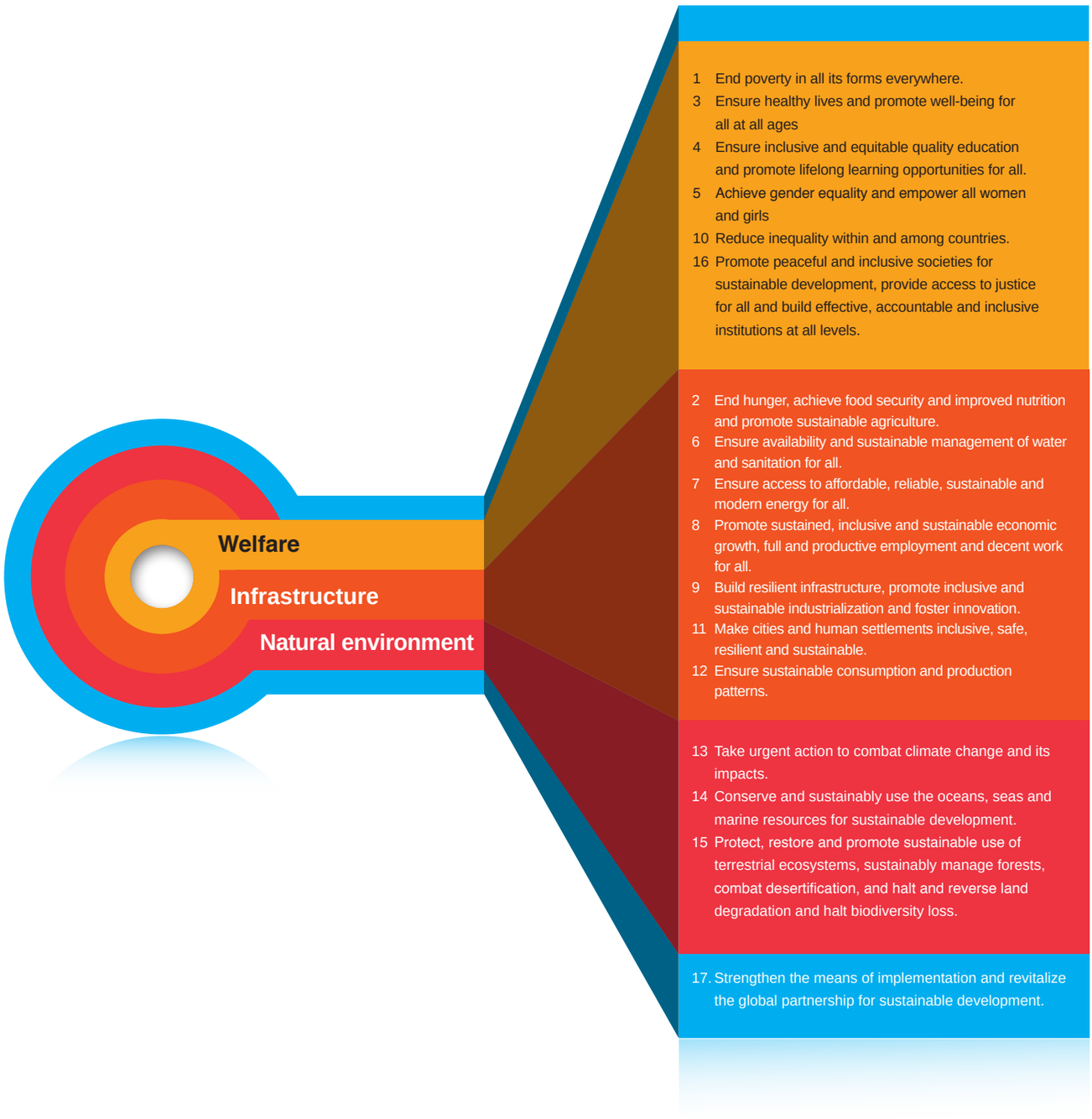
New connections

We need new scientific networks to provide the theoretical and experimental underpinnings for systems science, for example between sciences that address complexity and uncertainty (e.g. mathematics, philosophy and physics), scenario studies, big data analysis, and the social sciences and humanities. We also need to study the specific component systems by bringing in sciences that address biophysical, economic or health aspects. The experience of policymakers, farmers, patients, consumers, activists, technology users and the public is also a valuable source of knowledge that can be enriching to science.

It is crucial to connect with parties in civil society when picking solution strategies, generating knowledge and undertaking societal change.

The game changers listed above require close cooperation with industry; since multinational corporations are experienced in working across national boundaries and are in an ideal position to contribute to research on global inclusiveness. Small and medium-sized enterprises are a crucial factor in every societal change, especially in developing countries.

Dutch development organisations also possess a wealth of practical knowledge and experience that is crucial to this route. Cooperation between researchers and expert practitioners will not only help deepen our knowledge but also increase the likelihood that research results will be used, and subsequently improve the impact of research.



Between conflict and cooperation

The growing complexity of our society appears to involve conflicts and cooperation of all sorts and at every level. Conflicts differ in all sorts of ways, for example in their intensity, duration and history, the form they take, the parties affected, the subjects concerned and the means involved. Cooperation differs in similar ways. The public, policymakers, social workers, care providers, teachers, politicians and diplomats all have urgent questions about how best to handle disputes, how to identify causes, how to limit the damage, and how to promote constructive solutions.

This route is based on three principles:

Conflict and cooperation are both necessary

Conflicts are often regarded as the negative side of interactions between individuals, groups or nations, and cooperation as the peaceful and preferable alternative. What this idea ignores is that conflicts can activate a dynamic process that offers solutions for conflicting interests or values, one that in fact can lead to a new and better balance. Cooperation, conversely, may delay this creative, dynamic force and keep up the pretence of harmony. The first point of departure for this route is to acknowledge this seeming paradox. That is why virtually all societies have a legal mechanism in place to regulate discordant relationships and promote new cooperative ones through the instrument of legal dispute.

Quantifying and monitoring dynamic forces

The second important principle of this route is that the dynamic forces of conflict and cooperation must be quantified and monitored. We need to monitor them in order to determine where and when peaceful societies erupt into conflict. It is equally important to take stock of and explain the circumstances that afford a way out of conflict.

Which type of intervention will bring parties back together and assuage the pain, so that those affected can get on with their lives?

Only by knowing the causes and quantifying the impact of interventions can our actions be evidence-based and effective. Once a conflict has arisen, it is extremely important to remove all the causes, to compensate the victims, and to mend relationships. Otherwise, it is only a matter of time until the conflict is rekindled.

We also need to know more about the factors that help sustain and reinforce cooperation, solidarity and collaboration in societies, in institutions and among individuals. This is not about economic and political-legal factors alone; psychological factors can also play a role in eroding and building cooperative arrangements. For example, if inequality increases or people feel they are being treated unfairly or excluded, then the various groups' interests must be acknowledged and the right balance must be found between self-interest and the interests of others.

Multidisciplinary research

Conflicts and cooperation can be found on and between the micro, meso and macro levels; between people, social groupings, states, and in every imaginable combination thereof. Conflicts have their origins in dissatisfaction, economic disadvantages, pathology, lack of supervision, neglect, genetic propensity, and so on. More often than not, they are the result of the convergence and dynamic interaction of different causes. That is why multidisciplinary research is needed. By working together in multidisciplinary teams on conceptualisation, monitoring, diagnosis, treatment and follow up, we can arrive at a comprehensive model of conflict and cooperation. Better use of IT data, new machine-learning algorithms and methods for distilling patterns from a myriad of factors and data will improve cooperation and promote cross-fertilisation, with the synergies leading to new cross-disciplinary insights.

Major changes

In these turbulent times, changes in the nature and frequency of conflict happen so fast that they are outpacing established methods of conflict resolution. Three major changes are most striking.

The first is that the digital space is expanding, with more and more human action taking place in that space, leading to more frequent conflicts. Cyberconflicts differ from conflicts in non-digital space. Cyberconflicts are borderless, have a somewhat different etiology and dynamic, and are otherwise, and most importantly, harder to trace and quantify.

Second, the nature of war has changed dramatically in recent decades. Instead of the traditional country-versus-country scenario, war increasingly pits one population group against another, sometimes even within the borders of a single country. In many cases, the warring factions deliberately target civilians. Worldwide, the flood of refugees that this has unleashed is leading both to conflicts and to solidarity at all levels of society. Terrorism, violent extremism and the precautions taken against them have made deep inroads into the lives of people worldwide in recent years, causing major psychological, social and economic damage.

The third change is the growing importance of victims in conflicts and the legitimacy that is derived from the victim role. The search is on for alternative methods of conflict resolution, in part because of the extreme work pressure among authorities. That pressure has led to a critical failure to resolve minor conflicts between individuals or between an individual and the state, putting pressure on the democratic rule of law. These trends require additional, multidisciplinary, groundbreaking research.

We need to contemplate the traditional paradigms and engage in historical study and reflection to uncover parallels. Thanks to these basic principles, it becomes possible to identify at least three game changers.

At the same time, we need to consider new research methods and develop new cross-disciplinary concepts.

Causes of conflicts: searching for tipping and dipping points

We must begin by studying why people, organisations or states engage in deviant behaviour, and by examining conflicts between these parties. Insurmountable differences in value systems and conflicts of interest may result in inequality, which has a disruptive effect on individuals, families, population groups, domestic and international affairs, or the world order.

The question is which categories of deviant behaviour or conflicts form the tipping point. At what point does a divorce become a battleground? In what situation will ‘skirting the rules’ escalate into a banking crisis? When does a political dispute erupt into war?

Equally important is to study the opposite side of the coin: How can cooperation be resumed? How do we achieve deradicalisation? Why do people who have lived a life of crime sometimes return to the straight and narrow and become law-abiding citizens?

Resolving the crisis of legitimacy: successful conflict resolution

We urgently need research on how to resolve the crisis of legitimacy among victims. Possibilities include positive intervention by means of recognition, treatment and compensation, or negative intervention by means of denial, force or power play. Research on new conflict resolution and cooperation practices is needed. Understanding the causes of a legitimacy crisis may give us the tools to develop new conflict resolution and cooperation practices. Besides traditional forms of crisis management, we can also respond to deviant behaviour in innovative ways. For example by having the organisations or parties directly affected deal with infringements themselves rather than leaving it to independent bodies, by using agreements as a precautionary measure, or by developing extreme forms of regulation and publicly naming and shaming on social media. To what extent can we reconcile these ideas with the foundations of western democracy? To what extent do they actually work? Research of this kind must have a transdisciplinary dimension, with the effectiveness of new approaches being tested out in the real world.

Complexity in conflict: correlations and interactions

Failing states often suffer from a combination of corruption, misrule, crime, slow economic growth, a lack of prospects, human rights violations, hunger or a refugee problem. How are these trends related? What is the cost to society? Which salutary pretexts for intervention do these disruptive cycles offer us?

We need to study cycles in which conflicts have escalated to destructive levels, as well as situations in which cooperation allowed an injustice to persist for years on end. The focus should be on the interaction between the micro, meso and macro levels. For example, would it be possible to mitigate the harmful effects of a macro-level conflict, such as war, with cooperation at another level, for example solidarity with and social support for refugees? The interconnected nature of conflicts and the trade in resources worldwide, and the associated ecological destruction that takes place in conflict areas, raise questions of an even higher order and require more interdisciplinary research.

Answering the cluster of research questions described here will only be possible if we develop a number of new measurement methodologies, innovative monitoring tools and new concepts. Big data analysis, genetics and epigenetics, machine learning, and physiological and neurological tracking all play an important role in this context. But the solution does not lie in technology alone. A multidisciplinary approach that also seeks the relationship between the micro, meso and macro levels also implies a demand for new conceptualisations, with conflict resolution strategies from Child and Family Studies emulating strategies borrowed from war studies.

There is a need for an overarching, integrated focus. Wars are not resolved by removing only one of the causes; a partial solution to the refugee crisis will merely shift the flood of refugees elsewhere; and parents embroiled in a nasty divorce are often at such loggerheads that only overarching intervention can prevent further damage being done to their children. Given the huge cost to society of conflicts and the length of time that it takes to recover from them, investments in this subject will more than pay for themselves.

Creating value through responsible access to and use of big data

The impact of the phenomenal rise in the number and variety of databases – big data – is evident in every sector of society, from scientific research to the economy, from health to government, and from the financial sector to every facet of daily life. Big data is not simply 'a lot of data'; it also means new data combinations and continuous flows of data. This creates new demands on infrastructure and technology, on people who work with this data, and on society that implements it.

From automatic detection of cybercrime to improvements in health care efficiency, the impact of big data is growing in virtually every facet of science, the economy and society. Only recently have we had sufficient computing power, computer memory, network connections, data storage and, above all, smart algorithms, analysis techniques and software to analyse and use the results of large and diverse datasets. The urgency of this subject can be seen in the Dutch National Research Agenda itself; big data plays a role in questions in every single domain.

How does big data function as a game changer? The revolutionary power of big data lies in combining many different units of data. That only becomes possible when databases are open and accessible. This also means that we must deal responsibly with this data, however. In the decades ahead, the aim is to develop the right tools and infrastructure to ensure responsible access to and use of big data, leading to value creation in the economic, societal and scientific domains. The economic value of big data worldwide will exceed 45 billion Euros in 2017, according to estimates.

This value can be put down to the use of big data in a myriad of different economic sectors and to the growing big data economy itself. The societal value of big data lies in training people in data science and associated disciplines, raising public awareness of data, and implementing data-driven research in practically every societal domain. The scientific value of big data is its ability to improve our capacity to distil useful information from large databases or to link them, for example DNA banks, population registers or climate change simulations.

To meet the demand for big data expertise and create as much value as possible, we need to do a number of things. First we need to provide access to existing and new analysis techniques and automatic decision support systems that work with different types of data – such as transactions, oral or written texts, images and measurements – by means of a large, varied toolbox of software, analysis methods and the associated infrastructure and skills. Experimental environments are needed to educate parties to work with data (alone and together). We need to build an open, accessible and interoperable infrastructure in which data can be collected, stored, analysed and shared. We must also explore the potential of data markets, where people and enterprises can trade data use rights. Legislation must be evaluated and updated to derive the maximum benefit from data combinations, with due respect for the privacy of individuals. Finally, the basics of data science must be taught at all levels of the education system to deliver the tens of thousands of data science specialists that the Netherlands will require in the near future.

Value creation must take place responsibly. A concerted search to strike the right balance between what we can, may, and must do with big data is the key game changer for this route. Equality, transparency, accuracy, completeness, reliability, confidentiality and other democratic values must be embedded in the design of big data instruments. Applied algorithms must be transparent and not be coloured by political, regional, ethnic or gender preferences. The involvement of big data users is vital. All these aspects must be addressed in present and future research.

Impact

Big data has a huge impact on:

Quality of life

By ensuring more transparency, better protection of privacy, and fewer wrong or unfair decisions, big data can improve the quality of life in care, traffic, smart cities, and leisure activities, and also improve the digital capabilities of the population.

Urgent political and government issues

The Dutch government can improve its quality and efficiency considerably by making smart use of big data to tackle urgent challenges, such as efficiency in the care sector, digital citizen services, modernisation of education, tracking crime and cybercrime, mobility, achieving environment goals, food security, and resolving international conflicts.

Economy

New big data methods, models and techniques will provide the basis for economic and intellectual export products. Making public data openly accessible for the benefit of local government, energy supply, public transport and education will create new economic opportunities. It is crucial for our economy to guarantee value creation in the Netherlands and the European Union, given the long-term effects of emerging data monopolies and the associated intervention strategies outside the EU.

Labour force and employment

With a view to the growing role of big data, automatic algorithms and robotisation in many different sectors, we must gain competence in data science to ensure the competitiveness of Dutch trade and industry and the growth of the Dutch economy in future.

Open science and open innovation

The Netherlands is ideally placed to take the lead in research on big data. Europe is a strong proponent of open science and open innovation. The rising use of distributed databases requires a maximum level of cooperation between researchers, enterprises and parties in civil society. When it comes to access to databases, the influence of the Dutch polder model is clear. Unlike the data monopolies that have arisen elsewhere, in the Netherlands different data owners and data users are beginning to cooperate, with each one benefiting in its own way from data sharing.

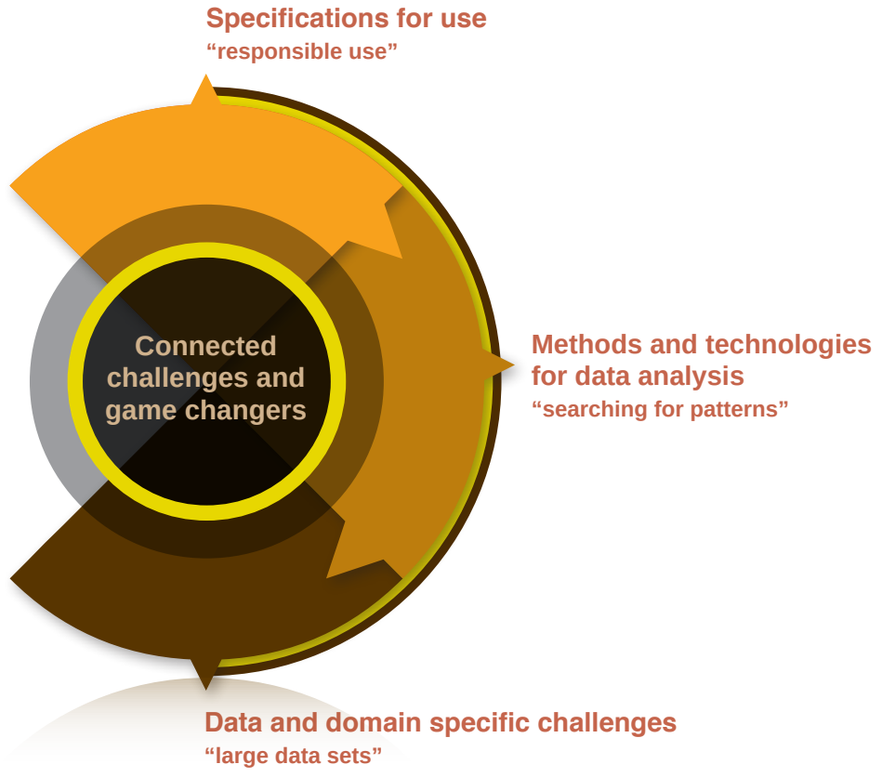
The Netherlands has a large and active ecosystem in big data research and applications that is unique in the world. SURF is responsible for the national e-infrastructure in education and research. The Netherlands eScience Center (NLeSc) makes digital technology available in response to the demand in applied research. Many research universities and some universities of applied science have set up data science centres in recent years. Data science educational programmes are slowly getting off the ground and new cooperative networks have recently been created. Government ministries, regional governments, knowledge-based institutions and other organisations are also forming alliances to boost big data applications. Finally, the Netherlands has one of the best digital infrastructures in Europe, also referred to as the ‘digital mainport’. It is very important to the Netherlands that this digital mainport is designed to be energy efficient. Data centres already account for approximately four per cent of the national electrical energy consumption.

Building bridges

To make responsible use of big data while increasing access to it requires universities, knowledge-based institutions, infrastructure providers, authorities, enterprises and civil organisations to work together closely. Many current big data alliances in the Netherlands are relatively small in scale and are nested within broader research programmes. Ambitious big data programmes do not receive enough funding to achieve the impact envisaged here, and pay little attention to synergies between the two knowledge elements of the game changer: responsible and low-threshold value creation from big data. With sources of funding and budgets ebbing, effective action has become difficult. To build bridges between legal, ethical, cultural, social, economic, business, informative science and technological aspects, and to boost the impact of big data efforts in the Netherlands, we need to invest more in research. At least a quarter of that investment is expected to come from private sources.

In the years ahead, we must focus on:

- Encouraging value creation in domains of application by setting up trial sites and large-scale public-private valorisation projects. Toolbox projects, technology transfer initiatives, the promotion of staff mobility, and multidisciplinary knowledge dissemination in order to make the big data ecosystem sustainable.
- Creating the potential for multidisciplinary research. The educational and scientific foundations of big data must be bolstered and extended to include data science that is embedded in all areas of application. This ranges from research in technology and the natural sciences to legal and

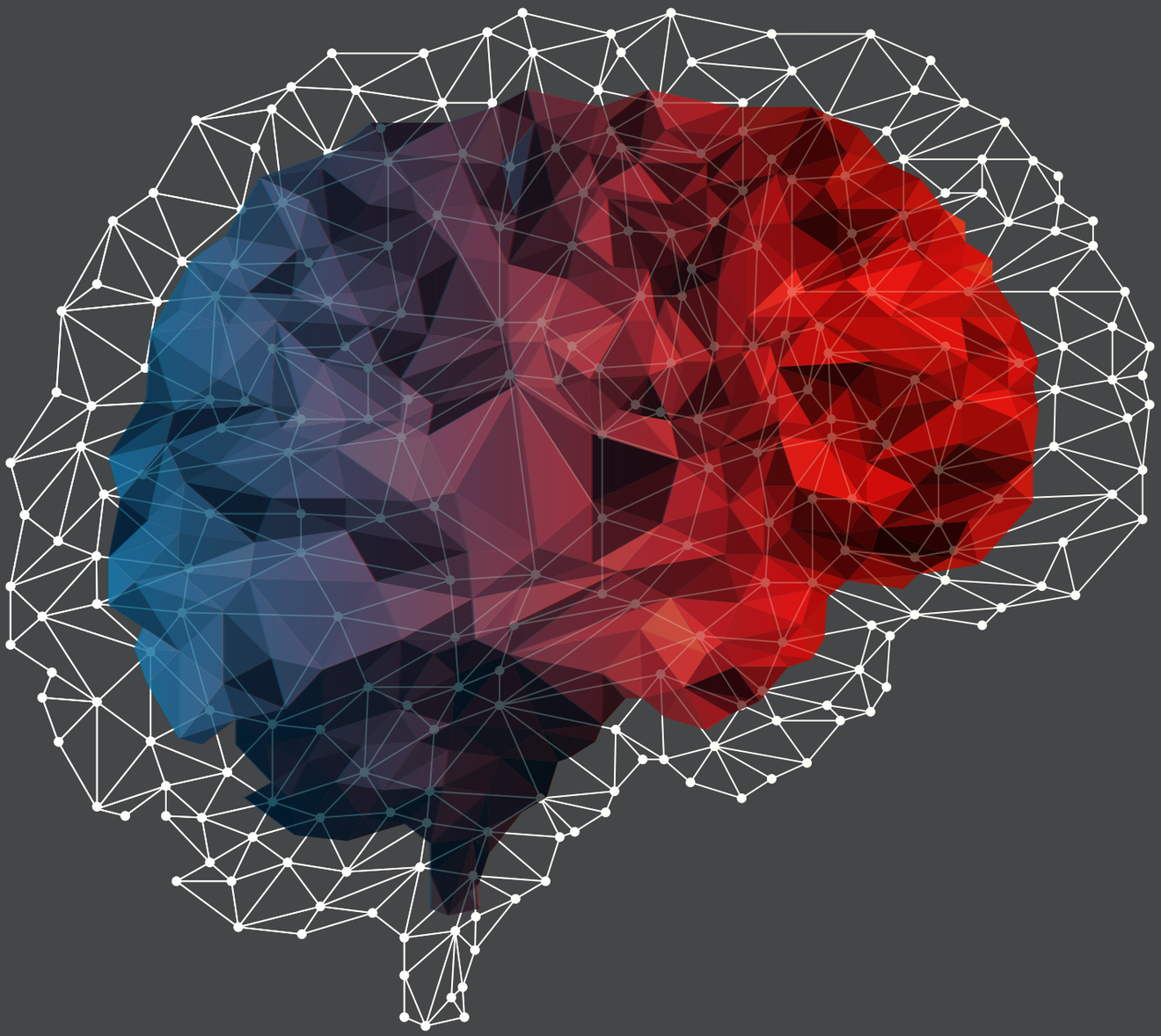


Three perspectives along the big data route that have led to the game changer ‘Value creation through responsible access and use of big data’.

socio-economic research. Research universities and universities of applied sciences are attracting talented new staff and students (including from abroad) who will tackle the challenge of responsible access to large databases.

The Netherlands’ role as a digital mainport must be enhanced and extended to include big data research and applications. This means investing in high-end SURF facilities and services, for example up-to-date, centralised computing power, fast networks and specialist data stewards who can build bridges between IT and applications, and in open and interoperable infrastructures that support big data across the entire scientific and economic spectrum. Developing the big data game changer not only means investing in outstanding science and value creation; it is also a critical success factor for many of the other routes in the Dutch National Research Agenda. Digital technologies and data science play the role of innovator driving other innovators in many different domains. To tackle the challenge of making maximum and responsible use of big data, we need long-term, multidisciplinary cooperation between universities, knowledge-based institutions, government ministries and enterprises.

Epilogue



IIn this epilogue we reflect on the routes described above and briefly consider the overall picture that emerges from the individual route descriptions and what it means. The many opportunities that we have identified constitute an impressive list of anticipated breakthroughs in the most diverse domains. The methods used to assemble the Dutch National Research Agenda and the Portfolio for Research and Innovation have led to an unparalleled concentration of knowledge, insight and intuition. We have opened a new window on the future.

The portfolio affords us opulent views and dazzling vistas, a panorama of challenges and opportunities. But we can also discern certain tracks and connections in that lush landscape. Several routes link compartments or sectors that are now often viewed, analysed or managed as separate entities. Below, we take a brief look at a number of themes that cut across multiple routes. We then consider an underlying trend that is emerging in various areas of research and that can be seen, more or less explicitly, in many of the routes and cross-cutting themes.

Cross-cutting topics

As we outlined in the introduction, several themes are addressed in multiple routes. Some concern organisational or institutional prerequisites. Others focus on the necessary infrastructure. Still others touch on the importance of education and talent development. In addition, there are also research topics that play a role in multiple routes. We describe a few of the most prominent ones below.

- Digitisation and big data

  Thanks to its exponential growth, the digital world is seeping into the very heart of society and influencing every branch of research and innovation. Advanced tracking devices and sensor technology make it possible to store and process enormous quantities of data concerning every facet of the cosmos, the natural environment, society and humankind. This is giving us new opportunities for value creation. While this subject is a route in itself, big data is also clearing a path to research in an unending list of new areas. Many of the routes show that we have only just embarked on a series of scientific breakthroughs based on big data research.

- Sustainable economic growth

  Many of the proposed breakthroughs concern potential new technologies and organisational arrangements that join economic growth to sustainability. These routes emphasise the need for new technologies and systems of production, transport and logistics, construction and housing, including their social aspects.

- Citizen empowerment

  Many of the routes refer to citizen empowerment. The shift in the relationship between authorities and citizens is a game changer in and of itself. Research can identify the consequences for competences at both individual and societal level, and indicate what this transition means for production systems and public authorities.

- Design and management of the living environment

  Sustainable environment management plays an important role in several routes, addressing all the aspects of sustainability, i.e. people, planet and profit. The routes emphasise the necessity of new patterns of production and consumption on the one hand, and the need for new forms of national and global governance on the other. There is an urgent need for integrated conceptualisation, modelling and monitoring of these aspects.

- Individualisation and customisation

  Several different routes focus on the individual. Primarily, this is clear in personalised medical care and medical techniques, but also in personal lifestyle, nutrition and exercise choices. This trend has consequences for the way health care is organised. Individualisation is also a factor with respect to education, a topic of interest in several routes. It also plays a role in conflict management. More abstractly, all of the routes emphasise the importance of variety as opposed to averages.

Without exception, these cross-cutting topics concern broad trends that not only have an enormous impact on society and the economy, but also influence many areas of research.

Complex systems

Each of the routes projects its own view of the future and of potential pioneering breakthroughs that lie ahead. Taking the routes as a whole and looking at the overall themes, however, we can also discern underlying trends that run deeper and go well beyond any individual route or theme. These trends are emerging simultaneously in a wide range of fields and are making themselves felt, more or less explicitly, in virtually every route. One striking trend – that is also of strategic importance for the entire portfolio – is the study of complex systems aided by pattern recognition in large, diverse databases.

It is growing increasingly important in every discipline to be able to discover patterns in large quantities of data, and that ability therefore plays a role in every research agenda. Digitisation makes it possible to express discrete phenomena and separate facets of reality – of society, living nature or the physical world – in one and the same digital form. That ability allows us to recognise and compare patterns, and to make and study unexpected connections that were unimaginable and impossible to study before. The exponential growth of the digital world is revealing inherent connections between areas of reality that we used to think of as separate.

In many routes, an integrated systems perspective plays a role in recognising patterns in large quantities of disparate data. In each case, complex and dynamic interactions are studied by means of an all-encompassing model that links different domains and orders of scale. Which orders of scale are relevant, depends on the routes and themes involved. For example, the order of scale for conflicts may range from individual to group to state; there may be scales that go from molecular to biosphere level, or that run from a building to a neighbourhood to a district and on to a city, a region and a country.

Such differences in themes and orders of scale obscure the underlying similarities. The integrated systems perspective plays a more or less explicit role in many of the routes, however. Key concepts in the natural sciences, the social sciences and the humanities are emergence, complexity, resilience, and cross-scale dimensions, although these terms are not always used explicitly.

Systems science attempts to consider the whole instead of concentrating on separate component systems. A system's behaviour is determined by interacting component systems with an important role for feedback. There is an urgent need to expand our understanding of how complex systems operate. We can acquire that understanding by considering reality and its dynamics from different perspectives, and by studying how the whole system of components behaves. This requires complementary and, oftentimes, disparate measurements from different vantage points and at different length and time scales.

The areas of research in which systems science can force breakthroughs are very different from one another. At a higher level of abstraction, however, the questions that they address are strikingly similar. Emergence links every possible order of scale, and the separate building blocks at each order of scale display rich, complex behaviour governed by universal organising principles. If this list of routes makes anything clear, it is that an integrated systems approach has enormous potential. Not only does it play a role in a large number of routes, but it may also allow us to exploit a hitherto unexplored potential for close cooperation, or even integration, between different routes.

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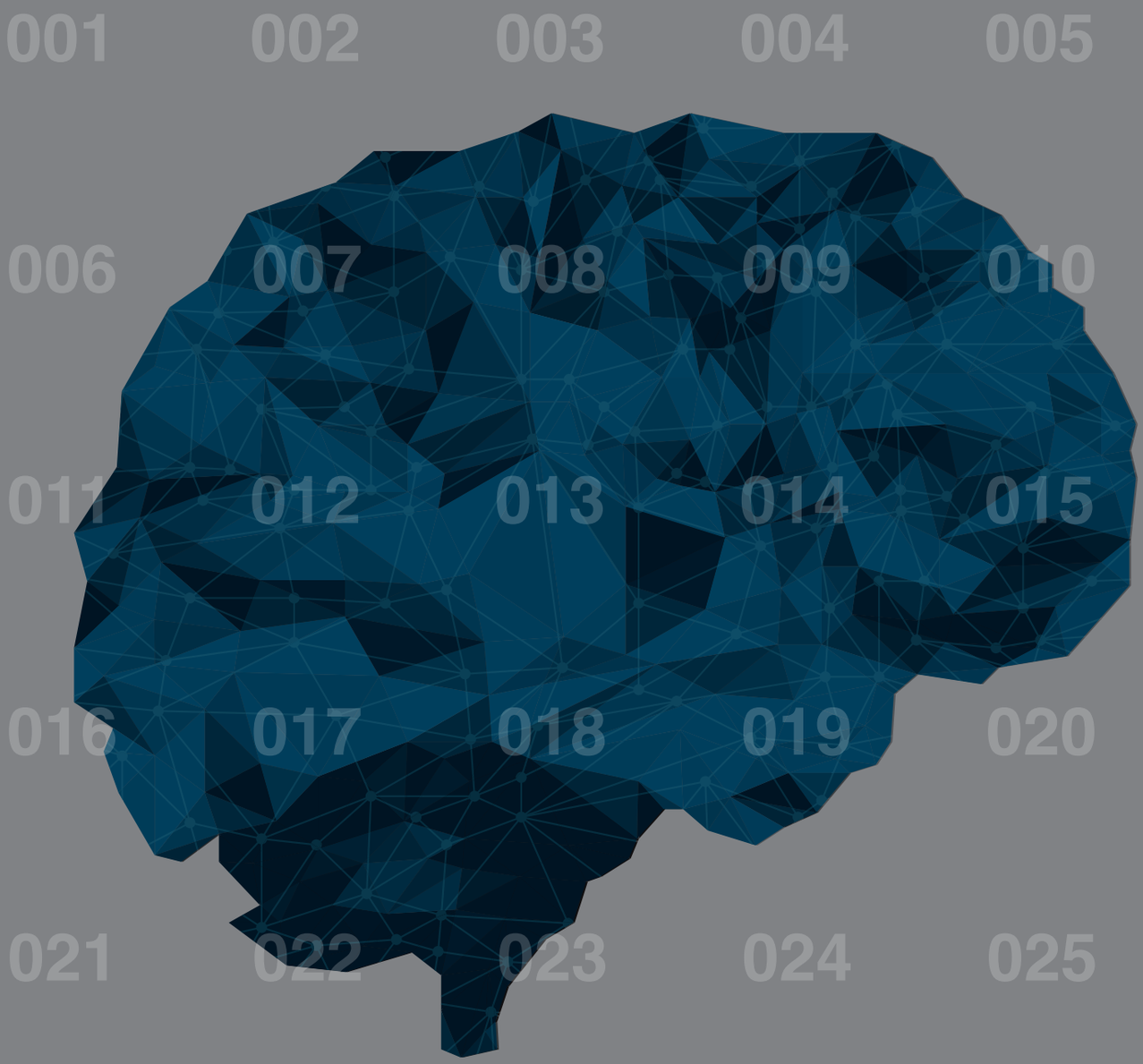

Dutch national research agenda