Awti Adviesraad voor wetenschap, technologie en innovatie

A MORE FORCEFUL CHOICE FOR KEY TECHNOLOGIES

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A more forceful choice for key technologies

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Summary

Key technologies deliver ground-breaking innovations which help progress on all fronts. They lead to better medical care, cleaner transport and more efficient and cleaner production. Key technologies thus have a major and unassailable impact on science, society and the economy. However, their development also raises questions and concerns, for example in relation to safety and privacy. The global nature of the development of key technologies and the speed with which that development takes place means these are questions that cannot be resolved within the confines of national borders. Although the Netherlands is currently in a good position in relation to these technologies, other countries have been investing in them for longer, investing more and in a more targeted way. It is only recently that the Netherlands has included key technologies in its innovation policy; the public resources for these technologies are limited. If we leave the development and application of these technologies to other countries, we will become dependent on choices made elsewhere which have a major impact on our society and economy.

In this report the Advisory Council for Science, Technology and Innovation (AWTI) addresses the question of what approach is needed to make the most of the opportunities offered by key technologies whilst controlling the potential negative effects.

Pursue an active policy: develop an integrated approach, with considered choices and more resources

An integrated approach is needed to ensure that - in collaboration with international partners - the development, application and dissemination of key technologies in the Netherlands is channelled in the right direction. Such an integrated approach is the only way that the Netherlands can maintain the leading role it holds at present.

An overarching approach which goes beyond individual ministries will pool the strengths of business, research institutes, civil-society organisations and public authorities to provide a boost for key technologies. Adopting such an approach will enable the government to bring together technological developments, economic opportunities, societal challenges and public values. Investing in technology alone is not enough; successful application of the technologies also requires actions in other policy domains, for example education, labour market and safety. Integrated judgements on all aspects relating to the development and application of key technologies are currently not being made. There is a lack of interdepartmental coordination. The emphasis is on economic opportunities and solutions to societal problems, with the result that values, dilemmas and concerns in society currently receive too little attention.

To maintain its place on the global high-tech stage, the Dutch government needs to instil a clearer direction in the investments in and development of key technologies. The government is currently unable to steer the development of key technologies adequately; it has virtually no ability to bring together resources and initiatives to create greater striking power, because most of the funding is channelled through generic and fiscal instruments. The government facilitates, while knowledge and research institutes and businesses make choices. This leads to dilution and fragmentation. An integrated approach opens the way for targeted and properly thought-through choices. To achieve this, the government needs to set up a directional assessment framework so that it is clear for all concerned which strategic considerations are important for the Netherlands: which are the societal challenges that require breakthroughs in key technologies? Which public values need to be incorporated from the start? Which strengths does the Netherlands wish to develop and exploit? In which niches does the Netherlands wish to lead or follow? In which technologies does the Netherlands want to be independent? What are the opportunities for joining forces with other national, regional and international initiatives and alliances?

Choosing makes focus and critical mass attainable, enabling the Netherlands to influence developments. Making choices is essential, but it is not possible to choose between key technologies at the general level of, say, artificial intelligence (AI), nanotechnology or photonics – all key technologies in which the Netherlands has a leading position and which offer ample opportunities. Making choices is however possible at a number of deeper levels: between specific technologies, components, potential applications and the stronger and less strong aspects of innovation ecosystems.

The government creates the directional framework and calls on stakeholders to develop national programmes to boost the development of key technologies. The government does not itself choose between these programmes, but asks independent experts to make a selection with the aid of the directional framework. This approach will simplify the current strategy for key technologies and ensure that choices are properly thought through and considered and less dependent on compromise, vested interests and powerful lobbyists.

An integrated approach will only deliver results if the Dutch government invests considerably more in key technologies than it does at present. AWTI urgently recommends investing an additional sum of between 0.5 and 1 billion euros per year. This will bring the Netherlands more into step with other countries which invest a minimum of 0.1% of GDP specifically in key technologies. This money is needed because the challenge is too great for businesses, research institutes and private financiers to address on their own. Higher government investments will also make it easier to sign up

to major European research and innovation projects, to attract and retain top talent and to open the way to breakthroughs in research and development.

AWTI makes three recommendations to government for organising and embedding an integrated approach with considered choices and more resources.

Recommendation 1
Build a portfolio of national key technology programmes

Making optimum use of the opportunities offered by key technologies for society and the economy whilst at the same time remaining in control of the potential negative effects requires properly considered choices. Those choices must weigh all aspects relating to key technologies. To be able to make choices based on quality and potential - and ignoring vested interests – AWTI advises the government to stimulate national key technology programmes. Ask research institutes, businesses and civil-society organisations what is needed in specific fields of technology to maintain and strengthen the Netherlands' international position. These stakeholders will formulate national key technology programmes to address this question. They are in the best position to know what is needed, and they can tap into international alliances and which regional initiatives and clusters they can bring into the process.

National key technology programmes bring together research and development across the entire knowledge and innovation chain focusing on a specific technology or combination of technologies. They combine strengths and bring together national and regional initiatives. The programmes are ambitious and have clear objectives to achieve breakthroughs. They tap into international alliances and also develop activities around demonstrations, testing and upscaling. They are interdisciplinary and take into account public values in the development of key technologies.

Government sets the directional framework incorporating the strategic judgements regarding technologies that are important for the Netherlands. The government then organises a selection process based on this framework to decide which national programmes will receive additional support. The government also maintains the health of the knowledge base, because this is the only way to ensure that new technologies can be developed whilst maintaining the knowledge absorption capacity.

Recommendation 2
Set up a Key Technologies Taskforce and a DG Consultation Forum

AWTI recommends that the government set up a Key Technologies Taskforce to manage the portfolio of national key technology programmes. This Taskforce would invite coalitions to put forward proposals for programmes, from which it will then make a choice. The Taskforce will be assisted in this by independent assessment committees which

assess the proposals on the basis of the assessment framework and derived indicators and weighting factors. The Council advises that the Taskforce be placed organisationally within the Netherlands Organisation for Scientific Research (NWO).

Organising and embedding the integrated approach requires interdepartmental coordination and liaison. AWTI recommends that this takes place in a special consultative forum between the Directorates-General of the most relevant ministries (DG Consultation Forum). Key technologies are a shared responsibility; the DG Consultation Forum must provide a stimulus based on shared interests, goals and resources. The DG Consultation Forum constructs the assessment framework on behalf of the government.

Recommendation 3
Invest extra, specific resources

Ambitious plans have been developed, but the public resources available to carry them out are insufficient. Current plans and initiatives mainly bring together existing efforts and funds; they do not offer anything extra. The Council believes that, in combination with an integrated approach, between 0.5 and 1 billion euros extra per year is needed to fund national programmes for key technologies. This funding must not come at the expense of investments in the broad knowledge base.

Advice

1

Background: How can the Netherlands maintain a grip on key technologies?

Where technology has a fundamental impact on science, society and the economy, we refer to it as a ‘key technology’. Examples include electricity or, more recently, the Internet. Key technologies can lead to innovation and improvement: better medical care, cleaner transport, more efficient and cleaner production. However, their development also raises questions and concerns, for example about safety, the environment and privacy. How can the Netherlands continue to play a significant role in the development of key technologies while maintaining control over the potential consequences of their application?

1.1 Key technologies are already having a major and unassailable impact

Key technologies can help achieve ground-breaking innovations and have major societal impact. They attract a great deal of attention and appeal to everyone’s imagination. The media constantly reports on their development and use: artificial intelligence (AI), robots, hydrogen technology, autonomous vehicles and super-batteries. These technologies have in reality become an essential part of our daily lives. They help us make progress now and in the future on all fronts: scientific, economic and societal, for example by making possible solutions to challenges in areas such as climate, safety, mobility and care.

What are key technologies?

There are several definitions of key technologies (see Appendix 1). They are characterised by the fact that they are interdisciplinary and cut across sectors, require knowledge-intensive development and go through volatile innovation cycles. They open the way for ground-breaking process, product and/or service innovations in a wide variety of sectors. They are generally clusters of different underlying technologies. Frequently cited key technologies are nanotechnology, quantum technology, photonics, ICT, artificial intelligence (AI) materials technology, advanced production technologies, micro and nanoelectronics, chemical technologies and life sciences technologies.

Great expectations

Key technologies and their application in specific, ground-breaking innovations are regarded as highly important for increasing productivity and thus boosting the earning capacity of the Dutch economy. They lead to new economic activity, create new markets, increase competitiveness and strengthen labour productivity[1] - all aspects that are essential for a strong economy, prosperity and well-being. At the same time, key technologies – together with societal innovations, new business models and changes in behaviour – can contribute to finding solutions to major challenges.[2] New materials can for example lead to stronger wind turbines and more efficient solar cells, or batteries with higher energy storage capacity.[3] Photonics are key to the development of lighting systems which open the way for efficient crop growth or sensors for use in precision agriculture and food quality monitoring.[4] Quantum technology should make it possible to analyse molecular interactions at (sub)atomic level, something which in turn is crucial for research on new medicines.[5]

In practice, it is mainly the combination of different key technologies which makes possible new breakthroughs.[6] A lab-on-a-chip which can be used to provide a personal diagnosis close to the patient is possible thanks to a combination of nanotechnology, advanced materials, photonics, genomics and AI. Similarly, when combined with photonics, nanotechnology and communication technologies, AI provides the building blocks for autonomous and digitally interconnected vehicles.[7]

There is also uncertainty about the impact of key technologies on society

Key technologies will only have a favourable impact on society if the questions and concerns about their potentially disruptive influence are also addressed. Digital platforms such as Uber and Airbnb offer unprecedented new opportunities for the services sector, but also lead to new inequalities between businesses, employees and consumers. Nanotechnology makes new, smart materials possible, but also begs the question of what impact nanoparticles have on human and animal health and the environment. Life sciences technologies help make crops more resistant to drought and increased soil salinity, but also raise concerns about negative long-term effects on nature. Quantum technology, AI and Big Data analytics make it possible to perform large-scale, sophisticated analyses of large quantities of data but at the same time create dilemmas

1. European Commission (2018a); European Commission (2015); OECD (2016); European Commission (2017); OECD (2017); Van der Zee (2017); WRR (2013); Schumpeter (1942).
2. Bakker et al. (2018); OESO (2016); Minister and State-Secretary for Economic Affairs and Climate (2018); Mazzucato (2018a), Topsectoren (2017).
3. Bakker et al. (2018).
4. PhotonicsNL, PhotonDelta en Dutch Optics Centre (2018).
5. Quantum Delta NL (2019).
6. Bakker et al. (2018); European Commission (2014); Butter et al. (2015).
7. Bakker et al. (2018).

about privacy, safety, transparency and the allocation of responsibilities. In addition, large international companies, sometimes in collaboration with the governments of large countries, are striving for global dominance in some key technologies such as AI and quantum technology. This in turn raises new questions. Will the Netherlands still have free access to these technologies in the future? Do current developments in key technologies fit in with the needs of Dutch (and European) society?

1.2 The Netherlands is doing well, but international developments are proceeding faster

The Netherlands is in the leading group in the development and application of key technologies, but other countries are also in that group and are investing more and in a more targeted way.

The Netherlands among the leaders

Dutch research into key technologies is class-leading.[8] Dutch researchers publish a great deal and are cited by scientists throughout the world. Dutch research can therefore be described as excellent or first-class in virtually all key technologies[9]; it is international and cross-sectoral.[10] The Netherlands is accordingly well represented in international research consortia and European research programmes.[11] In some key technologies, such as imaging technology and Big Data, Dutch research actually has a greater impact than that of internationally renowned institutes such as MIT and Harvard. Strong public-private partnership, including through the Dutch 'Top Sectors' programme, is a great strength of the Dutch research and innovation ecosystem.[12]

The Netherlands also performs well in the production and commercialisation of products and components based on key technologies.[13] This is particularly the case in systems engineering: combining and integrating key technologies (such as photonics and advanced fabrication technologies) into working systems and production processes.[14] Dutch research is widely cited internationally in patent applications, especially in the fields of micro and nanoelectronics, photonics and advanced materials.[15] Dutch research thus delivers great economic value and is globally acknowledged.[16]

8. Elsevier Research Intelligence (2018); European Commission (2018b).
9. Excellence is determined based on the number of citations. Excellent research means publications are in the top 10% most cited publications in the world. First-class research means publications are in the top 1% most cited publications in the world.
10. This manifests itself in the relatively high number of co-publications with international partners and businesses.
11. AINED (2018); Dorst et al. (2016); Vennekens et al. (2019).
12. European Commission (2019a); Van Dijck & Van Saarloos (2017); OECD (2014); Koens et al. (2018).
13. European Commission (2018b).
14. European Commission (2018b); PhotonicsNL, PhotonDelta and Dutch Optics Centre (2018); Quantum Delta NL (2019).
15. European Commission (2018b).
16. Elsevier Research Intelligence (2018).

The Netherlands also has a well-developed innovation ecosystem, with an attractive research environment, highly educated population and a high degree of collaboration between the business community and research institutes. The Netherlands is one of the most competitive and innovative economies in the world.[17] The Dutch start-up ecosystem is growing; Amsterdam-StartupDelta is in fifteenth place in the Genome Global Startup Ecosystem Ranking and ranks fifth in Europe.[18] The number of start-ups is growing, as are the amounts invested in them. The Netherlands is also in the leading group in the field of digitalisation, an area in which industry scores well.[19] Here again, one of the strengths is public-private partnership focusing on digitalisation, for example in the Smart Industry programme. The same applies for the digital infrastructure and enterprise culture.[20]

Other countries are making more, and more targeted, investments in key technologies

The Netherlands thus enjoys a substantively strong position internationally. However, it is questionable whether the Netherlands can hold onto that position, because its investments in key technologies are less targeted than in other countries.

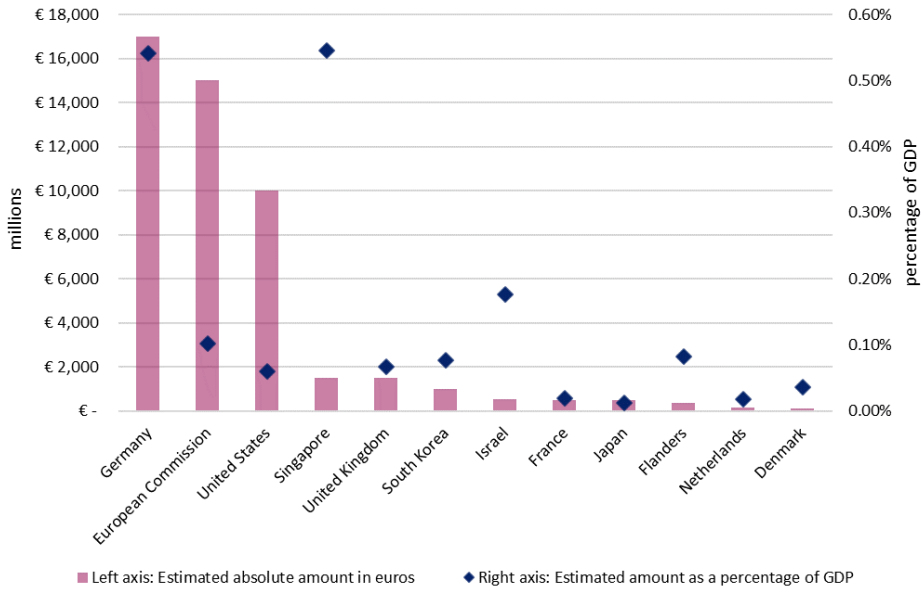
Governments throughout the world seek to support technology development because they are convinced that it ultimately leads to economic growth, employment and indirectly to greater well-being. Governments are now persuaded that they need to place the emphasis on key technologies.[21] Together with the business community, they are accordingly investing heavily in them. China and the United States, in particular, are vying for world leadership in the development of key technologies. The European Commission also invests a great deal.

The magnitude and form of these public investments differ widely from country to country. Several countries set aside substantial amounts specifically for key technologies.[22] In Denmark and Flanders, the amounts run to several hundred million euros per year, while Germany and the US invest billions (see figure 1). There are marked differences, not only in absolute terms, but also as a proportion of gross domestic product (GDP). Germany invests the most in key technologies, both in absolute terms and in relation to GDP. Singapore invests much less in these technologies in absolute terms, but in relative terms

17. Schwab (2019); European Commission (2019a, b, c).
18. Startup Genome (2019).
19. Valdani, Vicari & Associati (VVA) and WIK-Consult (2019); European Commission (2019d).
20. Valdani, Vicari & Associati (VVA) and WIK-Consult (2019).
21. European Commission (2009); European Commission (2012); European Commission (2017); Mazzucato (2013); Minister and state-secretary for Economic Affairs and Climate (2018); state-secretary for Economic Affairs and Climate (2019); WRR (2013); Scholten et al. (2019).
22. Scholten et al. (2019) investigated the approach and extent of specific public investments in key technologies for several different countries. These are all investments made by national governments in which an explicit choice was made in advance to invest in these specific technologies, regardless of whether the initiative arose top-down or bottom-up. The choices were laid down in policy, covenants and programmes focusing specifically on one or more key technologies.

its investments are comparable to those of Germany. Flanders invests more than the Netherlands, in both absolute and relative terms.

Figure 1. Annual specific public investments in key technologies



No precise figures are known for China, which is therefore not included in this graph. It is estimated that the Chinese government invests many billions.

Source: Scholten et al. 2019, supplemented by own analysis for Israel and China.

Most countries select a number of key technologies in which to invest. Only Germany and the EU opt to invest in all technologies because of their importance for their broad economy and their manufacturing industry. Singapore and Denmark make highly specific choices in order to build on local strengths, accommodate specific weaknesses or address specific regional challenges.

To date, the Netherlands, France and Belgium have invested in science and innovation primarily through generic channels. What this means in practice is that they encourage research and development (R&D) in a broad sense, for example through fiscal measures. Part of this funding goes into key technologies, but the precise proportion is often unknown.[23]

23. Scholten et al (2019); Rathenau Instituut (2019); OECD (2019); Analyses of the use of fiscal instruments provide little or no insight into the technology fields for which the tax support has been used. The Netherlands Enterprise Agency (RVO) carried out

Foreign strategies for key technologies

In contrast to the Netherlands, which only included key technologies in its innovation policy in 2018, the European Union and other countries have had extensive strategies in place for some years.

The European Commission (EC) launched its strategy for key technologies in 2011, and invests around 15 billion euros per year in their development and utilisation.[24] Germany has had a national High Tech Strategy since 2006, and in 2018 alone the Germany government invested around 15 billion euros in key technologies.[25] The federal government in the United States invests comparable amounts.[26] China launched the ambitious 'Made in China 2025' policy in 2015 along with the 'Internet Plus' initiative, which is aimed at making China the world leader in high-tech sectors such as artificial intelligence, robots, aerospace, electric vehicles and microchips. The precise amounts involved are not known, but it is estimated that the Chinese government invests many billions.[27]

In the field of AI in particular, a conveyor belt of countries are launching plans and strategies with accompanying investments. Since 2017 at least 25 countries, from the United States to China and from France to South Korea, have announced national strategies worth billions of euros in a bid to benefit from the development and potential of AI.[28] Other countries are also not standing still in the field of quantum technology. The European Commission initiated a Quantum Technologies Flagship programme in 2017 with a value of 1 billion euros. The United Kingdom has had a national strategy for quantum technology since as long ago as 2013, in which 600 million pounds has been invested to date. Germany, Canada and the United States also have large-scale national quantum technology programmes, and China has announced plans to build a National Laboratory for Quantum Information Sciences at a cost of 10 billion dollars.[29]

an analysis of the evaluation of the WBSO R&D tax credit scheme to ascertain the technology fields for which the WBSO has been deployed. The top three were ICT (25.9%), mechanical technology (22.7%) and electrical engineering (12.1%). See De Boer et al. (2019).

24. Scholten et al. (2019).
25. Die Bundesregierung (2018).
26. Scholten et al. (2019).
27. MERICS | Mercator Institute for China Studies (2019).
28. Mols, B. (2019).
29. Quantum Delta NL (2019).

Failure to keep up with global developments means giving up control of key technologies

It is vital that the Netherlands keeps up with global developments in key technologies in order to be able to exploit the opportunities they offer society and economy in a way that fits in with our public values. If the Netherlands leaves the development and application to other countries, it will become dependent on developments elsewhere which have a major impact on our society and economy. A clear example of this is the dominance of Chinese and US technology companies in the platform economy, in Cloud services and in the digital infrastructure (such as 5G).[30]

Pursuing an active policy will make it attractive for international companies and knowledge organisations to seek solutions in collaboration with Dutch partners. Collaboration in the development of key technologies is essential for a small country like the Netherlands. It also expands the opportunities for Dutch businesses on the global market for these technologies. For many key technologies, the parties who first manage to penetrate the market successfully (first movers) end up dominating the market, and are then in an almost unassailable position. This 'winner takes all' effect comes into play if the first movers are able to incorporate all the knowledge and data in their core processes and applications and if they are difficult to share.[31]

If the Netherlands wishes to have influence, it will have to join in: in research and development, in education and training, in experimenting with technologies and their applications, and in linking key technologies to societal challenges and public values.

1.3 Request for advice: How can the Netherlands derive optimum benefit from key technologies?

The developments outlined above prompted AWTI to publish this advisory report to the government to address the following question:

What approach is needed to make optimum use of the potential of key technologies and to control any negative effects?

30. European Commission (2017); European Commission (2018a); European Commission (2019f). See also reports in the media: Betlem (2018); Hueck & Van Wijnen (2019); Van Wijnen (2018); Broekhuizen (2018); Olsthoorn (2019); De Lange en Leupen (2019).
31. Taskforce AI (2019); AINED (2018); Barwise & Watkins (2018).

Creation of this report

In preparing this advisory report, we carried out desk research on the rationale for technology policy, various approaches to technology policy and governance and the current Dutch approach to key technologies. We also looked at experiences in other countries. Appendix 2 contains a list of references. In addition to desk research, we held discussions with a number of experts and policymakers, a list of whom can be found in Appendix 3.

This report was prepared by a project group consisting of Council members Nienke Meijer (chair), Roshan Cools and Jos Benschop, and staff members Annelieke van der Giessen and Kathleen Torrance (secretaries), Michiel van Well and Odile Ridderinkhof.

2

Advice: Develop an integrated approach with considered choices and more resources

An integrated approach is needed to ensure that – in collaboration with international partners – the development, application and dissemination of key technologies in the Netherlands are channelled in the right direction. Such an integrated approach is the only way that the Netherlands can maintain the leading role it holds at present. That is necessary to make the most of the opportunities offered by key technologies whilst at the same time maintaining control of their potential negative effects.

An integrated approach cuts across ministries and pools the strengths of business, research institutes, civil-society organisations, citizens and public authorities to promote key technologies. All kinds of aspects play role in the application of these technologies, not all of them technological. An approach which cuts across the different policy domains is therefore needed. This will also enable questions or concerns raised by the applications to be better thought through. The approach therefore links together economic opportunities, societal challenges and public values.

To maintain its place on the global high-tech stage, the Dutch government needs to instil a clearer direction in investments in and the development of key technologies. To achieve this, the government needs to set up a directional framework so that it is clear for all concerned which strategic considerations are important for the Netherlands. The government also needs to organise a process which forms a basis for well-informed choices for key technologies in which the Netherlands can make a difference. This approach will simplify the present strategy on key technologies and avoid dilution of resources and loss of striking power. It will ensure that the choices are properly considered and well-informed and are less dependent on compromise, vested interests and powerful lobbyists.

An integrated approach will only deliver results if the Dutch government invests substantially more resources in key technologies, and in a more targeted way. AWTI urgently advises the government to invest an additional sum of between 0.5 and 1 billion euros per year; that is the only way of keeping pace with other countries.[32]

32. Most other countries in the comparative study by Scholten et al. (2019) spend at least 0.1% of GDP specifically on key technologies. Scholten et al. (2019) calculated that the Netherlands spends 144 million euros per year specifically on key technologies. If the Netherlands were also to invest around 0.1% of GDP specifically in key technologies, it would have to spend a minimum of 800 million euros per year specifically on key technologies.

This chapter substantiates this advice. Chapter 3 makes recommendations to the government for translating this advice into practice.

2.1 An integrated approach includes other policy domains and public values

The Council calls first instance for an integrated approach to the development, application and dissemination of key technologies. That is necessary to ensure that all manner of aspects related to these technologies can be properly thought through and managed.

An integrated approach ensures better linkage to other policy domains

Investing in technology alone – in research & development – is not enough. The application of key technologies also requires action in other policy domains, such as education, labour market and safety, because of the impact these technologies have on society. They deliver necessary technological breakthroughs which make possible solutions to societal challenges, but their impact goes beyond specific sectors or policy domains. Many aspects which are not specifically technological play a role, such as earnings models, competitive relations in the market, the presence of suitable infrastructure, scope in the existing legislation and regulations, policy objectives and the availability of trained staff. Adaptations are often necessary in all areas to ensure fruitful application of key technologies.[33]

An integrated approach addresses concerns and questions in society

Integrated judgements about all aspects related to the development and application of key technologies are currently not being made. There is a lack of interdepartmental coordination. The key technology policy has been assigned to the government's mission-driven Top Sectors and Innovation policy, which falls under the aegis of the Ministry of Economic Affairs and Climate. As a result, the emphasis has come to lie on economic opportunities and solutions to societal issues. To ensure that the values, dilemmas and concerns of society are also optimally addressed, it is essential that other ministries are also involved. Too often, it transpires only late in the day that certain technologies and their application encounter resistance in society, or that technological development can have adverse consequences – think of genetic modification or biometric sensor technology, for example. The government must ensure that public values are taken into account from the start in the development and application of key technologies, or even that they form the starting point. That is better than seeking to embed them later or trying

33. See AWTI (2018) for aspects which influence the utilisation and dissemination of innovations. Volberda & Heij (2019); Maclaine Pont et al. (2016).

to repair them through regulation and frameworks. An integrated approach makes it possible to link policy actions aimed at exploiting opportunities on the one hand to policy actions intended to prevent undesirable effects on the other.

Existing national strategies merely bring together unconnected initiatives

Besides the Ministry of Economic Affairs and Climate, other ministries also support the development and utilisation of key technologies. The Ministry of Education, Culture and Science does this with science policy. Line ministries such as the Ministry of Defence, the Ministry of Health, Welfare and Sport, the Ministry of Infrastructure and Water Management and the Ministry of Agriculture, Nature and Food Quality do this via programmes to promote innovation in their sectors and their social mission. There are some national strategies and programmes aimed at fostering interdepartmental innovation and renewal, for example the National Digitalisation Strategy and the recently launched Strategic Action Plan for AI.[34] The strategies and plans place items on the agenda, list ambitions and identify overarching themes, but what they mainly do is sweep together existing measures, initiatives and budgets which were set up separately from each other. They contain too few concrete policy measures and have no coherent approach for addressing challenges. Although the challenges and associated dilemmas are mentioned, no connections are made between technology development and public values.[35]

2.2 An integrated approach makes focused and properly considered choices possible

The government is currently unable to provide sufficient direction to the development of key technologies, and is not able to bundle sufficient resources and initiatives together to create more striking power. This is because funding for research and innovation is largely channelled through generic instruments (higher education and science policy and innovation policy) and via indirect fiscal instruments.[36] Decisions on where investments are made are currently left to research institutes and business. However, this leads to fragmentation of research and innovation funding. Dutch parties are accustomed to

34. There are also attempts to increase the level of collaboration. For example, the Secretaries-General of four ministries work together in a 'mission-driven' way, and there is a National Innovation Community has been set up to bring together staff from different ministries to share innovation knowledge, experiences and methods.
35. See also reflections by the Rathenau Instituut: Rathenau Instituut (2018); Kool et al. (2017) and in the press NRC (2019); FD (2019).
36. Roughly 20% of central government support for R&D and innovation comprises indirect support through the tax system; this form of indirect support applies for 90% of innovation policy.share of indirect tax support for R&D and innovation in the Netherlands (0.17% of GDP) is thus high compared with other OECD countries and has risen sharply over the last 10 years. Only Belgium, France and Ireland spend a higher percentage of GDP on fiscal support for R&D. See Velzing (2018); Vennekens et al. (2019); KNAW (2018b).

engaging in dialogue and reaching compromises in a broad coalition.[37] In these often lengthy processes, established parties engage in dialogue, each from the basis of their own justifiable interests. The government can then only react to the initiatives and choices made in this bottom-up process. It is unclear how and why the government subsequently makes choices; is it the best-organised technologies which receive most attention? Is it the sectors and advocates with the best narrative?

An integrated approach will enable the Netherlands to invest more effectively in key technologies, because these investments will then be based on considered and broadly supported choices.[38] The government must encourage all businesses, research institutes and civilised society organisations to make choices and invest in research and development in those key technologies in which the Netherlands can make a difference. There are several technologies where Dutch companies and knowledge organisations are attractive international partners and which are in a good starting position. Making a difference requires critical mass (see also 2.3). Making choices avoids dilution of resources and loss of striking power. It also provides clarity to private actors regarding future earning opportunities, so that they too can invest in key technologies.

What choices need to be made?

Making choices is essential, but not between key technologies at the general level of, say, artificial intelligence (AI), nanotechnology or photonics – all key technologies in which the Netherlands has a leading position, which offer ample opportunities for society and the economy and which allow linkage to societal challenges. AWTI advises against making choices at this level, but rather at deeper levels: between specific technologies, components, potential applications and the stronger and less strong aspects of innovation ecosystems. How the government can ensure that choices are made is discussed in chapter 3. Briefly, the Council advises the government to stimulate bottom-up formulation of those national key technology programmes which create links between technologies, fields of application and missions. The government also sets the framework that forms the basis on which considered choices can be made.

37. Goetheer et al. (2018).
38. See also Mazzucato en Perez (2015). They make clear that 'picking winners' it is not so much about whether or not choices are made, because that happens in any event. It is above all about how 'intelligent' the 'picking of directions' can be made. In relation to mission-driven innovation policy, Mazzucato (2018b) also calls for governments to follow a strategy of 'picking the willing': "Thus missions require picking the willing: those organizations across the economy (in different sectors, including both the public and private sphere) that are "willing" to engage with a societally relevant mission."

An integrated approach must be flexible

The uncertainties surrounding investments in key technologies mean that the integrated approach must be flexible. In the first place, it must offer a clear framework and continuity for investments. Secondly, it must embed interdepartmental coordination. Thirdly, policy choices, for example in favour of specific key technologies or coalitions of knowledge partners, must be adaptable to the rapid pace of international developments. The government must be able to step up the pace for promising developments or to change direction as needed.[39] This demands monitoring of developments in key technologies and of the effects of the approach.

2.3 More resources cushion risks, provide grip, attract top talent and increase the chance of breakthroughs

Government, businesses and research institutes have developed a number of initiatives in the recent period aimed at boosting the development of key technologies and aligning them with societal missions and challenges. These are well-intended and justified ambitions, but there is a lack of the public funding needed to carry out the plans and remain in the vanguard. This is because the initiatives mainly bring together existing efforts and resources, and offer nothing extra. The Council believes that extra resources are urgently needed, in combination with an integrated policy approach. There are several sound reasons for this.

The investments needed are greater than developers can fund on their own

The development of key technologies is highly uncertain and takes a long time. The technological outcomes and applications are moreover difficult to predict. It is a process in which scope for experiments and a long time horizon are essential. Businesses, knowledge partners and private financiers are investing heavily in technology development, but the challenge is greater than they can meet on their own. Higher investments by the government are therefore crucial. Moreover, higher government investments will make it easier to top up (match) funding for large-scale European research and innovation projects.[40] The public resources allocated to this are currently

39. The literature also refers to this as a 'tentative governance' approach, i.e. an approach in which there is adequate scope for experimenting, learning, reflection and revision. Kuhlmann et al. (2019) see *tentative technology governance* as an overarching concept which covers all kinds of new governance aspects such as adaptability, responsiveness, reflexiveness and experimental governance.
40. Matching is the principle whereby research institutes have to invest their own resources because research funders such as the Netherlands Organisation for Scientific and research (NWO) or the European Commission often reimburse only a proportion of the total research costs.

often inadequate, whereas Dutch researchers are in a very good position to make use of the opportunities in European research programmes.[41]

Higher investments will give the Netherlands more influence on the direction of development

Many developments take place outside the Netherlands, and the international competition is substantial. Dropping out of the leading group means that others will shape the game and its rules. Only if the Netherlands remains in the leading group will it be able to exploit the opportunities for science, society and the economy in a way that fits with our public values. An integrated approach, combined with more funding, will enable the Netherlands to influence the direction of development, ensure that Dutch companies and knowledge organisations remain attractive to international partners, provide access to international knowledge and networks and encourage the business community to compete on global markets. The Netherlands must use the strength of other countries to speed up the development and utilisation of key technologies at home.

Higher investments will enable the Netherlands to attract global talent

A great deal of talent is needed for the development of key technologies. That talent is in great demand worldwide, and the Netherlands will lose these people if there are better opportunities elsewhere.[42] The presence of a good research infrastructure and the availability of adequate research funding are key conditions for attracting, developing and retaining top talent.

Top talents want to work at top institutes and class-leading companies.[43] The popularity of Dutch specialist research centres in the field of quantum technology is a clear example of this. Top talents and strong clusters in the field of quantum technology attract the attention of other talented researchers internationally, as well as of large, leading companies wishing to invest in the Netherlands.[44]

Higher investments increase the chance of breakthroughs

The resources available for research and innovation are becoming too fragmented, and as a result are too limited to achieve real breakthroughs. Investing more resources in a select number of national key technology programmes would enable the Netherlands to achieve a sharper focus, create more critical mass and achieve more. More public investment would also elicit more private investment.[45]

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41. Vennekens et al. (2019).
42. Hueck & Van Wijnen (2019a); Taskforce AI (2019).
43. Schwab (2019); AINED (2018); Quantum Delta NL, 2019; KNAW (2018a).
44. Quantum Delta NL (2019).
45. This is also referred to as the leverage effect. See KNAW (2018b) and AWTI (2016b).

Insufficient specific investment in key technologies

Since 2018, research and innovation in relation to key technologies has been stimulated through the mission-driven Top Sectors and Innovation policy of the Ministry of Economic affairs and Climate.[46] The knowledge partners in the top sectors have agreed to invest 670 million euros in key technologies in 2020.[47] Only 99.5 million euros of this total is public money, out of total public resources for the entire mission-driven Top Sectors and Innovation policy of 1.3 billion euros in 2020. Of this public funding of just under 100 million euros, 12 million is provided by the Ministry of Economic affairs and Climate; the remainder is made up of proposed budgets by applied research (TO2) institutes, the Netherlands Organisation for Scientific Research (NWO) and the Royal Netherlands Academy of Arts and Sciences (KNAW).[48]

In parallel with this, Dutch businesses and knowledge organisations have developed ambitious national agendas and strategic action plans in the fields of photonics, quantum technology and AI. The state-secretary for Economic Affairs and Climate has welcomed these agendas and action plans, but has no additional budget to invest in them,[49] to the great disappointment of the initiators and experts.[50]

In a letter to Parliament on the long-term growth strategy for the Netherlands, the government stresses the importance of key technologies, research and innovation for the future earning capacity of the Netherlands. In this letter, the government announces plans for a strategy for investing in key technologies, but does not provide any specific resources.[51]

As described in section 1.2, foreign governments are investing substantially more specific resources in key technologies than the Netherlands.

46. Minister and State-Secretary of Economic Affairs and Climate (2018); State-Secretary of Economic Affairs and Climate (2019); Topsector HTSM (2019).
47. Via the Kennis- en InnovatieConvenant (Knowledge and Innovation Covenant) 2020-2023, for which a Knowledge and Innovation Agenda for Key Technologies was developed (KIA-ST).
48. See table 1 in the Knowledge and Innovation Covenant 2020-2023.
49. Ministry of Economic Affairs and Climate (2019a).
50. Hueck en Van Wijnen (2019b); Olsthoorn (2019); Bronzwaer (2019a en b).
51. Minister of Economic Affairs and Climate (2019b).

3

Three recommendations for establishing an integrated approach

To ensure that the Netherlands is able to continue playing a leading role in key technologies, an integrated approach is called for, in which the government provides additional targeted impulses to these technologies based on considered choices. AWTI translates this advice into three concrete recommendations to the government.

The integrated approach advocated in chapter 2 offers a framework with rules for developing and utilising key technologies. It represents a simplification of the present strategy for key technologies. It ensures that choices for key technologies are properly informed and based on content rather than on compromise, vested interests and lobbying.

AWTI makes three recommendations for putting this advice into practice: (1) build a portfolio of national key technology programmes; (2) install a Key Technologies Taskforce and a DG Consultation Forum; (3) invest extra, specific resources. This chapter elaborates on these recommendations.

3.1 Recommendation 1: Build a portfolio of national key technology programmes

To make the most of the opportunities technologies offer to society and the economy and retain control of their negative effects, the Netherlands must make well-considered choices (see chapter 2). Those choices must weigh all aspects associated with key technologies. The choices make focus and critical mass possible, ensuring that the Netherlands is able to influence the development of the chosen technologies. To achieve this, AWTI recommends that the government stimulate the establishment of national key technology programmes. These programmes must align with international developments. The government creates an assessment framework and organises a process in which the most promising programmes for additional support are chosen on the basis of this framework. Finally, the government must ensure that the knowledge base remains healthy, because it makes possible intelligent choices and maintains the knowledge absorption capacity.

Foster the development of coalitions around national key technology programmes

Choosing is essential, but not simply between general categories such as AI, nanotechnology or quantum technology. All these technologies are important, and the Netherlands performs extremely well in some areas of them. An exclusive choice would

therefore not be sensible. The advice is therefore to choose at a deeper level, by asking research institutes, businesses and civil-society organisations what is needed in the area of specific technologies to maintain and strengthen the Netherlands' position internationally. Encourage stakeholders in all categories to put forward ideas for technology programmes; they are in the best position to know what is needed and how they can align with international alliances and regional initiatives, and how to involve ecosystems. Then establish a process whereby considered and independent programmes are chosen which receive extra support. The Council envisages this process as follows.

National key technology programmes are multi-year programmes of substantial size and involving collaboration between a broad coalition of research institutes, businesses, civil-society organisations and citizens' platforms. They span the entire knowledge and innovation chain around a given key technology.

The national key technology programmes bring together research and development for a specific technology or combination of technologies. They are ambitious and have clear targets for achieving breakthroughs. They offer opportunities for international collaboration and also develop activities in the areas of demonstration, testing and upscaling.

The national programmes are interdisciplinary and take public values into account in the development of key technologies. An interdisciplinary approach is needed because the interface between disciplines is precisely where new applications can arise – think of the use of sensor technology and virtual and augmented reality for cognitive behavioural therapy, for example. Collaboration and sharing of ideas between science and technology, social sciences and the humanities. This collaboration also promotes the development of technologies and applications which align with shared public values.

Coalitions develop the proposals for key technology programmes. They pool strengths and bring together national and regional initiatives. The draw on the Dutch tradition of public-private partnerships. They are also explicitly accessible to young businesses, promising researchers at the start of their careers and civil-society organisations. The coalitions are multidisciplinary, enabling them to work on key technologies in an interdisciplinary approach with an awareness of public values.

The coalitions decide what investments and activities are needed for the further development and application of key technologies. The coalition members also provide

additional resourcing (matching) and work on the basis of consortium agreements which also regulate the intellectual property rights.[52]

Ensure that programmes are aligned with international developments and initiatives

The Netherlands cannot do everything on its own. Many developments in key technologies take place elsewhere, and the Netherlands can make use of the strength of other countries and enter into international partnerships to accelerate the development and application of key technologies at home. AWTI advises that the coalitions in the national key technology programmes explicitly align with international initiatives, alliances and programmes.

International collaboration can readily take place at European level. By remaining closely keyed in to the Brussels agenda and the choices made at European level, the Netherlands can preselect at national level from European innovation choices and technologies. Key technologies are high on the agenda within the European Union, and there are several large-scale programmes and initiatives. They offer many opportunities for additional funding and pooling strengths, on the condition that the Dutch knowledge partners are sufficiently well resourced to be able to top up European funding (matching).

International collaboration offers the promise of international partners and talents recognise the Netherlands' strengths in relation to key technologies, if they see opportunities to achieve joint breakthroughs and if they are persuaded of the attractiveness of the Dutch knowledge and innovation system. Bilateral cooperation and talent-sharing programmes are of crucial importance for this, as well as a coordinated approach involving international branding and the positioning of the Netherlands in relation to key technologies.[53]

Incorporate regional initiatives and ecosystems in national programmes

The centre of gravity of knowledge development and innovation is increasingly shifting towards the regions. Companies and research institutes work together closely in regional innovation ecosystems on specific key technologies and in knowledge-intensive industries. They contain the crucial elements such as knowledge infrastructures, strong public-private partnerships and top talent to secure a strong position in international networks. Several regions have programmes and initiatives to promote research, development and innovation in key technologies. AWTI advises the coalitions in the

52. This approach is comparable to the use of consortia in the national and European research programmes.
53. AWTI (2017b) STI diplomacy.

national key technology programmes to make use of the strength of regional innovation ecosystems and to link regional initiatives to the national programmes.

Provide an assessment framework for making choices

The government needs to formulate an assessment framework which enables national key technology programmes to be selected on the basis of considered choices. 'Considered' here means weighing up what the Netherlands needs in the long term and which interests play a role in that. Examples of considerations which fit in with this integrated framework includes the following:[54]

- Societal impact in the short and long term.
  - Which societal needs and challenges are important?
  - How does the programme contribute to resolving those challenges, and does it address questions relating to societal issues? Does it contribute to solution pathways for one or more societal challenges?
- Importance of public values and interdisciplinarity.
  - Which public values must be included from the start?
  - How are disciplines interlinked in order to achieve breakthroughs at the interfaces of key technologies, scientific disciplines and sectors? How does the technology development programme link to societal values? How is 'value-aware development' of key technologies given form?
- Economic opportunities in the short and long term.
  - What are the most important economic opportunities that the Netherlands should be targeting?
  - To what extent does the programme offer opportunities for companies to develop and market new applications?
- Required scientific impact in the short and long term.
  - Which breakthroughs in technology development are needed?
  - To what extent does the programme offer opportunities for breakthroughs in technology development, and over what timeframe? At which phases of the research and at which technology readiness levels (TRL) is the programme aimed?
- Ambitions for the position of the Netherlands in the EU and in the world.
  - Which strengths does the Netherlands wish to develop and utilise to be able to make a difference?

54. The assessment framework developed by the Ministry of Economic affairs and Climate for the Key Technologies Knowledge and Innovation Agenda is a good starting point. The AWTI report Oppakken en doorpakken ('Grasp the challenge, shape the future') (2016) also offers pointers for an assessment framework.

- In which niches does the Netherlands wish to be active? What position does Dutch business occupy in international value chains?
- Does the Netherlands wish to be a leader or follower with the programme? How closely does the programme align with existing knowledge, expertise, infrastructure and economic activity?

- Strategic considerations.
  - What are the strategic priorities for the Netherlands?[55] In which technologies does the Netherlands wish to be independent?
  - How does the programme align with those strategic priorities?
- Opportunities for strengthening the Dutch innovation ecosystem.
  - Which aspects of the Dutch innovation ecosystem could be strengthened?
  - How does the programme tap into the strengths of the Dutch innovation ecosystem around the theme of the programme? Does the programme make use of the strengths of regional innovation ecosystems? Does the programme link activities across the entire research and innovation chain? Does it offer scope for new and small players? Is research and development linked to market creation in order to facilitate utilisation and dissemination?
- Opportunities for combining strengths with other regional, national and international initiatives and alliances.
  - How does the programme bring together different national and regional initiatives? How does it key into other alliances and networks? What opportunities does it offer for international collaboration?

Ensure that the knowledge base remains healthy

Making choices from strong national programmes and aligning with international developments is only possible if the Netherlands maintains a solid and broad knowledge base for key technologies. This fruitful breeding ground is indispensable for the development of new, sometimes unsuspected key technologies, and it is essential to continue investing in it.[56]

The knowledge base also strengthens the capacity of Dutch businesses and research institutes to absorb new knowledge and use it for implementation in the Dutch context (knowledge absorption capacity).[57] Without a solid knowledge base, the Netherlands will be unable to apply and utilise key technologies for the benefit of society and the economy. There is then little point in making specific investments. The knowledge base

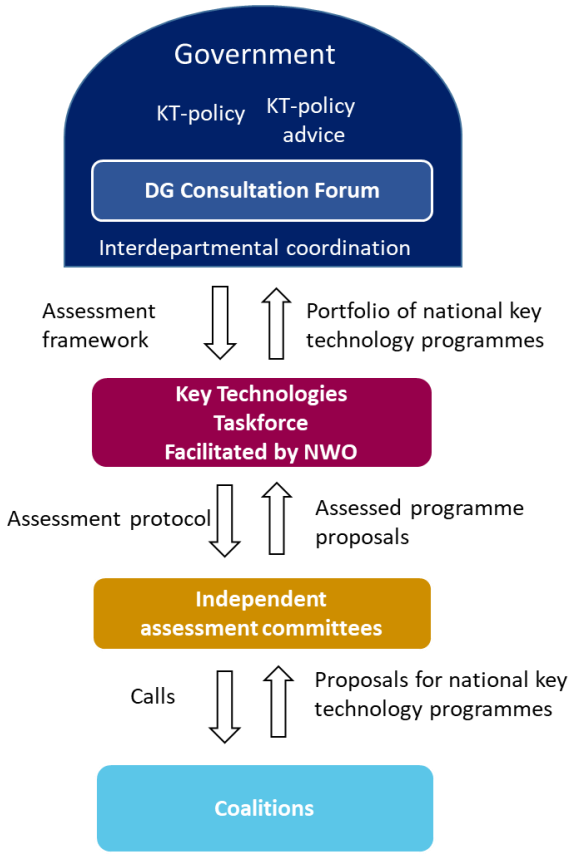
55. One way of setting strategic priorities is to identify 'strategic innovation assets', i.e. knowledge, know-how, infrastructures, research and production facilities, companies, value chains, ecosystems and technology positions which are of value to society and which are important for present and future competitiveness, prosperity and employment. See TNO (2019).
56. AWTI (2016b) and AWTI (2017b).
57. AWTI (2016a); AWT (2005); AWTI (2016b).

consists of the public knowledge infrastructure, with institutes which train people and which develop and disseminate new knowledge through fundamental and applied research. It incorporates high-grade, accessible research facilities and a digital research infrastructure.

3.2 Recommendation 2: Set up a Key Technologies Taskforce and a DG Consultation Forum

To organise and embed the integrated approach, two changes in governance are needed. The first is to set up a Key Technologies Taskforce to manage the portfolio of national key technology programmes and select national programmes. The second is the formation of a consultation forum (consultation between Directors-General) for interdepartmental liaison and coordination. Figure 2 shows how the Taskforce and the DG Consultation Forum relate to each other.

Figure 2 Governance of national key technology programmes



Set up a Key Technologies Taskforce to manage the national programmes

A Key Technologies Taskforce manages the portfolio of national key technology programmes (see 3.1), translates the government's assessment framework into specific indicators and assessment factors, invites coalitions to put forward proposals for the programmes and makes a selection from those submitted.

Members are appointed in a personal capacity by the government and come from a variety of backgrounds. Taskforce members are needed who have proven expertise, but also young, promising researchers and entrepreneurs (start-ups and scale-ups) with a fresh approach and a sense of the 'state of the art'. The Taskforce also contains a delegation from the DG Consultation Forum, which inputs the strategic priorities for the Netherlands.

The calls for national programmes can vary; they may for example include calls for programmes which accelerate developments because they have potential for use in different domains and for different missions; or for programmes focused on 'early-phase' development without a firm focus on particular applications. Or they may include programmes for crossovers between key technologies. Calls may be open to all key technologies or restricted to certain technologies, and they may address strategic priorities. To facilitate a flexible response to developments in key technologies and changing priorities, the Taskforce periodically issues new calls.

The Council advises that the Taskforce be placed organisationally within the Netherlands Organisation for Scientific research (NWO), which has the necessary experience, procedures and capacity to manage national programmes for key technologies.

Independent assessment committees advise the Taskforce on the selection of national key technology programmes

The Key Technologies Taskforce will choose a select number of programmes from each call.

The proposals for national programmes are assessed by an independent committee which is put together specifically for a call. The assessment committee issues a recommendation to the Taskforce, which makes the final choice. Like the members of the Taskforce, members of the assessment committee are appointed in a personal capacity. They have knowledge of specific technology fields or fields of application or sectors, or else they bring to bear expertise on societal values and considerations. These experts may come from the Netherlands or elsewhere.[58]

58. The composition and appointment of the assessment committee is comparable to assessment committees in other national and European research programmes.

The assessment committee uses the government's assessment framework as translated by the Taskforce into specific indicators and weighting factors.

Funding for the national programmes is awarded for ten years, in two five-year stages. After the first five years, additional funding may be awarded in order to speed up developments or make adjustments to the programme. This provides long-term certainty and ensures the necessary flexibility.

Set up a DG Consultation Forum for interdepartmental liaison and coordination

Key technologies are a responsibility of the whole of government, not just one ministry or minister. This means that an impulse is given to the development and application of these technologies on the basis of shared interests and goals and using combined resources.

The DG Consultation Forum is the appropriate forum for liaison and coordination in relation to key technologies.[59] Its participants are Directors-General from departments which formulate societal missions (Ministry of Agriculture, Nature and Food Quality, Ministry of Economic Affairs and Climate, Ministry of Infrastructure & Water Management, Ministry of Defence, Ministry of Justice & Security and Ministry of Health, Welfare and Sport)[60] and ministries which operate in other domains such as education, labour market and privacy (Ministry of Education, Culture and Science, Ministry of Social Affairs and Employment and Ministry of the Interior and Kingdom Relations). The government assigns the following brief to the DG Consultation Forum:

- Development of the assessment framework for national key technology programmes in the long term. This links the economic opportunities to societal challenges;
- Identifying which societal values are important in relation to key technologies, how these should be weighed against each other and how they can be embedded;
- Ensuring coordination between different policy domains which are important for the application and utilisation of key technologies.

Make use of exploratory studies

To increase the flexibility further, it would be better for the portfolio of national key technology programmes not to be 'cast in stone'. Developments in key technologies, societal challenges and public values cannot be predicted, but can lead to adaptations in the assessment framework, in the national programmes chosen and in the coalitions of knowledge partners. It is therefore necessary that the DG Consultation Forum and the Key Technologies Taskforce make use of exploratory studies, which monitor and identify new developments in science, technology and society, for example the emergence of

59. A DG Consultation Forum fits in with the initiative of the Consultation Forum of the secretaries-general 'to create a working method for unconventional and interdisciplinary collaboration' in order to address major societal challenges.
60. Ministry of Economic Affairs and Climate (2019).

new key technologies, their potential applications or new focus areas for society. Use can be made of studies such as the technology assessments by the Rathenau Instituut, technology monitors by applied research organisations (TO2) and forward-looking studies by the Netherlands Study Centre for Technology Trends (STT).

3.3 Recommendation 3: Invest extra specific resources

As argued in section 2.3, the government will need to make additional resources available for national programmes for key technologies. These must be specific resources which must not be made available at the expense of generic investments in the broad knowledge base.[61] As a guideline, between 0.5 and 1 billion euros extra per year should be considered (0.07 - 0.13% of Dutch GDP) to accelerate the development and application of key technologies. This will bring the Netherlands more into step with other countries, which are investing roughly 0.1% of their GDP in these technologies.[62]

The investment decisions must be taken out of the context of departmental interests. It is a joint responsibility of all departments to stimulate key technologies.

61. AWTI (2016b); AWTI (2017b).
62. Most other countries in the comparative study by Scholten et al. (2019) spend at least 0.1% of GDP specifically on key technologies. Scholten et al. (2019) calculated that the Netherlands spends 144 million euros per year specifically on key technologies. If the Netherlands were also to invest around 0.1% of GDP specifically in key technologies, it would have to spend a minimum of 800 million euros per year specifically on key technologies.

Annexes

Annex 1 Definitions of key technologies

The European Commission (EC) introduced the term *Key Enabling Technologies* (KETs) in 2009.[63] The Commission sees KETs as the driving force behind the renewal of the European economy, strengthening its competitiveness, creating sustainable employment and addressing the major societal challenges. KETs are knowledge and capital-intensive and are characterised by intensive R&D efforts and rapid innovation cycles. They are multidisciplinary, spanning, connecting and integrating different technology domains. They are not limited to one domain, but can lead to applications in the wider economy and society. This makes KETs technologies which, if their development is continued, will form the basis for a different way of living, working, innovating and manufacturing and will lead to new products, services and working practices.[64] The EC has designated six KETs: nanotechnology, micro and nanoelectronics (semiconductor technology), advanced materials, industrial biotechnology, photonics and advanced fabrication technologies.

In 2018 the European 'High-level Strategy Group on Industrial Technologies'[65] proposed a different classification and an expansion of the field of key technologies. They suggested reducing four existing categories to two broader categories (materials and nanotechnology; photonics, micro and nanoelectronics). They also broadened the category industrial biotechnology to life sciences and proposed adding two new key technologies, namely artificial intelligence (AI) and digital safety and connectedness.

The high-level group also proposed broadening the definition of key technologies, so that a key technology is one which generates (or will generate) a substantial impact on jobs, prosperity or well-being, is relevant for all phases of product development and for social and democratic participation, promotes sustainable development and green growth, promotes health or safety, fosters connectivity between systems and individuals, makes possible multiple and cross-sector industrial applications, promotes global excellence and new knowledge and leads to new forms of participation.[66] According to the high-level group, this will open the way to economic progress and could help reduce inequality. At the same time, key technologies will support the EU's industrial leadership.

In 2017 the National High Level Group on Key Technologies looked at technologies that are important for the Dutch economy.[67] This National High Level Group defines key technologies as follows: 'A key technology is a technology that is characterised by a broad field of applications or embraces a wide range of innovations and/or sectors. Key

63. European Commission (2009).
64. European Commission (2009).
65. European Commission (2018a).
66. It is unclear whether a technology must meet all the criteria listed in order to be classed as a key technology.
67. Reference to "MEMO SLEUTELTECHNOLOGIEEN, EZ, NWO, TNO, 28 June 2017" in Elsevier Research Intelligence (2018).

technologies are essential for resolving societal challenges and/or for making a major potential contribution to the economy through the creation of new economic activity and new markets, by increasing competitiveness and by strengthening jobs growth. Key technologies make possible ground-breaking process, product and/or service innovations. They are relevant for science, society and the market'. The National High Level Group grouped fifty key technologies in eight clusters: advanced materials, quantum technologies, photonics, digital technologies, nanotechnology, chemical technologies, life sciences technologies, and engineering & fabrication technologies.

Several foresight studies show that the present lists of key technologies will remain accurate for the next ten to fifteen years.[68] Thought is however being given to future key technologies. In 2019, for example, the EC asked a number of experts[69] for their ideas on future technologies. The experts identified the following technologies as crucial: biological transformation, including gene therapy, neurotechnology, human-machine interaction and smart farming; smart materials including renewable plastics, smart nanomaterials and 3D printing, low-energy data transmission, including 'smart dust' (wireless sensor networks) and coherent optics, Power to X technology (electrification of the process industry), including hydrogen technology and carbon capture and storage, and marine technology, including digital fishing and freshwater sources beneath the sea.

The OECD also identifies and analyses emerging technologies. In the 2016 Science, Technology and Innovation Outlook, the OECD highlighted ten emerging technologies which have great potential: Internet of Things, Big Data analytics, artificial intelligence, neurotechnologies, nanosatellites and microsatellites, nanomaterials, 3D printing (additive manufacturing), advanced energy storage technologies, synthetic biology and blockchain technology.[70]

The European Commission invests through the Future Emerging Technologies (FET) Programme[71] in transformative, pioneering, multidisciplinary, long-term, early-phase and high-risk research that is intended to lead to radically new, emerging technologies which could have a major impact on the economy and society in the longer term. There is no fixed classification or definition of what constitute Future Emerging Technologies; all scientific disciplines are eligible. The FET Programme encourages new crossovers, synergies and mergers between different scientific disciplines.

In addition to KETs and FET, there are also what are referred to as 'general purpose technologies'. These are technologies that have a place in virtually all activities of

68. Direction générale des entreprises (2016); Fraunhofer ISI (2014); Gokhberg (2016); Committee for the Future (2015); European Commission (2015b); European Commission (2015c).
69. European Commission (2019e).
70. OECD (2016).
71. https://ec.europa.eu/digital-single-market/en/policies/future-and-emerging-technologies.

economic production and interaction. They are characterised by wide applicability in most sectors of the economy; a high potential for technological improvement, leading to major cost reductions and growing availability; and complementarity with other innovations in other domains.[72] Electricity and ICT are examples of such technologies. Characteristic of a general purpose technology is that the constant flow of innovations in applications in turn drives the further development of this technology. ICT is also referred to as the 'key enabler' of the KETs: key technologies are based to a greater or lesser degree on a foundation of ICT.[73] Some are direct developments or 'specialisations' of ICT (such as Big Data analytics and AI). Other key technologies are the result of the convergence of ICT and other technologies, such as advanced robotics, autonomous vehicles and 3D printing, the Internet of Things and 'Industry 4.0', in which artificial intelligence is built into objects and appliances. Here, ICT comes together with mechanics and the use of optical and other sensors. Yet other key technologies are technologies which owe their further development to the availability of ICT as the primary instrument for research and development; examples include biotechnology, genomics and nanotechnology.

72. Bresnahan & Trajtenberg (1995).
73. AWTI (2015).

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