

SUSTAINABLE BREAKTHROUGHS

TOWARDS SYSTEM INNOVATION
IN THE ENERGY TRANSITION



The Dutch Advisory Council for Science, Technology and Innovation (AWTI) publishes solicited and unsolicited advisory reports to the Dutch government. Its independent reports are strategic in nature and focus on the contours of government science, technology and innovation policy. Council members are drawn from knowledge institutes and the business world. AWTI's work is founded on the principle that knowledge, science and innovation are vital for the economy and society, and will become more important in the future.

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Sustainable breakthroughs

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Summary

Background: Innovation is crucial for the transformation to sustainability by 2050

There is great urgency around the energy transition. The world faces a major challenge in achieving a substantial reduction of greenhouse gas emissions in the energy supply. The EU has set itself a target of being fully climate-neutral by 2050. The challenge facing the Netherlands is even bigger, partly because it has a fairly energy-intensive economy and because it possesses relatively few sustainable energy resources. To achieve sustainability in 2050, the Dutch economy, society and associated energy supply will all have to undergo a transformation.

Achieving that transformation will require a great deal of innovation from both the Netherlands and the EU: technological, institutional and social innovation will all be essential. While incremental innovations are a useful part of this process, genuine breakthroughs will also be needed on several fronts in order to realise the transformation to a sustainable system in 2050. These breakthroughs may be driven by technological developments, but may also stem from other developments, such as new rules, organisational structures or behavioural changes. A characteristic of breakthroughs is that they often do not fit easily into existing regulatory, infrastructural or organisational systems. As a result, they encounter many barriers.

How can the Dutch government provide optimum support for the necessary energy innovations? The government sought advice from AWTI to answer this question, based on the following request for advice:

How can Dutch innovation policy contribute to the transformation of the energy system that is needed to achieve the government's energy and climate goals?

Analysis: Current energy innovation policy not yet optimal

AWTI observes that the current policy is not yet optimised for fostering energy innovation. First, there are shortcomings in the policy approach for energy innovation. Policy choices are not made on the basis of a vision for what a sustainable Dutch economy, society and energy supply should look like in 2050; instead, choices are made based on where the Netherlands is starting from, rather than where it needs to end up. Additionally, the current energy innovation policy devotes too little attention to strategic autonomy.

Second, the current energy innovation policy is insufficiently focused and devotes too little attention to breakthrough innovations. That is a problem, because breakthrough innovations are crucial for achieving a successful energy transition by 2050; in practice,

however, these innovations encounter the greatest obstacles. The Netherlands does not have a policy in place to support high-risk/high-reward ideas, yet those are precisely the ideas which can lead to breakthroughs. Moreover, in most cases Dutch innovation policy focuses on individual solutions, whereas breakthroughs require a vision that encompasses the entire system.

Third, the policy needs to be more cohesive. Dutch energy innovation policy is still too heavily focused on technology; non-technological aspects, which are also highly relevant for the successful implementation of innovations, receive less attention and are moreover still insufficiently recognised as a source of innovation. This also applies for the phasing out of undesirable practices: that can also be a source of innovation, but receives too little attention in policy. The policy is moreover fragmented, with a lack of connectedness between the different programmes. And finally, the 'last step' in scaling up an innovation often proves to be a bottleneck.

Finally, evaluations of policy are currently often too 'narrow', focusing on individual policy instruments instead of analysing the impact on system change and the relationship between different policy instruments. That relationship is crucial for innovation success.

Advice: Aim for breakthroughs that are needed for the energy transition.

AWTI advises the Dutch government and parliament to ***focus the energy innovation policy on breakthrough innovations that help foster the transformation to a sustainable Netherlands by 2050***. By making clear choices, ensuring the policy promotes breakthroughs more effectively and evaluating the policy in the context of its contribution to the envisaged transformation. This needs to be done based on a broad vision for a sustainable economy, society and the associated energy supply in 2050. That vision forms an essential basis for the policy.

AWTI calls for the specific policy for energy innovation to focus as a priority on promoting breakthrough innovations. These breakthroughs are essential for a successful energy transition. However, the many obstacles they encounter (remoteness from the market, the complexity of achieving system breakthroughs and the higher risks) mean they are very difficult to get off the ground. Specific support from government policy is essential to achieve these necessary breakthroughs.

AWTI makes three recommendations for translating its advice into practice (see below). It is vital that these recommendations are implemented as quickly as possible. Developing breakthrough innovations and making the required adaptations to the system takes a long time. It is essential to make a start now on achieving the breakthroughs that will define the system in 2050. Otherwise we are likely to be too late. The need to adapt the policy is urgent.

Recommendation 1. Instil direction and focus in the energy innovation policy

It is important that the government takes up its guiding role and makes clear choices. To achieve maximum innovation with scarce resources, choices will have to be made. AWTI proposes three interrelated actions to instil more direction and focus in the energy innovation policy:

Action 1. Choose the priorities in the energy innovation policy based on an up-to-date assessment framework.

The elements of this framework will be: alignment of the innovation with the vision for the future energy supply; the expected environmental, economic and social impact; strategic autonomy; and the chance of the innovation succeeding in the Netherlands.

Action 2. Select a limited number of mission-oriented innovation challenges (suited for the Netherlands) and set up multi-year innovation programmes for them, based on a planned approach and strong internal cohesion.

Action 3. Organise the governance to enable clear choices to be made.

AWTI advises that an independent, autonomous governing body be established, with solid substantive expertise and the authority to make clear choices for innovation projects based on the proposed assessment framework.

Recommendation 2. Make the policy suitable for breakthrough innovations

The policy design can be further improved to make it more suitable for fostering successful breakthrough innovations.

AWTI proposes the creation of two new policy instruments:

Action 1. Establish a high risk/high reward programme for energy innovations: the SPRIND programme in Germany or the American ARPA-E programme can serve as sources of inspiration here.

Action 2. Create a specific financial instrument to support upscaling. Investigate the possibilities of organising this at European level or creating leverage with EU policy instruments.

AWTI also advises improving the connectedness between different policy instruments. This will enable more promising innovations to develop into breakthroughs.

Action 3. Improve the connectedness between policy instruments for the different stages in an innovation project by setting up programmes which allow for automatic progression to the next step when one stage is completed successfully.

It is also important to devote more attention to the non-technological dimensions of innovation.

Action 4. In the case of technological developments, consider non-technological aspects and enabling parameters from the beginning. Make these aspects an integral part of innovation policy by ensuring that the policy on those other aspects keeps pace with the technological innovation policy.

Action 5. Acknowledge that non-technological dimensions are also an independent source of innovation and develop innovation policy aimed at eliciting and encouraging such innovations.

It would also make sense for the innovation policy to devote more attention to phasing out undesirable practices in parallel with the development of sustainable alternatives.

Action 6. Develop policy aimed at the phasing out of practices which are or will become undesirable. Ensure that this policy is properly aligned with the policy on developing alternatives, and also treat 'phasing out' as a topic for of innovation.

Recommendation 3. Include the context in evaluations and ensure that evaluations are geared to learning for system change

Finally, AWTI recommends that policy evaluations be used primarily as learning opportunities, and that policy be adapted based on the lessons learned. It is important that evaluations do not focus narrowly on a single policy instrument, but cover the broader system and embrace the need for cohesion across the policy arena.

Action 1. Ensure that evaluations do not focus solely on individual policy instruments and the 'direct' results (output and outcomes), but also on the context and process of which the policy instrument forms part. Use a broad array of evaluation frameworks and methods for this purpose.

Action 2. Use evaluations mainly as learning exercises with the aim of improving the policy or supporting portfolio management. Organise the evaluation-based learning process as a continuous process, enabling adjustments to be made during the implementation phase.

Background: Innovation is crucial for the transformation to sustainability by 2050

The world faces a major challenge in achieving a substantial reduction of greenhouse gas emissions in the energy supply. The 2015 Paris Climate Agreement set out a number of commitments to achieve this. The European Union formulated a specific ambition of becoming entirely climate-neutral by 2050, with an economy producing no net greenhouse gas emissions. This ambition coincides with the broader desire to develop an energy supply and an economy which as far as possible is based on principles of renewability and circularity.

A key requirement here is a sustainable energy system which meets the needs of the economy and society of the future. This requires innovation. Technological innovation alone is not enough to achieve this ambition; institutional and social innovation will also be required from the Netherlands and the EU. The request for advice submitted to AWTI is accordingly: How can Dutch innovation policy contribute to the transformation of the energy system that is needed to achieve the government's energy and climate objectives?

1.1 The need for the energy transition is urgent

There is a strong awareness of the need to make the Dutch economy and society more sustainable. The Netherlands has made international commitments to limit global warming to less than 2 °C, to reduce carbon emissions by 55% by 2030 and to become climate-neutral by 2050. The courts have also made clear that these objectives are mandatory and require effective policy.

The EU is increasingly becoming a driver and leader of the energy transition. The EU has always been important in terms of energy policy (energy markets, infrastructure), but climate policy has also been added to the mix in recent years. The 'green transition' was one of the two main focus areas for the previous European Commission (alongside the digital transition), and this was also reflected in the EU policy for research and innovation. For example, the EU wanted to ensure that a certain proportion of EU-sponsored research was aimed at promoting the achievement of the energy and climate ambitions.

The new European Commission headed by Ursula von der Leyen is also continuing the strong focus on the green transition, with the Clean Industrial Deal¹ as a key focus area. The Draghi report on the future of European competitiveness, which is broadly embraced within Europe, also describes making the economy carbon-free and lowering energy costs as among the key challenges for the future. According to Draghi, if Europe wishes to remain economically competitive, focusing on clean technologies will be of great strategic importance.²

Maintaining Europe's competitiveness on the world stage provides an additional challenge. The growth in AI and data infrastructure will lead to an enormous increase in energy consumption;³ these new developments place a heavy burden on the energy network and risk destroying all the progress made using green energy. This will make the goal of becoming climate-neutral by 2050 even more daunting.

There is a growing awareness in the Netherlands and the EU that we cannot blindly rely on countries such as China and the US. These two superpowers are becoming increasingly nationalistic, even where this is detrimental to their partners. A new world order is emerging, with a regrouping of superpowers which puts heavy pressure on Europe (and the Netherlands). As a result, strategic autonomy is acquiring an ever more prominent place on the agenda. This is not merely about commodities or technology, but also about the importance of meeting our own energy needs as far as possible. There is for example greater urgency in the Netherlands to end its dependency on gas, because of the phasing out of gas extraction activities in Groningen and the Netherlands' desire to end its dependency on Russian gas. These developments increase the urgency of targeting specific strategic innovations at national or EU level rather than leaving it to others. The concept of 'strategic autonomy' is discussed in more detail in Appendix 2.

There is also growing public pressure to speed up the energy transition. Public awareness around sustainability and the role of energy in achieving it has grown, and with it the desire and willingness of citizens to take positive action themselves. More and more bottom-up initiatives are emerging, such as citizen initiatives and local energy communities (energy cooperatives), which emphasise new forms of (local) organisation

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1. European Commission (2024a), *Europe's Choice. Political Guidelines 2024 – 2029*. Strasbourg: European Commission; European Commission (2024b), *A new plan for Europe's sustainable prosperity and competitiveness*. Brussels: European Commission.
 2. European Commission (2024c), *The future of European competitiveness*. Brussels: European Commission. Research moreover shows that Europe is lagging behind countries such as China in the development of clean technologies. See also: IEA (2025a), *The State of Energy Innovation*. Paris: IEA.
 3. The International Energy Agency (IEA) is predicting that global demand for electricity by data centres will more than double by 2030 to 945 terawatt-hours (TWh). That is more than the entire present electricity consumption by Japan. See: IEA (2025b), *Energy and AI*. Paris: IEA.

aimed at improving the sustainability of the local environment through partnerships between citizens and businesses in their local neighbourhood, village, city or region.⁴

1.2 The Netherlands faces a particular challenge

The energy challenge facing the EU is considerable, and the challenge faced by the Netherlands is even greater in relative terms. Despite the long-standing policy of becoming more sustainable, the Netherlands will need to do all in its power to achieve both its interim and end objectives; the Netherlands Environmental Assessment Agency (PBL) estimates that the Netherlands will fail to meet its objectives with current policy.⁵ Not only will all existing sustainability options need to be deployed to the full, but new options will also need to be developed in order to achieve a greener economy and society. Moreover, this will need to happen relatively quickly, given the goals of a 55% reduction in carbon emissions by 2030 and climate-neutral status by 2050. And all this will moreover need happen within the context of Northwestern Europe.

Creating a greener economy and society is essential for the Netherlands. Not only does the Netherlands have a fairly energy-intensive economy, it also possesses relatively few sustainable energy resources. The Dutch economy and society are heavily modelled on the wide availability of fossil fuels: not just natural gas, which the Netherlands has produced in large quantities for many years, but also coal, of which large quantities are imported through the Port of Rotterdam. This has led to the development of a large 'basic industry' in the Netherlands, including steel production, refining, (petro)chemicals and fertiliser production. Together, these sectors account for around 80% of the ultimate *industrial* demand for energy and raw materials in the Netherlands.⁶ However, this basic industry contributes only around 5% to Dutch GDP, less than the contribution from the rest of industry (9%).⁷ Put differently, basic industry consumes a great deal of energy per

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4. Nationaal Klimaat Platform (2024). *Lokale daadkracht versterkt. Voorstel voor Nationaal Programma Maatschappelijk Initiatief*. See also the Letter to Parliament from the Minister of Climate Policy and Green Growth of 29 September 2025 (ref.: DGKE-DSE/101327232) on the role of energy communities in the energy system.
 5. PBL, TNO, CBS and RIVM (2025), *Klimaat- en Energieverkenning 2025*, The Hague: Planbureau voor de Leefomgeving; see also: PBL, TNO, CBS and RIVM (2024), *Klimaat- en Energieverkenning 2024*. The Hague: Planbureau voor de Leefomgeving.
 6. Expertteam Energiesysteem 2050 (2023), *Energie door perspectief: rechtvaardig, robuust en duurzaam naar 2050*, The Hague: RVO, p. 83.
 7. Sustainable Industry Lab (2023), *Groene keuzes voor de Nederlandse basisindustrie. Klimaatneutrale productie in een circulaire economie*, Utrecht, pp. 3-4, based on figures from Statistics Netherlands (CBS), which can vary from year to year.

euro earned. The same applies for the large Dutch transport sector, which consumes a great deal of fuel for its relatively limited economic added value.⁸

Figure 1 illustrates the difficult starting position in which the Netherlands finds itself. The left-hand diagram shows where the Netherlands has come from (the situation before the 1997 Kyoto Protocol). The Dutch economy and society are historically highly energy-intensive (the left-hand side of the diagram), with a large number of activities which deliver relatively limited added value (the lower half of the diagram). Moreover, in the past the Dutch economy, society and energy supply were based almost entirely on fossil fuels (the red area in the figure). Steps have been taken in recent years to make the energy supply greener and reduce greenhouse gas emissions, based on the existing economic structure and society. The middle diagram in Figure 1 represents the current situation; The energy supply is greener than it was, but the economy and society are still highly energy-intensive and predominantly based on fossil fuels.

In theory, attempts could be made to make the entire economy and society more sustainable, for example through electrification. However, there is a great danger that this process would stall, for example because of the costs, which could prove to be much higher than the public and industry can bear,⁹ or because of the limitations of the electricity network. The latter is already happening in the Netherlands, even though we are right at the very beginning of a large-scale shift to electricity.¹⁰ Affordability (both of the process and the ultimate objective) is therefore important, otherwise the necessary transition will prove to be too big a burden, both financially and socially.

It is therefore unlikely that maintaining the current economic and social structure will be enough to achieve a transition to a sustainable energy supply in 2050. To have a realistic chance of making the Netherlands sustainable by 2050, the economy and society will also have to transform. Ideally, society and the economy will both transition to a much less energy-intensive state (moving from left to right in the diagram) while at the same time delivering greater added value (economic or social), corresponding to a shift from

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8. In the Council's view, the (added) value of basic industry and sectors such as transport must be seen not only in terms of energy versus added value; the basic needs that these industries meet, and their strategic importance, are also relevant. The aim should be to continue to meet those needs in the longer term with a much lower energy-intensity. The reality is that the economic structure that has developed in the Netherlands makes the mission of becoming more sustainable even more challenging.
 9. Minister of Climate Policy and Green Growth (2025a), *Stand van zaken maatwerkafspraken verduurzaming industrie*, Letter to Parliament, 30 June 2025; Minister of Climate Policy and Green Growth (2025b), *Het Windenergie Infrastructuurplan Noordzee*, Letter to Parliament, 15 July 2025.
 10. Rijksoverheid (2025), *Schakelen naar de toekomst – over bekostiging elektriciteitsinfrastructuur. IBO Bekostiging Elektriciteitsinfrastructuur*, The Hague. See also: Minister of Climate Policy and Green Growth (2025c), *Kamerbrief toekomstperspectief energie-intensieve industrie*, Letter to Parliament, 5 September 2025.

the bottom to the top in the diagrams in Figure 1. Moreover, the energy supply will be largely based on non-fossil fuels in 2050. The right-hand diagram in Figure 1 illustrates this transformation.

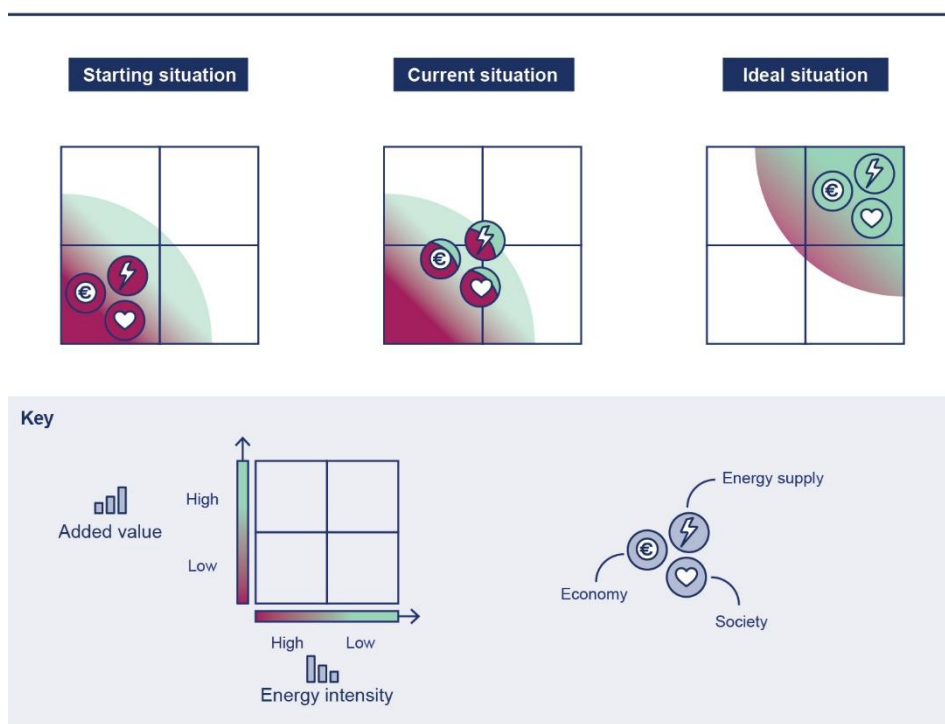


Figure 1 Development of the Dutch economy, society and energy supply on the road to a sustainable 2050

1.3 Sustainability by 2050 requires innovation

Creating a sustainable energy supply that is appropriate for the future economy and society will require innovation.¹¹ Technological innovation alone will however not be enough to make a genuine transition to a different energy system.¹² Institutional and

11. PBL (2024a), *Trajectverkenning klimaatneutraal 2050. Trajecten naar een klimaatneutrale samenleving voor Nederland in 2050*, The Hague: Netherlands Environmental Assessment Agency (PBL).

12. By 'energy system' we mean the whole of actors (organisations, groups, individuals), materials (products, technologies and infrastructure) and rules (regulations, values, norms and customs), within the energy domain.

social innovation will also be needed, at both national and EU level.¹³ Behavioural change and reducing our consumption of energy will for example be essential. While technology is not the central focus in this kind of innovation, it may well be a condition for its success. Examples might include new technological developments which enable users to collaborate and coordinate and optimise their activities, for example new equipment and (distributed) protocols and data commons.

It is important that the energy innovation policy allows scope for civic initiatives and the rise of local energy cooperatives. The importance of social and institutional innovation has only increased as the resources for energy research (which largely target on technological innovation) have reduced in the wake of recently announced spending cuts on grants for innovation.¹⁴

Broad interpretation of innovation

AWTI interprets innovation broadly. Innovation – or innovating – is about introducing and implementing 'newness': new ideas, new products, new technology, new rules, new services or new policy.¹⁵ AWTI's interpretation also expressly includes social and institutional innovations. A successful innovation is one where these things (can) actually take place within a given system.

Lay's thermal battery: technological and institutional innovation¹⁶

The Lay's crisp factory in the Dutch village of Broek op Langedijk is making its production more sustainable by switching from gas to green electricity. As part of this move, the factory is looking to use a thermal battery. Instead of frying directly with gas, electricity is now used to heat air; the heat is stored in large tanks filled with heat-retaining balls, known as steel slags, which ensure that the factory always has enough heat to fry potato crisps. The way the thermal battery works is simple: when electricity is cheap, the battery is charged with heat. When the electricity supply dips, or when it is very expensive, the battery releases that heat back into the production process. This enables the factory to keep running with no interruptions to production and without high energy costs.

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13. Paunov, C. *et al.* (2025), "What is unique about green innovation? Evidence from green hydrogen, green steel, batteries and electric vehicles", *OECD Science, Technology and Industry Working Papers*, No. 2025/05, Paris: OECD Publishing; IEA (2025a), *The State of Energy Innovation*, Paris: IEA.
 14. Minister of Climate Policy and Green Growth (2024). *Kamerbrief bij Klimaatnota en Energienota 2024*, Letter to Parliament, 24 October 2024.
 15. See also: AWTI (2024), *Natural connections - Embed social sciences and humanities research in innovation*. The Hague: AWTI.
 16. Van de Weijer, B. (2025), "'Groene' chips maken met duurzame stroom en een warmtebatterij: snack wordt klimaatvriendelijker", *de Volkskrant* 3 July 2025.

To ensure this new process runs smoothly, an innovative new type of electricity contract had to be developed, which Lay's signed with network operator Liander. Instead of signing up for a fixed number of megawatts, the factory is allocated a certain amount of electrical capacity each day. The factory can only use its plant if there is enough network capacity. The company only pays network charges for the electricity it draws in megawatts, for which it pays a reduced rate. In other words, Lay's only pays for the capacity it actually uses. This encourages it to use electricity outside the peak times, when it is cheaper and places less strain on the network. This helps the stability of the network and avoids extra costs to extend the grid. Liander is exploring whether this contract model might also be suitable for other large companies, thus keeping the energy transition affordable.

Successful innovation thus requires a multidimensional approach, incorporating both technological and non-technological steps. This is shown schematically in Figure 2. The yellow arrows represent technological steps, while the turquoise arrows mark progress on the non-technological dimension. The combination of technological and non-technological steps can enable a new idea to be successfully implemented in practice: a successful innovation, in other words (the bulb at top right).¹⁷ Some Innovation steps lead to major progress in the process or enable a substantial obstacle to be overcome. We refer to such key steps as 'leaps'.

Innovations themselves are also cogs which interlock with other innovations (and other developments in the system) in a way that can lead to a transformation of the entire system. Together, different (innovation) steps can lead to a successful innovation, while several innovations together can result in progress in the broader process of transforming the social system.¹⁸

17. As with every model, the reality is more complex. Non-technological innovation can influence technological innovation, and vice versa. It will also never be the case that all leaps move forwards: in practice, there will be the occasional leap backwards. For the sake of simplicity, innovation is presented as a linear process. This enables us to show the conceptual interrelationship between innovation, the technological and non-technological dimensions of innovation and the steps within those processes.

18. By social systems we mean systems that are related to social needs such as food, energy, education and mobility. They consist of actors (organisations, groups, individuals), materials (products, technologies and infrastructure) and rules (regulations, norms and customs). See: AWTI (2023). *Shaping the future - From optimisation to transformation*. The Hague: AWTI.

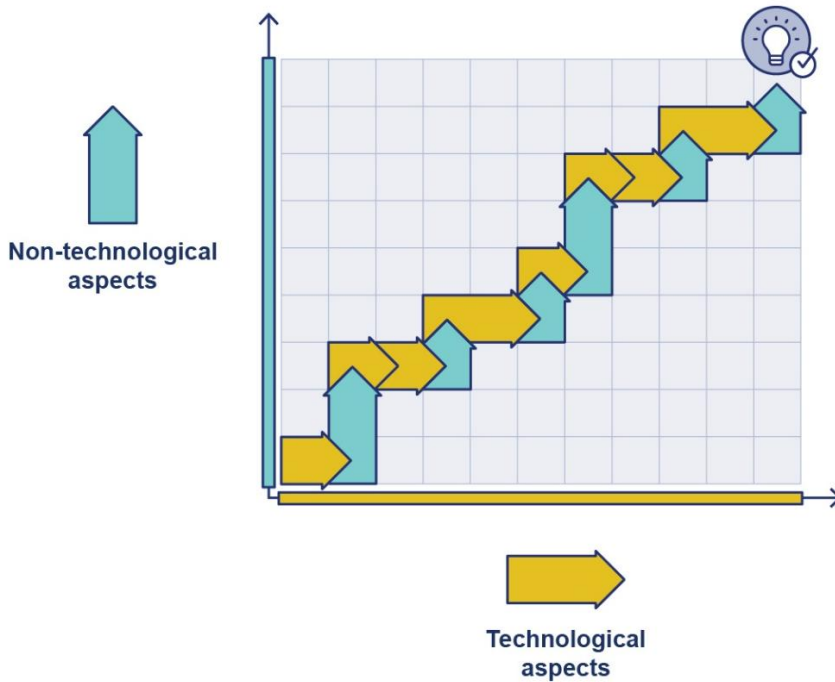


Figure 2 Successful innovation is an interplay of technological and non-technological steps

Energy transition is a system transformation

This illustrates how important the *systemic* aspect of the energy transition is. Achieving the envisaged transformation will therefore require innovation across the entire system.¹⁹ Incremental innovation is an important part of this process, because it will make the existing system better and greener, leading to 'optimisation of the existing and the known.'²⁰ This can be a way of reducing costs and thus improving the financial and social feasibility. However, it will not be enough to achieve the transformation needed to ensure that the Netherlands is sustainable by 2050; that will require major changes and revolutions.

19. We interpret transformations as radical fundamental changes in the structure, culture and infrastructure of our social systems which go beyond ordinary changes. See: AWTI (2023). *Shaping the future - From optimisation to transformation*. The Hague: AWTI.

20. AWTI (2023). *Shaping the future - From optimisation to transformation*. The Hague.

The need for breakthroughs

Achieving a (faster) transformation will require breakthroughs in a number of areas. A breakthrough is an innovation (or a number of related innovations) which can play a 'breakthrough' role in the transformation. Unlike incremental innovations, breakthroughs do not fit within the existing system. They therefore cause system friction, not just technologically, but also institutionally and socially. Non-technological developments (innovations) can also have a major impact, by removing obstacles and enabling breakthroughs to succeed.²¹ A breakthrough is therefore only successful if several parts of the system change. Breakthroughs lead to system changes, for example by creating new ways of supplying applications with energy, or changing the costs of the system.²² These system changes are needed to achieve a transformation. Breakthroughs are thus not only essential for securing major leaps in the available time frame, but also for achieving the right scale to ensure that the transformation is successful. Without breakthroughs, the transformation of the energy system, the economy and society will not be achieved before 2050.²³

More broadly,²⁴ breakthroughs can be breakthrough technologies. These are potentially radical technologies which are still in the initial phase of development, and thus still a long way from successful application.²⁵ There is a high risk that they will not succeed, but they can have a major impact if they do succeed (high risk/high reward), for example because they offer an economic opportunity to secure a leading international position. But non-technological innovations can also have an impact as system breakthroughs. In this report, we interpret breakthroughs as radically²⁶ different technologies or processes in industry; different modes of transport; and entirely new ways of organising the energy supply. Examples include technologies needed for green chemistry, electrical cracking of petrochemicals, sustainable fuels and CO₂ removal.²⁷ Examples of non-technological breakthroughs include a new structuring of the energy market, or new operating

21. IEA (2025a), *The State of Energy Innovation*. Paris: IEA.

22. Kooiman A., & van Tuyl, M. (2025), *Technologieradar: Welke disruptieve technologieën gaan impact hebben op ons energiesysteem?*, TNO2025 R10049, The Hague: TNO Public.

23. IEA (2025a), *The State of Energy Innovation*. Paris: IEA

24. Compare Datta, A. & S. Srivastava (2023), '(Re)conceptualizing technological breakthrough innovation: A systematic review of the literature and proposed framework', *Technological Forecasting & Social Change* **194** (2023) 122740.

25. AWTI (2020). *A better start - The key to growth of knowledge-intensive start-ups*. The Hague.

26. In this report we prefer the term 'breakthrough innovations' to 'radical' innovations: first because the notion of 'system breakthrough' is a crucial element in our analysis and argument; and secondly because it aligns with the terminology used in the request for advice from the government and parliament.

27. These are the examples given by the Dutch MP Henri Bontenbal in the parliamentary debate which ultimately led to the request for advice to AWTI and to the compilation of this report.

mechanisms such as distributed and local energy networks. The text box presents three examples of breakthroughs.

Ultra-tall wind turbines

The German Beventum project involves the development of wind turbines operating at a height of more than 350 metres. The project is supported by the German SPRIND agency (see textbox on p. 34). Wind speeds are greater and more constant at this height than on the ground, enabling these turbines to operate more efficiently and reducing the price per kWh generated. The breakthrough aspect of the programme is that Beventum is the first in the world to actually build and test a wind turbine at a height of 350 metres. Generating wind power at this height enables the wind potential to be increased substantially without the need for extra space or environmental impact. This technology offers particular promise for transforming the former mining regions in Germany, and will contribute to the regional production of green electricity and hydrogen. The programme has been designed so that smaller, regional companies can also participate in the accelerated rollout of this innovative technology.

More sustainable goods transport

The US project 'Transformative Rail Architecture to Decarbonize Freight' involves the development of a new system of autonomous, electric rail vehicles which can be used by existing railroad companies. The project is supported by the US ARPA-E agency (see text box on p. 35). The aim is to develop a technology that facilitates decentralised freight transport by rail. The breakthrough aspect of this programme is the use of autonomous battery-powered vehicles which can be used on existing rails without requiring large-scale infrastructural adaptations. This opens the way to making rail freight transport more sustainable quickly and cost-effectively. The project uses simulations to model technology implementation scenarios in the period up to 2050. This approach supports decision-making by stakeholders and so helps transform rail transport into a sustainable and emission-free logistical system. This breakthrough is expected to lead to savings of 33 billion US dollars in diesel import costs per year. That in turn should lead to a reduction of 4.5% in all US greenhouse gas emissions.

Carbon-negative homes

Another ARPA-E project involves the development of a modular construction system to build houses which are carbon-negative from start to finish. As well as using construction materials designed to limit carbon emissions, part of this breakthrough innovation also involves a new design process to make the houses easy to dismantle and recycle, with minimal waste production. The proposed design reduces greenhouse gas emissions compared with the first design. During the second build,

71% of carbon emissions are avoided, and if the house is rebuilt a third time, the reduction is 52%. The houses are designed to run entirely on electricity and consist of separate components that can be easily modified, enabling the building to change along with changing needs without a big increase in costs. The aim is that key components of the houses should have a service life that is up to three times longer than the usual 50 years for a conventional house.

1.4 Request for advice and scope

A successful energy transition will need to be accompanied by a transformation of the Dutch economy and society. It is therefore important to have a clear picture of the envisaged economy and society in 2050 and how the energy supply needs to be adapted for this. Relevant questions for this advisory report include: What innovations are needed for this? What policy is needed to support those innovations? What should the Netherlands focus on as a priority and what is needed to get the innovations off the ground that are necessary for an effective transition to a greenhouse gas-free energy system? Are new policy instruments needed for this? The national and international developments outlined earlier illustrate the relevance of a renewed perspective on energy innovation policy in the Netherlands.

Parliament and the government also felt that Dutch energy innovation policy should be re-examined. Rob Jetten, the Minister of Climate Policy and Energy in the previous government, explicitly requested the advice of AWTI in response to a request from the House of Representatives. In the parliamentary debate on system transition and climate policy after 2030 ('Systeemtransitie en klimaatbeleid na 2030') held on 20 April 2023, the MP Henri Bontenbal asked the minister whether 'The Netherlands is doing enough in terms of research and innovation relating to breakthrough technologies that the Netherlands will need for a green chemical industry, electrical cracking and carbon dioxide removal,' and whether the minister would be willing to request AWTI to publish an advisory report on this. In the subsequent letter presenting the National Energy System Plan (NPE), the minister promised to submit a request for advice to AWTI, and in the final version of the NPE he wrote: '[...] AWTI has been asked to publish its advice on the energy transition as regards investment, priorities and scope.'²⁸

28. Ministerie van Economische Zaken en Klimaat (2023), *Nationaal plan energiesysteem*, The Hague: EZK, p. 29.

Discussions between AWTI and the Ministry of Economic Affairs and Climate Policy resulted in the following overarching request for advice:

How can Dutch innovation policy contribute to the transformation of the energy system that is needed to achieve the government's energy and climate goals?

Among other things, the government's energy and climate goals incorporate the objectives for 2030 regarding greenhouse gas emissions (a reduction of 55% compared with 1990). The Netherlands must also be climate-neutral by 2050: if the country is still emitting greenhouse gases in 2050, those emissions must be fully offset by carbon removal, reducing the net emissions to zero.

Three focus areas

Based on this broadly formulated request for advice, the Ministry of Economic Affairs and Climate Policy²⁹ identified three specific focus areas on which it wished to receive advice:

- a) **Priorities:** *How should the Ministry set priorities and what is needed in the energy innovation policy to achieve the goals and innovation tasks set out in the NPE?*
- b) **Breakthroughs:** *How can the Ministry best facilitate breakthroughs and allocate them proportional attention and resources, given their role in the transformation?*
- c) **Measurability:** *How can the impact of the energy innovation policy on achieving the transformation of the energy system be made more transparent and measurable, and what is needed for this?*

The Council initially took a broader view of the energy innovation policy than these focus areas alone, though did explicitly incorporate them in its analysis (Chapter 2) and recommendations (Chapter 3). A brief summary is given at the start of Chapters 2 and 3 of the sections focusing specifically on the above topics.

Scope of request for advice

The request for advice speaks in very general terms about 'Dutch innovation policy' and its contribution to achieving the energy and climate goals. In responding to the request for advice, AWTI focuses on Dutch *energy innovation policy*, in other words that part of Dutch innovation policy which is concerned specifically with *energy* innovation. That is also the primary focus of the request for advice.

29. At the time that the request for advice was being crystallised, there was still a single Dutch Ministry of Economic Affairs and Climate Policy. In the present context, references to this Ministry should be interpreted as designating the Ministry of Climate Policy and Green Growth and the Ministry of Economic Affairs.

At the same time, AWTI remains cognizant of the interaction with relevant and related policy domains and of international developments. The government uses all kinds of policy to influence the development of the energy system and the path to climate-neutrality, including the innovations needed to achieve that. This is illustrated in Figure 3, which portrays not just the policy focusing specifically on energy innovation, but also instruments from general policy intended to promote research and innovation, from energy and climate policy, and from EU policy which influences energy innovation.

The programmes shown in the orange-brown blocks in the centre of Figure 3 (Top Sector programmes, Demonstration of Energy and Climate Innovation (DEI+) modules and the National Climate Investment Programme for Industry (NIKI) all fall under the energy innovation policy³⁰ and are predominantly focused on technological innovation.

General research and innovation policy also impacts on innovation in the energy sector; This is represented by the purple and yellow blocks in Figure 3. These programmes range from research funding programmes (including via the Dutch Research Council (NWO)) through tax breaks which encourage businesses to engage in research, development and innovation (R&D Tax Credit Scheme (WBSO))³¹ to investments to encourage innovation (Regional Development Agencies (ROMs) and InvestNL). In previous years, the National Growth Fund has also been used as a source of funding for large-scale, multi-year research and innovation programmes, including in the field of energy, such as the GroenvermogenNL project focusing on green hydrogen and chemistry.

General *energy* policy and *climate* policy (which together focus on reducing carbon emissions, promoting renewable energy and energy conservation) also have an influence on energy innovation. Several programmes falling under energy policy are shown in the green blocks in Figure 3, including the SDE++ subsidy programme for producing renewable energy and the Accelerated Climate Investment in Industry (VEKI) subsidy programmes.³² These are operating subsidies for renewable energy and CO₂ reduction. They can encourage innovations by supporting the operational costs of renewable energy and new carbon-reduction techniques, even if they are not yet fully competitive. Only the most competitive techniques are eligible for subsidy, so the programme provides an incentive to keep raising efficiency and reducing costs when developing new techniques.

30. These are: TSE ('Top Sector Energy'); EKOI (Energy & Climate Research and Development); MOOI (Mission-driven Research, Development and Innovation); PPS-I (PPS Innovation); DEI+ (Demonstration of Energy and Climate Innovation); NIKI (National Climate Investment Programme for Industry); previously there was the HER+ (Renewable Energy Transition), but this has now been incorporated within DEI+ and MOOI.

31. WBSO: Research and development (Promotion) Act.

32. SDE++: Subsidy programme for Renewable Energy Production and Climate Transition; VEKI: Accelerated Climate Investment in Industry.

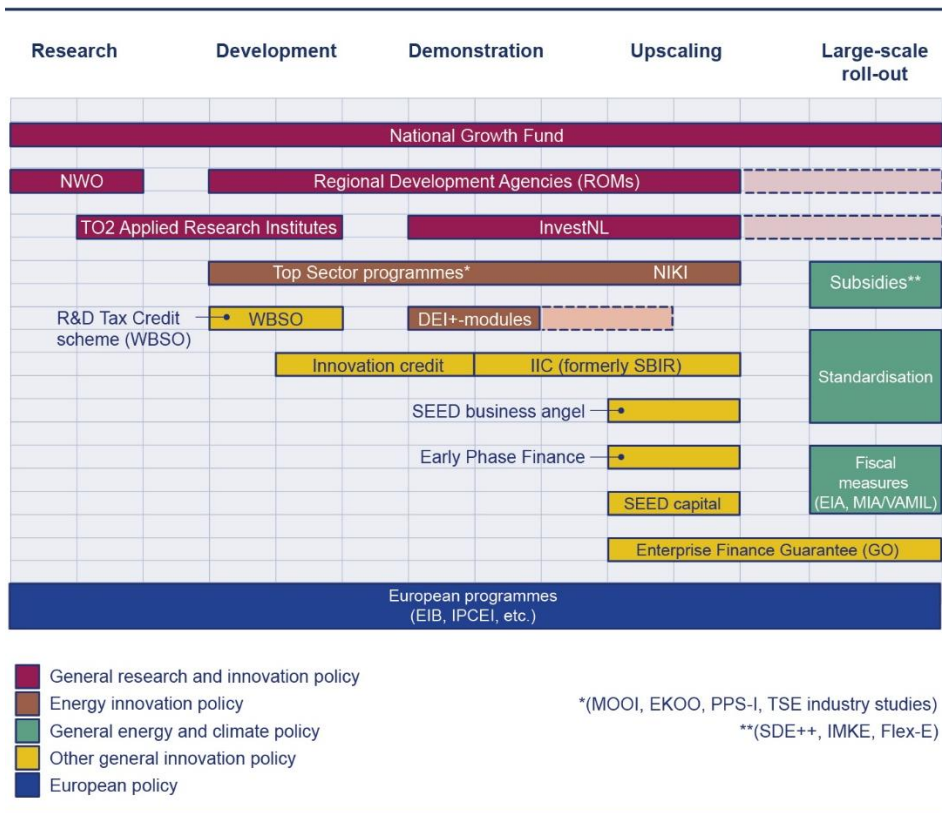


Figure 3. Different types of policy and their impact on energy innovation

The EU is playing an increasingly prominent role, with initiatives such as the Clean Industrial Deal (formerly the Green Deal) and other legislation. These initiatives impact the entire innovation chain (see bar at the bottom of Figure 3). EU policy influences energy research and innovation in all kinds of ways. There is for example EU legislation in place which will continue to have an impact in the future. This is not just legislation relating to the organisation of the energy markets, but also legislation directly impacting on the environment and climate, such as rules on renewable energy or the EU Emissions Trading System, the revenue from which is used partly to fund innovation and sustainability projects. The EU also has other funding instruments with a direct or indirect impact on energy innovation. Finally, there are policy instruments from (general) EU policy on research and innovation. Some of the support provided under these policies benefits energy research and innovation.

AWTI advisory report from 2016: 'Grasp the challenge'

This is not the first time AWTI has considered innovation policy for the energy transition. In 2016 the Council published the advisory report 'Grasp the challenge' ('Oppakken en doorpakken') at the request of the government. That report formed a sort of diptych with the advisory report on a carbon-free future ('Rijk zonder CO₂') published by the Council for the Environment and Infrastructure (Rli),³³ in which the Rli observed that with a serious investment of resources it would be possible for the Netherlands to be carbon-free by 2050, but that this would be an enormous challenge that would need to be supported by multi-year innovation programmes. Innovation would be indispensable for achieving this goal by 2050. At the time, AWTI advised on how the energy innovation policy would need to be structured (see Appendix 1 for a summary of that report).

In its 2016 advisory report, AWTI put forward recommendations for a more targeted use of both innovation policy and energy policy to promote the energy innovation that was so vitally needed. AWTI called for the development of the vision for the energy supply of the future, and that this should be followed by ensuring that public investments in the energy innovation policy should be focused primarily on *radical* innovations. In addition, AWTI suggested that more incremental innovations could be encouraged, via European regulations, Dutch energy policy and (Dutch) general innovation policy. To keep pace with other comparable countries, the report recommended a total annual budget of 400-450 million euros for energy innovation (in 2016, the budget was approximately 250 million euros).

All kinds of things have happened since the publication of that advisory report. Energy policy and innovation policy have been updated, partly along the lines recommended by AWTI. For example, the National Energy System Plan (NPE) sets out a vision for the energy system of the future. Energy innovation is currently also organised on a mission-driven basis, as advocated by AWTI, though does not go so far as to focus those missions on *radical* innovations. And while the budget for energy innovation initially increased after 2016, it now appears to be falling again.³⁴

33. Rli (2015), *Rijk zonder CO₂: Naar een duurzame energievoorziening in 2050*. The Hague: Raad voor de leefomgeving en infrastructuur.

34. RVO (2024), *Monitor publiek gefinancierd energieonderzoek 2023*, p. 5.

1.5 Creation of this report

This report was compiled in a number of stages. AWTI performed a policy analysis, studied a number of energy innovation cases in the energy domain and held talks with numerous energy experts. Appendix 5 contains a full list of all interviewees. Our policy analysis focused on national and European innovation policy.

The energy innovation case studies can be divided into two categories.

First, three energy innovation processes were studied to gain a better understanding of the chief obstacles and the most difficult steps in enabling an innovation to succeed. These case studies illustrate which conditions and parameters have to be met for the successful facilitation of such an innovation. The innovation case studies focused on offshore wind power generation, steam production using electricity, and salt batteries. They are each discussed in Appendix 4.

Second, a broader case study was carried out on the transformation of the energy system based on the large-scale use of hydrogen. This case study focused on both the facilitating and inhibiting aspects of this transformation. The lessons from this case study were incorporated in this advisory report.

In the final phase of creating this advisory report, a draft version was submitted to an external reviewer to reflect on the consistency of the draft and identify any gaps. The reviewer's comments were then incorporated in the report under the responsibility of the Council. The reviewer for this advisory report was:

- ▶ Dr. B.M. (Martien) Visser, emeritus lector in Energy & Networks, Hanze University of Applied Sciences Groningen and Senior Fellow of the Centre for International Energy Policy (CIEP)

Project group

This report was prepared by a project group consisting of Council members Ellen Moors (chair), Chokri Mousaoui, Marleen Stikker and Peter Werkhoven, and staff members Hamilcar Knops (secretary), Bart Gulden and Isabel Pieterse.

Analysis: Present energy innovation policy is sub-optimal

Based on its analysis, AWTI concludes that the Dutch innovation policy for energy is not yet ideally configured for the transformation to sustainability by 2050. The analysis revealed shortfalls in the conceptualisation of the energy innovation policy and that the current policy is insufficiently focused on breakthrough innovations. The policy is also not as cohesive as it might be. Finally, policy evaluations are often too limited, failing to take account of the broader context of related policy and the system as a whole.

This chapter describes the analysis carried out by the Council. It incorporates the three focus areas highlighted by the government (priorities, breakthroughs, measurability).

Setting the right priorities in the energy innovation policy is still proving to be difficult. That is because the underlying vision takes too little account of the economic and social transformation needed to achieve sustainability in 2050, because no clear choices are being made and because the importance of strategic autonomy currently receives too little attention (see sections 2.1 and 2.2).

Additionally, breakthroughs and the breakthrough innovations needed to achieve them receive too little attention in the present policy. Too little of the available funding is directed towards breakthrough innovations, and existing shortcomings in the policy mix tend to play to the disadvantage of breakthrough innovations (see sections 2.2 and 2.3).

When it comes to 'measurability', it is inherently difficult to measure the impact of the innovation policy now, if its success only becomes apparent in the longer term. Policy evaluations that are too narrow in scope will never be able to reveal the impact on the ultimate success of the innovation or the system transformation (see section 2.4).

2.1 Shortfalls in conceptualisation of innovation policy

There is a vision for the energy system ...

The National Energy System Plan (NPE), published in December 2023, sets out the government vision for the future of the Dutch energy system.³⁵ The NPE also focuses on the different transition pathways needed to achieve that future. AWTI endorses the importance of such a vision in creating clarity and engendering support for the transition among relevant actors. It is crucial to constantly monitor the cohesiveness of the system,

35. Rijksoverheid (2023), *Nationaal Plan Energiesysteem definitief vastgesteld*. The Hague.

or as the Netherlands Environmental Assessment Agency (PBL) rightly put it: ‘it is very important to maintain a comprehensive view’.³⁶ The NPE therefore marks a major step forward. The absence of such a vision in the past prompted AWTI to advise the government to base its energy innovation policy on a clear vision for the future energy system.³⁷

... but it is insufficiently connected to a vision for the transformation of the economy and society and the associated energy system in 2050

Yet the NPE is still heavily focused on making the *existing* economy and society more sustainable. It primarily set out a vision (‘plan’) for the energy system of the future, based on the economy and society of today: it focuses on making ‘present-day’ processes greener. The NPE largely takes as its starting point the existing sectors, seeking to make them more sustainable through new forms of energy or energy conservation. The NPE appears not to consider which sectors we might want to keep and which could be discarded, or what form they should take or how big they should be. This is illustrated in the centre image in Figure 4: the ‘sustainable’ vision set out in the NPE focuses primarily on the energy system, but rather less on the necessary transformation of the economy and society.

However, creating a sustainable energy supply for the *existing economy and society* is a very major challenge for the Netherlands (see section 1.2). It therefore makes more sense to develop a comprehensive vision for the sustainable economy and society of the future and the energy supply that will require³⁸ (right-hand illustration in Figure 4). Such a comprehensive vision allows scope for the radical reconfiguration of the Dutch economy or society, potential resulting from the breakthrough innovations which are needed to make a decisive leap forward in the energy transition.

36. PBL (2024b), ‘Ook controversiële opties nodig voor klimaatneutraal Nederland in 2050’. News bulletin on the PBL website, 24 April 2024.

37. As advised by AWTI in its advisory report ‘Grasp the challenge’ (‘Oppakken en doorpakken’) from 2016.

38. In the run-up to the formulation of the NPE, the Expert Team for the Energy System in 2050 did work up various scenarios for the future of the Dutch economy and society; see Expertteam Energiesysteem 2050 (2023), *Energie door perspectief: rechtvaardig, robuust en duurzaam naar 2050*, The Hague: RVO. The intention is that the NPE should be revised every four years. However, that does not nullify our point that in order to make the right choices about which innovations should be promoted, it is better to start from a vision of the target system rather than starting from the perspective of the existing system.

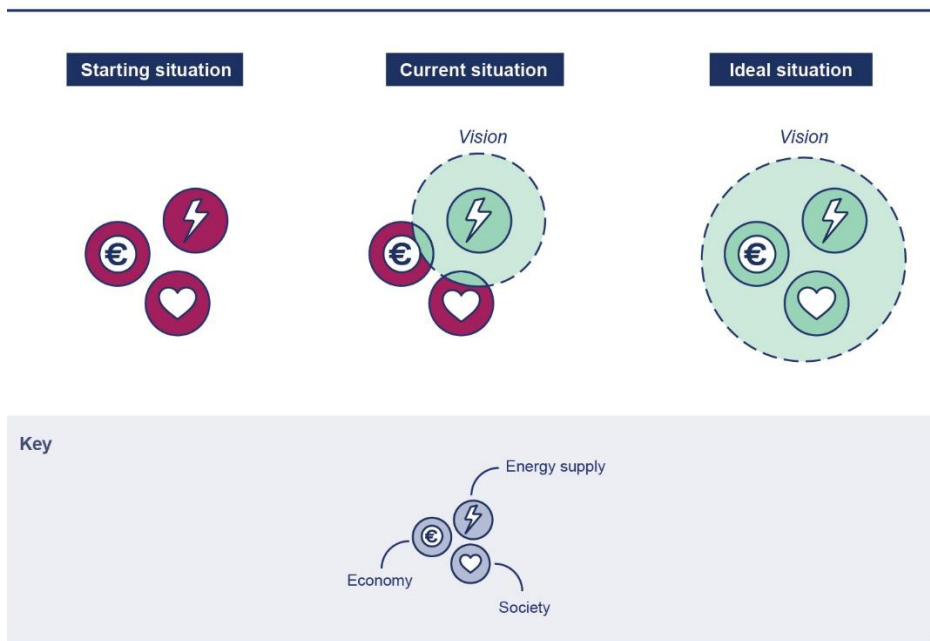


Figure 4. From a vision for the energy supply alone to a broad vision for a sustainable economy, society and energy supply in 2050

The urgency of developing a vision for the future which incorporates the economy, society and energy supply is underlined by today's realities. Because the plans to make the present energy supply greener (based on the present economy and society) are already running into delays or even grinding to a halt, partly because of the high costs. We are seeing a trend where several companies are unwinding their plans for greater sustainability.³⁹ These are not only fossil fuel companies operating in the oil and gas industry; 'green' companies are also running into difficulties. Companies such as Eneco no longer participate in tenders for offshore wind power because they do not believe it is financially viable. Other companies, such as Northvolt (batteries) and Emergya (turbines) have gone bankrupt. A lack of policy continuity into the long term exacerbates the situation. If there were a clear, fully supported vision for the future economy, society and energy system, it would be simpler to pursue consistent policy and easier for citizens to take decisions.

It is not just AWTI that is calling for a vision for the future in which the economy, society and innovation are seen as an interrelated whole. The Dutch Council of State, for example, pointed out in its Advice on the Draft Climate Plan 2025-2035 that all the

39. C. Hensen & P. Luttikhuis (2025), 'Hoe gaat het met de energietransitie? Elke partij wacht tot de ander iets doet', in *NRC* 27 March 2025.

geopolitical, demographic and economic developments, as well as the limited physical space in the Netherlands, meant it could not be assumed that the country could simply continue along the well-beaten path. We will have to reflect on how we wish to configure our future economy and society. However, the Council of State concluded that such a vision (a 'coherent picture of what is needed for a successful transformation to an innovative and sustainable economy') received insufficient attention in the Draft Climate Plan, and that part of that vision should involve discouraging or discontinuing certain activities. The government has a key role to play here.⁴⁰ The Netherlands Scientific Climate Council (WKR) Also recently called for the development of a climate vision that focuses on the long term (more than 25 years into the future), is cohesive (incorporating a vision for the economy and society and integrating policy domains) and which appeals to the public.⁴¹

A cohesive vision for how the transformation to a sustainable 2050 can be achieved forms a necessary basis for policy, including the energy innovation policy. That vision should take account of the role played in it by innovation and the government, what that means for society and the structure of the economy, and the importance of strategic autonomy. It is not possible to do everything, and clear choices have to be made. The government has an important leadership role to play in the energy transition.⁴² Energy innovations often take a long time to come to fruition, and it is therefore essential to respond to new developments early. In the early 1990s, for example, Denmark played a pioneering role with a number of offshore wind projects, but it was not until 20 years later that this really got off the ground. By making choices based on a vision, the government gives direction to stakeholders in the economy and society in how to channel their efforts.⁴³ The public and business community need such a directional perspective in climate and other policy, a view substantiated by research carried out by the Netherlands Institute for Social Research (SCP).⁴⁴

A vision such as this means looking at the longer term (2050). It is possible that real-life developments in the years ahead will necessitate adaptation of the long-term vision, for example because certain developments occur very fast and have a positive outcome, or conversely because others fail to meet their potential. Unexpected external developments

40. Raad van State (2025), *Advies W19.24.00360/IV over het Ontwerp-Klimaatplan 2025-2035*, 19 February 2025.

41. Wetenschappelijke Klimaatraad (2025), *Vaart maken met visie. Met toekomstvisie richting geven aan klimaatbeleid*, WKR-rapport 005, The Hague: WKR.

42. B. ter Haar (2025), 'Zo simpel mogelijke energietransitie vergt stevige (waterstof)keuzes', ESB-blog.

43. See also: AWTI (2016), *Grasp the challenge. Daring to go for energy innovation (Oppakken en doorpakken. Durven kiezen voor energie-innovatie)*, The Hague: AWTI.

44. Y. de Kluizenaar, G. ten Berge & J. Iedema (2025), *Klimaat en Samenleving. Burgerperspectieven*, The Hague: SCP.

can also be disruptive. It is therefore essential to ensure that a broad vision can be adapted periodically.

Lack of a broad vision is a problem for energy innovation policy

The vision for the energy system of the future takes too little account of what a climate-neutral economy and society in 2050 should look like. That is problematic for the (energy) innovation policy.

First, a vision for what kind of economy and society the Netherlands will have in 2050 heavily influences the choice of which players and which innovation programmes we deploy now. An example is the case study on the use of hydrogen: will this be used in the future in oil refining, to produce 'cleaner' steel or as a fuel for transport? A preference for one of these possible applications might for example translate into a choice as to which parties should be involved now. In practice, this realisation does not yet appear to have fully penetrated; the current policy is heavily focused on generating a supply of hydrogen. At present, it makes no difference if a participant may be involved in a route which ultimately turns out not to be the preferred option.

Second, taking the present economy and society as a basis creates a *bias* in favour of established parties and systems, with little or no scope for radically new ideas, concepts or different economic structures. There is a danger that potential game-changers will be missed, whereas they could potentially take us onto an entirely different path, perhaps making it easier to achieve the climate goals, for example. They can moreover reinforce the Netherlands' strategic autonomy in relation to energy, and could in practice also prove to be a new source of (economic) competitive advantage. On the other hand, existing parties do harbour a great deal of knowledge that can be used for the benefit of the transition. A successful transition therefore makes maximum use of knowledge held by existing players, whilst also offering space for new players.⁴⁵

Third, a vision for the future energy system which is heavily based on how things are organised *now* generally makes new, different forms of organisation harder to accommodate: the various (bottom-up) civic initiatives are an example of this. This bias against forms of organisation that differ from the norm is problematic. By contrast, a vision which also allows for a transformation of the economy and society can more easily accommodate such different organisational forms.

45. See also AWTI (2023), *Shaping the future – From optimisation to transformation*. The Hague: AWTI.

Lesson from the hydrogen case: what is the ultimate vision?

The innovation case study on the large-scale use of (green) hydrogen focuses on three different uses for hydrogen. Each route has its own innovation challenges, but the most striking thing is that each route has its own 'outcome'; each has a different ultimate impact on the energy system and the economic structure. This can be briefly summarised as follows:

- While using 'green' hydrogen in refineries is reasonably easy to do (replacing existing hydrogen with green hydrogen), it does imply that the refining of fossil fuels continues, where the aim is to phase this out.
- Using 'green' hydrogen in steel manufacture reduces the use of carbon (and therefore emissions of CO₂) to some extent during the production process, and requires a focus on innovation in the steel manufacturing process.
- 'Green' hydrogen can be used in transport in various ways. Each option requires its own combination of innovations and investments in support infrastructure. Moreover, to some extent each option involves different parties.

Theoretically, it would be possible to achieve the large-scale use of hydrogen simultaneously in all three cases. In practice, however, it would be difficult to generate the necessary quantities of hydrogen in the Netherlands, or to import it at acceptable costs. It therefore makes more sense to choose one option for which use of hydrogen should be made a priority.

Seen from this perspective, it is important to make clear decisions in advance as to where we wish to go with a particular option, such as hydrogen. The choice made will then help determine which innovation challenges are selected for further development, which stakeholders are involved and what supporting policy is needed.

Insufficient attention for strategic autonomy

Appendix 2 presents a description of 'strategic autonomy' in relation to the energy supply and what this means for the energy innovation policy. In essence, strategic autonomy is concerned with the question of who/which parties we are willing (or unwilling) to be dependent on. There is both a geographical dimension to this (which countries or regions are we willing or unwilling to be dependent on?), and an economic dimension (will we become dependent on one or more companies, and what economic power do they have?). The answer to these questions determines the extent to which we as a country, our citizens, society, businesses or civil-society organisations retain a degree of freedom in relation to energy, or whether that freedom is heavily restricted in practice.

To manage these dependencies and reduce our own vulnerability, the Council sees four strategies (see Appendix 2 for a more detailed discussion):

- ▶ Genuine autonomy of a region (our country, the EU). This guarantees independence from other countries or regions because the 'home' region can fulfil the whole chain from raw materials to end product.
- ▶ Dispersed dependencies with several options, leading to reduced vulnerability (for energy, for example: several energy resources or sources from which particular fuels, raw materials or products are obtained).
- ▶ Developing 'dominance' in one or more crucial links in a chain (around a product or technology); this dominance can be used as other a trade-off/leverage vis-à-vis countries/parties on whom there is a dependency in other links in the chain.
- ▶ Building up a leading position in the chains of the future. This involves shifting the focus to the new chains that will determine the future. This is potentially a way to mitigate dependence in the chains. It is an interesting strategy for limiting dependence in the future, especially for countries/regions which are so far behind in certain existing chains that they are likely to be permanently dependent on others.

Strategic autonomy is receiving a lot of attention, especially when it comes to the availability of raw materials. The Council notes that this strategic autonomy is still insufficiently reflected in the policy around energy innovation. It could be fairly simple to include it in (subsidy) programmes for research, as a 'bonus'. A 'premium' could then be paid in the scaling-up phase, or in the market, for contributing to strategic autonomy. However, the Council sees no evidence of this in practice, with the case of salt batteries being a good example (see Appendix 4). Given the growing importance of strategic autonomy, this should be incorporated more emphatically in the energy innovation policy.

There is a clear link between strategic autonomy in raw materials and energy. Suppose the EU barely produced steel or aluminium anymore; this would lead to a much lower need for (fossil) energy and therefore to less dependence on the countries which supply that energy. At the same time, however, a dependence would arise because of the need to buy in steel and aluminium. Judgments in relation to dependence should ideally take such shifts into account. Preference should be given to those areas of dependence which can be most easily mitigated.

Strategic autonomy will therefore have to be part of a broad vision for a (sustainable) economy, society and energy supply in 2050. Since geopolitical developments are uncertain and difficult to predict on such a time scale, it is crucial to make an assessment now of the areas where we wish to be autonomous ('critical' parts of the energy supply, infrastructure or economy); where autonomy is desirable but not essential; and where autonomy is less vital. During this process, it is helpful to map the vulnerabilities for all layers of the energy system based on historical sensitivities, scenario analysis and stress

tests. This layered structure will then work through into the broad vision and the subsequent policy choices. The identified vulnerabilities can then be minimised in the broad vision through the strategy referred to earlier, embracing options such as autonomy, diversification, strategic inventories, reuse, interoperability and adaptability.

2.2 Insufficient focus on innovations needed for breakthroughs

Clearer choices need to be made

Partly under the influence of the 2016 AWTI advisory report, an Integrated Knowledge and Innovation Agenda (IKIA) for energy and climate was developed in 2019,⁴⁶ and updated in November 2023.⁴⁷ This first IKIA was developed ‘bottom-up’ based on the various existing ‘tables’ and consultative structures, in which the sector (businesses and knowledge institutes) and government came together. This process generally does not lead to clear choices (to do just a few things), and that was also the case here. The IKIA initially contained no fewer than 13 multi-year mission-driven innovation programmes (MMIPs); that number has since grown to 16 MMIPs.

The Council believes that Dutch energy innovation policy could have more impact in the long term by focusing on a limited number of innovation projects which are a good fit for the Netherlands and which play to the unique opportunities for the Netherlands. If the Netherlands concentrates on a small number of innovation projects where we can genuinely make a difference, including internationally, *with a view to the transformation in the long term*, this would contribute both to the envisaged energy transition and to the economy. The plain fact is that the Netherlands represents only a small proportion of the global research and innovation capacity (in the order of 1 percent); the vast majority of all required energy innovations will thus *not* come from the Netherlands.

Currently too little attention for breakthroughs in energy innovation policy

Rigorous choices to develop only between four and six energy innovation programmes have thus not been made. Nor has the energy innovation portfolio focused on ‘radical’ innovations which lead or will lead to breakthroughs in the energy system, despite AWTI recommending this in 2016. Although some attention is given to breakthrough innovations in the energy innovation portfolio, it certainly does not dominate.

46. For the first IKIA (2019-2023) see the website: <https://www.klimaataakkoord.nl/themas/kennis--en-innovatieagenda>.

47. For the new IKIA (2024-2027): <https://www.topsectoren.nl/publicaties/publicaties/publicaties-2023/november/02/ikia-klimaat-energie-2024-2027>.

There are several reasons for this. First and foremost, It is a result of the goals set in the energy innovation policy in recent years, in which the focus was more on the short term. Energy innovation had to contribute to a reduction of carbon emissions by 2030 or to a lowering of costs of the SDE+ subsidies. Both are short-term effects, which can be achieved primarily through incremental innovations. In addition, the desire to increase earning capacity exerted a heavy influence, automatically leading to a greater focus on options which would produce quick wins. The fact that the research and innovation programming was also determined principally by the ‘incumbent’ parties meant that incremental innovations were a more logical choice than developing radical new options. And even when existing parties do consider radical new solutions, regulation often stands in the way: it is not part of their position or responsibility (this is the case with network operators, for example), or the solution itself does not fit in with the existing system.



Figure 5. The Netherlands has no high risk/high reward instrument

Lack of a high risk/high reward instrument

Dutch energy innovation policy also contains no instrument for stimulating new ideas which, though high-risk, have a potentially high impact (Figure 5). Some other countries have put in place such a high risk/high reward instrument. An example within the EU is the SPRIND programme in Germany. This programme focuses on a number of themes besides energy, and puts social value at centre stage alongside economic value. An older example is ARPA-E in the United States. This is an agency which focuses exclusively on energy-related projects which carry a very high risk but which, *if they succeed*, will also

have a major impact. The underlying philosophy is that the impact of the small number of projects that succeed will be so great (in terms of jobs, a leap forward in knowledge, market opportunities) that the social and economic payback will more than offset the public investment. The United Kingdom has also recently set up a similar funding programme (ARIA – see textbox). AWTI has previously called for a similar funding programme for high risk/high reward projects to be set up in the Netherlands.⁴⁸ To date, that has not happened, although in its action plan to devote 3% of GDP to R&D, the Dutch government recently announced an 'exploratory study' to assess the added value of a National Agency for Disruptive Innovation (NADI), based on the international examples referred to.

Examples of agencies for high risk/high reward projects

SPRIND

The Federal Agency for Breakthrough Innovations SPRIN-D, or SPRIND, is a German R&D funding agency. It was founded in 2019 with the aim of identifying and financing disruptive innovations. During the startup phase, in 2019-2022, SPRIND had a budget of at least 151 million euros. SPRIND was initially planned to be an agency for an experimental phase of ten years, beginning in 2019. The total budget for the entire period of ten is expected to be around one billion euros.

SPRIND focuses on projects which create a completely new market, fundamentally change an existing market to create a new ecosystem, or resolve a major technological, social or environmental problem. All topics are relevant for SPRIND, as long as they are based on European values and are non-military (though dual use innovations are supported). In contrast to pure research funding, SPRIND aims to support the development of new marketable products, technologies, business models and/or services which bring a lasting improvement to people's lives. The focus is therefore on both economic and social added value.

A new law in Germany, the SPRIND-Freiheitsgesetz, allows SPRIND to use different types of funding, such as validation contracts, equity investments, mezzanine finance or subsidies. This enables SPRIND to operate in a targeted, precise, flexible and non-bureaucratic way.

48. AWTI (2016), *Grasp the challenge. Daring to go for energy innovation (Oppakken en doorpakken. Durven kiezen voor energie-innovatie)*, The Hague.

ARPA-E

The *Advanced Research Projects Agency – Energy* (ARPA-E) was set up by the US Department of Energy in 2009 with the aim of promoting scientific and technological innovations which will fundamentally transform the way in which we generate, store and use energy.

ARPA-E accordingly focuses on identifying and supporting high risk/high reward research. ARPA-E employs a variety of programme directors and managers, each responsible for specific technological fields such as energy storage, smart networks and sustainable production. The teams consist of experts who are able to assess and drive both the technical feasibility and the potential of new technologies. The budget in the 2023 tax year was 470 million US dollars. The agency supports projects to the tune of around 1 million dollars.

A key part of the ARPA-E organisation is the Technology to Market (T2M) team. This team helps with the commercialisation of technological innovations, from mapping market opportunities to upscaling.

An example is the SCALE-UP programme, Which helps promising energy technologies previously funded by ARPA-E to grow towards the scale required for commercial application.

ARIA

The Advanced Research Invention Agency (ARIA) Was set up in the United Kingdom to fund breakthroughs in research and innovation in neglected areas. Formed in 2023, ARIA is financed by the Ministry of Science, Innovation and Technology. It has a budget of 800 million pounds, spread over five years (2023 to 2028). ARIA focuses on high risk/high reward research, in fields such as bio-engineering, AI and climate science. ARIA operates as autonomously and flexibly as possible. The UK parliament has for example exempted ARIA from the public tendering rules by creating the Advanced Research and Invention Agency Act 2022. ARIA Is also exempt from Freedom of Information requests, with a view to reducing the administrative burden.

Limited attention for breakthroughs impedes achievement of the energy transition

The fact that breakthrough innovations receive too little attention in Dutch energy innovation policy is a problem for several reasons. A number of radical innovations will be needed for an effective transformation to a sustainable economy and society by 2050. Those radical innovations will in most cases not happen automatically; if there is anywhere that support from the government is needed, it is for these radical

breakthroughs. Ideally, the government should focus its support on those (crucial) developments which would not get off the ground *without* government backing. The energy innovation policy should therefore be additional to market efforts and investments. By making clear choices, setting explicit targets and giving direction and ensuring that the enabling conditions are met, the government will give businesses and citizens the space and encouragement to innovate and take steps towards the desired transformation. Radical breakthroughs moreover offer the Netherlands the possibility of assuming a new, strong position in the future. They will ensure that we occupy one or more key positions in new chains of strategic goods or services, and that is good for our strategic autonomy.

Governance and risk-averse culture standing in the way of promoting breakthroughs

We mentioned earlier that the 'bottom-up' process which led to the formation of the IKIA (Integrated Knowledge and Innovation Agenda) generally does not lead to a clear choice to focus on doing just a few things. A choice in favour of breakthrough innovations is therefore less likely to be made within that process. Moreover, responsibility, resources and implementation in relation to energy innovation are located in different places. On top of that, our interviews revealed that the division of roles (or responsibilities) within the Top research sectors is currently not entirely clear. Who makes which choices at the level of a Top Sector and at the level of the subordinated Top Consortia for Knowledge and Innovation (TKIs)?

The governance that has been applied in recent years is not sufficient to make clear choices to focus on a limited number of innovation projects and support breakthrough innovations. The development of the National Growth Fund is interesting in this regard. It has an Advisory Committee,⁴⁹ tasked with selecting a small number of proposals for which a multi-year innovation programme can subsequently be developed and implemented. This Committee succeeded in selecting a limited number of programmes. The structure of the Advisory Committee corresponds reasonably well with the Energy Innovation Task Force proposed by AWTI in 2016. It was envisaged that it would consist of a number of suitably authorised national and international experts, who would use an assessment framework to make clear choices and select a limited number of radical innovation programmes for eligibility for government support.⁵⁰

49. See: <https://www.nationaalgroeifonds.nl/over-de-commissie>

50. AWTI (2016), *Grasp the challenge. Daring to go for energy innovation (Oppakken en doorpakken. Durven kiezen voor energie-innovatie)*, The Hague.

In addition to the governance around setting the agenda, the risk-averse culture within government is also an obstacle. Since promoting innovation involves the use of public funds, there is a sense within government of needing to avoid 'failure', but also a fear of relinquishing 'control'. That creates a bias in favour of less risky projects and prevents a full-blooded focus on a small number of radical but also more uncertain innovation programmes. This is in stark contrast to the governance within the US ARPA-E,⁵¹ where a programme director has a great deal of freedom to take independent decisions as to which calls will be issued and which projects will (continue to) be funded.

Still too much focus on individual solutions rather than on the system

There is another reason for the difficulty in setting priorities. There is generally too much focus on individual solutions ('point solutions'), and too little on (their impact on) the energy system as a whole. To a degree that is understandable, because most stakeholders are active around those 'point solutions'. Moreover, the field is organised into sectors and subsectors or aligned with particular technologies. Yet it is problematic, because the interrelationships create a need for a comprehensive vision which is focused more on (effects at) system level.⁵²

This also applies for the 'goal' of the energy and climate policy, which is heavily focused on reducing emissions of CO₂ (and other greenhouse gases). But the reality is that all fossil-based carbon (C) extracted eventually ends up as CO₂. It might therefore be a more interesting (and more effective) option to (additionally) focus the policy on reducing the extraction of carbon (C). This underlines the importance of viewing innovation and the need for innovation more from the perspective of the system, for example by taking into account the entire 'carbon chain'.

One particular point made by the government in its request for advice to AWTI is how it can best facilitate 'breakthroughs', 'given their role in the transformation'.⁵³ The system perspective is essential here, because the success of a breakthrough innovation depends on a number of factors. And, given that it is a breakthrough, something new or different from what currently exists, there is a good chance that it will not fit easily into the existing system. Moreover, it is ultimately not a matter of a specific (isolated) innovations, but of taking a genuine step towards the transformation of the entire energy system.

51. The British ARIA and German SPRIN-D also aim for a similar governance ethos.

52. Cf. PBL (2024b), 'Ook controversiële opties nodig voor klimaatneutraal Nederland in 2050'.

53. See also (2023), *Shaping the future. From optimisation to transformation*, and AWTI (2025), The Hague.

Another advantage of the system perspective is that it challenges us to think about how best to organise a transformed system in a way that makes it a good fit with the 'new' system. For example, our electricity system has traditionally been organised in a top-down way, with a market based on energy (kWh). Perhaps a different form of governance (more locally based) will be more appropriate for a sustainable electricity supply in the future, and a market that is based on capacity (kW), or a different organisational form, such as self-organisation. These are changes that are not specifically related to a single innovation, but to the transformation of the energy system as a whole.

2.3 Need for more cohesive policy

Energy innovation policy still too focused on technology

Dutch energy innovation policy is still heavily focused on technology;⁵⁴ three of the four programmes which constituted the energy innovation policy in recent years were focused on technology: the DEI+, HER+ and TSE programmes.⁵⁵ The fourth programme (MOOI)⁵⁶ is mission-based and adopts a more comprehensive approach from the perspective of the relevant dimensions (technology, economy, social). AWTI believes that the latter is a good development.

The fact that the energy innovation policy is still focused primarily on innovation in the technological dimension is problematic. Other aspects, such as the role of institutions and behaviour, and enabling conditions such as infrastructure, are at least as relevant for the success of an innovation. This is also evident from the innovation case studies which the Council analysed in more detail in preparing this advisory report: offshore wind power, steam production using electricity, and salt batteries (see Appendix 4 for an overview). The case studies make clear that organisational form, market and regulation are crucial for the success of the relevant innovation processes. The salt batteries case study is discussed in the text box. Although these case studies are concerned with different processes of technological development, aspects such as the legal position regarding energy storage and the ultimate business case are vital factors in the success of this innovation process.

54. This is exacerbated by the fact that most of the attention has traditionally been focused on the production side of energy (sustainable or cleaner fuels) and less on the distribution or use of energy, an area where aspects such as behaviour, rules, etc. play a more prominent role.

55. DEI+: Demonstration of Energy and Climate Innovation [Demonstratie Energie- en Klimaatinnovatie]; TSE: Top Sector Energy; previously there was HER+ (Renewable Energy Transition ['Hernieuwbare Energietransitie']), but this has now been folded into DEI+ and MOOI.

56. MOOI: Mission-driven Research, Development and Innovation [Missiegedreven Onderzoek, Ontwikkeling en Innovatie].

Innovation case study: salt batteries

Non-technological aspects determine success

New ways of storing energy will be an essential part of the future (sustainable) energy system. One disadvantage of traditional batteries is the need for rare minerals in their production, which largely come from outside the EU. Using salt to store energy is therefore an interesting option, given the plentiful local supply of this mineral. Various energy storage technologies based on salt are currently being developed in the Netherlands (see Appendix 4 for two examples, and an article from the *Financieele Dagblad* newspaper from 2024 for further examples)⁵⁷. What these options have in common is that the technology is still being developed, while at the same work is ongoing to determine precisely what their business case will be and how they can be aligned with the regulatory and market systems. An example is the technology being developed by Aqua Battery, using membrane technology. Another initiative is a joint project by TNO (Netherlands Organisation for Applied Scientific Research) and TU/e (Eindhoven University of Technology) involving thermochemical storage, i.e. storage of heat, in a salt battery, something now being worked on by a spin-off (Cellcius). The essence of these projects is the interplay between technological progress and the development of potential applications and business cases, as well as clear parameters around regulation and licensing. It is also striking that there is currently no financial incentive ('premium') for contributing to strategic autonomy. Everyone sees the strategic benefits of salt batteries (the ingredients needed are obtainable locally), but no one is yet 'paying' for them.

Too little attention for the importance of non-technological aspects in innovation

The importance of non-technological aspects is also acknowledged in the literature on innovation and transformation processes. For example, the TransMission framework, developed by the TransMission Institute, identifies a number of key processes in relation to innovation, including key processes around the institutional dimension (such as 'market formation' and 'sector organisation and coordination') and the importance of enabling conditions such as 'infrastructure'.⁵⁸ These aspects (such as regulation, market

57. E. Selderbeek (2024). 'Elk type batterij telt in zoektocht naar langdurige energieopslag', in: *Financieele Dagblad* 24 June 2024.

58. L. Simons, A. Nijhof, & M. Janssen (2023), *TransMissie: De missiegedreven transitieaanpak voor het managen van complexe veranderprocessen*. Utrecht: TransMission Institute. N.B. among other things, relevant non-institutional key processes include knowledge development and resources (budget, infrastructure, etc.).

structuring and infrastructure) are often precisely those areas where the government either has a monopoly or plays a key role as director or source of finance.

These non-technological aspects are of particular importance for breakthroughs. Institutional changes or new infrastructure will also be needed for new, radically different options from the prevailing structures in the existing system. This may mean that we have to organise the energy system differently. The new Energy Act offers a good example; it still takes the old model of market liberalisation as a starting point, in which every player has a specific role and responsibility. This fosters fragmentation, with no focus on thinking and operating at system level. At the same time, individual actors only mobilise if it is in their own interests. The challenge is therefore to organise the field in such a way that benefits at system level also accrue to the relevant actors.

In practice, the different dimensions that are important in innovation processes are not coordinated closely enough. It may be that an energy innovation programme has supported one or more steps in the technological dimension, but that too little or nothing has been done in relation to the necessary rules, markets, infrastructure or required stakeholder networks. Figure 6 illustrates this.

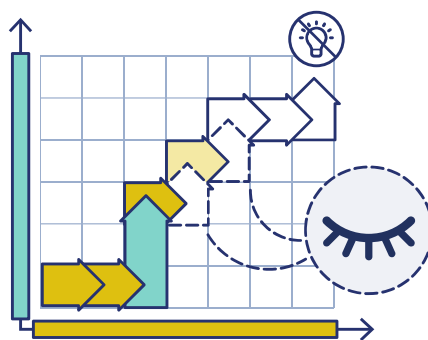


Figure 6. Insufficient recognition of non-technological aspects of innovation

It is therefore problematic for breakthroughs or radically new solutions if too little attention is given to these other dimensions. There is a danger that progress will be made on the technological front but that no transformation takes place because the necessary steps on the social or institutional front have not been taken. The innovation case study on 'Steam from electricity', for example, shows that technically, generating steam using

electricity (rather than gas, as is common at present) is perfectly possible, but almost never takes place in practice because the necessary *institutional* conditions have not been met, for example the right contracts which could also price in any 'services' provided to network operators. At present, therefore, there is no breakthrough based on the institutional dimension.

Innovation case study Steam from electricity:

Lack of success due to absence of institutional conditions

Steam is used in industry in large quantities in a variety of processes. At present, steam is generated using gas. If we stop using gas, generating steam from electricity will be the only clean alternative remaining (unless alternatives emerge to the use of steam). Technically, this is already perfectly possible (by using an e-boiler), But it is currently too expensive to generate steam. Realising this option in practice will therefore require essential steps to be taken both in the market and in the institutional organisation (see Appendix 4). In the market, a shift would be needed in the relationship between the prices of electricity and gas. At institutional level, the right contracts need to be created for users of steam. One possibility would be for such a contract to enable users of steam to provide services to (local) network operators. Another option would be for several users of steam within the same area to forge some kind of partnership to lower the costs of switching to steam from electricity. This is an example of an innovation case study where the required developments are not so much technical, but lie primarily in other dimensions (especially institutional).⁵⁹ A further pitfall is that focusing on the option which might appear the most valuable *now*, namely a hybrid steam plant fuelled by gas and electricity, means deferring the full phasing out of gas as a fuel for generating steam.

An interesting recent development in the Netherlands is the MOOI programme (Mission-driven Research, Development and Innovation [Missiegedreven Onderzoek, Ontwikkeling en Innovatie]). This entails an explicit call for multidisciplinary collaboration and involving the demand side/customer/user in submitted projects. It is an attempt to view all relevant innovation dimensions (technological, institutional and social) as an interconnected

59. At times when the electricity price is low, it is already feasible to generate steam using electricity; see: H.P.A. Knops, A.C. Patil & R.M. Stikkelman (2014), "Power-to-value": Converting Excess Wind Power into Valuable Products or Processes', *Proceedings of IAAE Conference*, IAAE: Rome. Knops *et al.* (2014) refer to the Port of Rotterdam as a cluster where there was a good chance of implementing this option. However, institutional obstacles mean this has not yet happened. The Maastricht-based paper manufacturer Sappi has however recently announced plans to produce steam from electricity and to provide services to the network operator (see B. van de Weijer (2024). 'Vol stroomnet? Een elektrische reuzenboiler kan wonderen verrichten', in: *de Volkskrant* 25 June 2024).

whole. It is helpful to evaluate how successful the MOOI programme is on this point, though it is difficult because some of the incentive programmes for research and or innovation are not open to all types of players.

Non-technological innovation crucial but receives too little attention

A second problem is that the institutional and social aspects are not yet fully recognised as an option for innovation or as part of *innovation* policy; see Figure 7. On the one hand there is sometimes a lack of awareness that adaptations to market structuring, for example, or regulations (should) also form part of policy designed to promote innovation(s). For example, all kinds of options are currently being explored for storing electricity, based on the idea that this is a crucial element in an electricity system dominated by ‘unpredictable’ sources such as solar and wind power. At the same time, the legal status of electricity storage has not yet fully crystallised, with the result that storage capacity currently lags behind (direct) electricity production. This makes the business case for storage less attractive and thus impedes the innovation processes. Creating a clear legal and economic perspective for storage should form part of a (comprehensive) policy to promote such innovations.

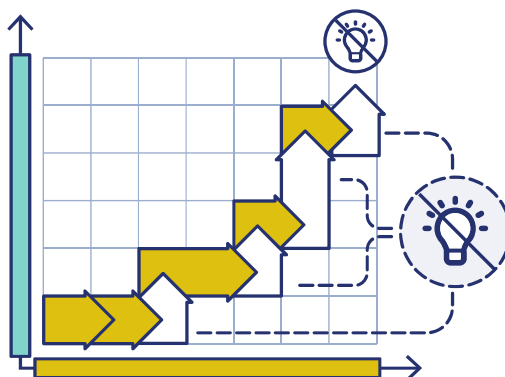


Figure 7. Non-technological aspects not sufficiently recognised as an independent source of innovation

This example illustrates that – aside from any specific technology – social and institutional innovations are also possible which can promote the transformation towards the envisaged energy system of the future. Finding a good solution to the legal and economic

status of 'storage', can help with the integration of all manner of storage options. A good example of how a legal development can lead to innovation is the introduction of the concept of the 'renewable energy community' in EU regulations, and the mandatory requirements for EU member states to "[create] an enabling framework to promote and facilitate the development of [such] renewable energy communities."⁶⁰ This provided a helping hand for these energy communities in the Netherlands, making this Brussels instrument a driver of institutional innovation. Another area where institutional innovation can drive many more innovations (including technological) is the development of a new market model which is better aligned with the energy sources where the capacity costs are highest (e.g. wind and solar power). Such a model could eliminate many of the present (economic) uncertainties around energy prices (kWh).⁶¹ An example is the MODES consortium (Market Organisation of the Dutch Energy System), an NWO research project looking at how the Dutch energy sector should be organised during and after the energy transition.⁶² Why should projects like this not be able to continue to develop within the innovation policy? This could create a sort of traction from the social and institutional dimensions which can exert a pull effect on technological innovations.

It is worth devoting structural attention to institutional innovations which are ongoing, possible or necessary within the broader arena of the transformation of the entire energy system. Relevant actors could in some cases become 'unusual suspects', for example parties that are currently not represented in the Top Sector Energy. That will require targeted attention: the energy innovation policy will also need to accommodate the innovation needs of these actors. The converse also applies, i.e. where institutional innovations require innovations in the technological domain. For example, if energy cooperatives wish to engage in a form of technical management, whether or not linked to agreements with network operators, this might require new equipment and/or protocols. In this example an institutional development (innovation) requires innovations on the technological front. The question is whether the policy mix is sufficiently geared up for this.

60. See Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (*PbEU* 2018, L 328/82).

61. The main fixed costs with wind turbines and solar panels relate to the installed capacity (kW). In the present electricity market, however, prices are all calculated based on the amount of energy generated (kWh). With an uncertain, and to a certain degree uncontrollable number of hours and therefore average capacity produced by wind turbines and solar panels, it is very difficult to 'translate' those kW costs into the kWh price needed to break even. This creates economic uncertainty for the operator of the wind turbine or solar panel, and that uncertainty will in turn have a 'price'.

62. See: NWO (2025), *Market Organisation of the Dutch Energy System (MODES)*. NWO. <https://www.nwo.nl/projecten/nwa164622003>.

Too little recognition of phasing out as a topic for innovation

At present, then, non-technological aspects are insufficiently regarded as topics for (institutional or social) innovation. The same applies for the 'phasing out' of undesirable practices. This is because the innovation policy is focused mainly on promoting new solutions, with less attention for how undesirable practices can be phased out.

An example of encouraging innovation through phasing out is 'horizon legislation', which makes it mandatory to phase out certain practices over time, such as the emission of certain substances. There may be many ways to meet those future rules. In principle, horizon legislation leaves stakeholders free to choose one or more methods and to innovate as necessary. Another example of stimulating innovation on the phasing out side is the 'Gas-free neighbourhoods' programme, in which all kinds of ways are being investigated and trialled to see how neighbourhoods can end their dependency on gas and what impact that has.⁶³

Policy is too fragmented: policy instruments not well aligned with each other

Another shortcoming of the energy innovation policy is its fragmentation, with different rules governing different steps in the innovation process (see Figure 3 in section 1.4). The connectedness between those rules is not optimal; when one step has been successfully completed, with support from a particular funding scheme, a new procedure governed by a new funding programme has to be gone through for the next step, in which applicants have to compete other candidates once again. Moreover, each funding scheme often applies different criteria, and often has a different assessment committee. We heard this complaint about poor coordination between 'successive' policy instruments in many of our interviews with stakeholders. Another complaint here is that many policy instruments require participants to compete with each other for financial resources, thereby discouraging collaboration at national level, even though in certain cases such collaboration could deliver a more effective end result. Figure 8 illustrates the problem. Because a different policy instrument applies for each successive innovation step, it is more difficult to go through all those successive steps.

63. This Programma Aardgasvrije Wijken was evaluated in 2022; see: <https://www.rijksoverheid.nl/documenten/rapporten/2022/10/14/evaluatie-programma-aardgasvrije-wijken> and for the progress of the trials (baseline date end of 2024) see: <https://www.nplw.nl/data-en-monitoring/rapporten/voortgang-proeftuinen>

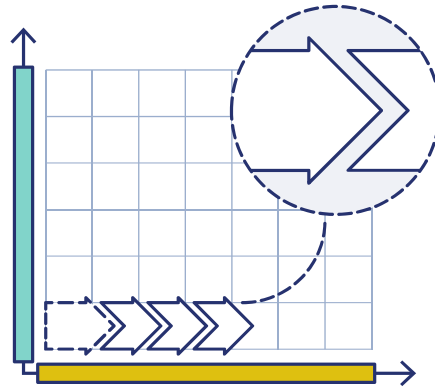


Figure 8. Poor connectedness between policy instruments for innovation

A number of initiatives have been launched in recent years intended to resolve this fragmentation. For example, the National Growth Fund Offered substantial multiyear funding for larger integrated projects, enabling different phases in the research and innovation process to be linked long term. Eight Growth Fund Projects received funding within the 'Energy and Sustainable Development' theme.⁶⁴ However, the present government has decided that there will be no new National Growth Fund rounds. Despite this, it is worth evaluating to what extent the design of the Growth Fund and the projects has led to better connectedness between the different phases in the innovation process.

Upscaling is often a bottleneck

Too often, at the end of the innovation chain there is no ready market. After all the steps in the innovation process using the existing funding schemes have been completed, the step towards upscaling often proves to be a major problem. Sometimes this is due to legal restrictions (such as rules around state aid) which prevent the government from giving a helping hand. But it is also regularly the case that there is not yet a market for the innovation. In such cases, finding funding for upscaling is very difficult. Even where there is a potential market, large sums of money are needed to finance upscaling. However,

64. Rijksoverheid (undated). *Thema Energie en duurzame ontwikkeling* (website). The Hague: Nationaal Groeifonds, available at: <https://www.nationaalgroeifonds.nl/overzicht-lopende-projecten/thema-energie-en-duurzame-ontwikkeling>.

that funding is less widely available in Europe than in countries such as the United States. Figure 9 illustrates this problem: the final step to a potentially successful innovation via upscaling often proves impossible because of a lack of the necessary enabling conditions (often financial).



Figure 9. Upscaling is often a bottleneck preventing successful innovation; finding funding for upscaling is often very difficult.

2.4 ‘Narrow’ evaluations do little to help system policy

One focus area in the request for advice was ‘measurability’: “*How can the impact of the energy innovation policy on achieving the transformation of the energy system be made more transparent and measurable, and what is needed for this?*” It is important when developing an effective energy innovation policy to have an insight into how much that policy contributes to achieving the goals and innovation challenges that ensue from the vision for the future energy system.

The Council notes that the different programmes supporting energy innovation are evaluated periodically. However, it is difficult to measure the precise impact of the measures because any impact will not become visible until well into the future. It is for example not possible to determine in 2025 what the effect of a given energy innovation

(step) on greenhouse gas emissions will be in 2030. In fact it is even difficult to determine the effectiveness and efficiency of programmes which have expired.⁶⁵

While it is good that these evaluations take place, the Council observes two caveats. First, what are the criteria for success? In the extensive evaluation of the energy innovation programmes over the period 2012-2021, the conclusion is that “the overarching picture that [...] emerges is [...] that the programmes [...] appear to have accelerated the development of energy innovations”.⁶⁶ This conclusion is based mainly on interviews with stakeholders. Apart from the fact that ‘acceleration’ is a difficult concept to prove, the Council would argue that the energy innovation policy should be promoting developments that are *additional*, in other words that would not have got off the ground at all without support. These developments are also more readily evaluated, because prospective participants would have to indicate that without support they would not have begun the innovation process in question.

As a second caveat, the Council emphasises the need to remain very clear about what we mean by innovation. The evaluation referred to above concludes that “it is less clear to what extent energy innovations are used in the market.”⁶⁷ In the usual interpretation of what constitutes (successful) innovation, the fact that it is ultimately applied in practice is however a condition. Applying this condition creates attention for evaluating factors that help determine whether a technological innovation is applied in practice.

The evaluation of the energy innovation programmes also revealed the difficulty of evaluating projects focusing on non-technological (dimensions of) innovation. For example, the evaluating organisations Dialogic and SEO had access to data on projects focusing on institutional parameters; this revealed that it is currently not fully possible to incorporate all dimensions of an innovation process in the evaluation processes.

An evaluation should not only make clear the effects at individual project level, but also the (future) impact of the envisaged innovation at *system* level, and whether the innovation contributes (or is expected to contribute) to the envisaged *transformation*. This calls for a ‘broader view’ of the policy ambitions. The question here is not just whether the innovation in question has ‘succeeded’, but also what the ultimate impact is on the system and whether it has brought the envisaged goal closer or led to its achievement. The specific nature of the evaluation of transition and system policy have been analysed

65. Dialogic & SEO (2023), *Evaluatie Energie-Innovatieregelingen 2012-2021*. Commissioned by Ministry of Economic Affairs and Climate Policy.

66. Dialogic & SEO (2023), *Evaluatie Energie-Innovatieregelingen*, p. 76.

67. Dialogic & SEO (2023), *Evaluatie Energie-Innovatieregelingen*, p. 77.

and discussed in the literature in recent years.⁶⁸ A key characteristic of this type of policy is that the relationship between problem and solution is often not linear or unambiguous. It can therefore be difficult to map the effects of the policy accurately. It is therefore vital to be clear from the start about the policy objectives and associated logic.⁶⁹

The hydrogen case study is another illustrative example (see page 30). Part of the Dutch hydrogen agenda is aimed at increasing the supply of 'green hydrogen'. However, a relevant question is what we ultimately wish to do with that hydrogen and what effect that will have within the future energy system and economy. Will we use hydrogen to continue refining oil, to find a greener way to make steel, or for transport? Each route has a different ultimate impact on our energy and carbon management. In a 'limited' evaluation against the background of the intermediate goal of producing more 'green' hydrogen, the conclusion could be that the goal has been achieved. But that evaluation does not produce an answer to the question of what the subsequent effect of that hydrogen was on our energy and climate management and what this means for our future economy and society.

In the Council's view, the biggest challenge for evaluations is to broaden the viewpoint. At present, most evaluations focus on a single policy instrument and whether it has led to (the desired) output. This is shown in Figure 10. However, evaluation is most useful when it starts from the desired impact on the system and the transformation. A broad view of innovation such as this takes account of the different relevant dimensions. For example, the evaluation of a measure aimed at technological development may conclude that the technological development itself was successful, but that the envisaged impact on the system has not been fully achieved. This failure is then very likely due to obstacles in other dimensions, for example the lack of a market or the appropriate regulations. Conversely, an attempt at institutional innovation may fail because the required technical capabilities ('conditions') are not present.

68. See e.g. Commissie Evaluatiemethoden Systeem- en Transitiebeleid (2022), *Durf te leren, ga door met meten*. The Hague: Ministerie van Economische Zaken en Klimaat; L. Verwoerd & E. Kunseler (2025), 'Lerend evalueren: een methode voor beleidsevaluatie van complexe veranderopgaven', in: D. Hanemaayer, J. Mevissen & V. Patyn (eds.), *Themareeks Methoden en benaderingen in de beleidsevaluatie*. Beleidsonderzoek Online.

69. Janssen, M. (2023), *Adviesnota monitoring en evaluatie missiegedreven innovatiebeleid*, Utrecht: Copernicus Institute of Sustainable Development - Utrecht University.

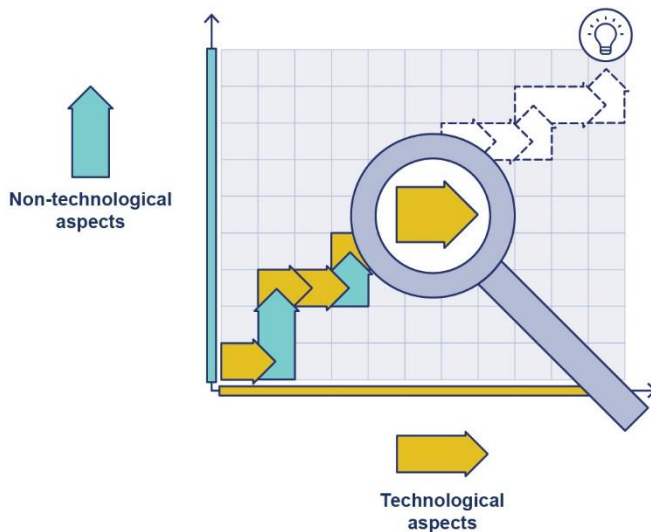


Figure 10. Evaluations (represented by the magnifying glass) are frequently too ‘narrow’, focusing on individual policy instruments rather than seeing them as part of a cohesive whole together with other policy or the broader system.

It is also important to bear in mind the process *around* the innovation policy itself. The OECD, for example, observes that the goals and structures of mission-driven innovation policy can change during the implementation phase. It is therefore essential that the policy itself is also adaptable. This depends heavily on the adaptability of the governance around policy initiatives; this should also be included in the evaluation.⁷⁰

A final, crucial consideration is what is done with the outcomes of evaluations and monitoring. It would be good if those outcomes also work through into the portfolio management of innovation programmes and in the policy cycle. The principal goal of such evaluations is after all to draw lessons and to make improvements based on those lessons. This makes portfolio management a suitable policy domain for such evaluations. As regards drawing lessons about policy, one lesson from the evaluations could be the realisation that the necessary conditions need to be in place in plenty of time. The policy can also be improved to make it more effective, not only based on experiences with the (Dutch) policy, but also by incorporating experiences and lessons from other countries,

70. OECD (2024), ‘Monitoring and evaluation of mission-oriented innovation policies: From theory to practice’, *OECD Science, Technology and Industry Working Papers*, No. 2024/09. Paris: OECD Publishing.

for example by looking at the interrelationship between the different policy instruments (the policy mix) in the energy innovation system in those other countries and what can be learned from that.⁷¹ Another input in drawing lessons for policy can come from research on technology development and how this can best be supported with policy.⁷² The insights from this type of research are mainly relevant for policy instruments focusing on technology development. However, the Council stresses that use of these insights (in relation to technology development) must be embedded in a broader vision for energy innovation policy, which starts from the perspective of the system and of which the non-technological aspects also form an integral part.

71. The IEA publishes numerous studies on energy innovation policy in other countries. See e.g.: <https://www.iea.org/reports/germany-2025>; <https://www.iea.org/reports/designing-energy-efficiency-policies-to-enhance-affordability>.

72. See e.g.: M. Junginger, & A. Louwen (Eds.) (2020), *Technological Learning in the Transition to a Low-Carbon Energy System. Conceptual Issues, Empirical Findings, and Use in Energy Modeling*, Academic Press.

Advice: Aim for breakthroughs for the energy transition towards sustainability by 2050

AWTI advises the government to configure the energy innovation policy so that it focuses on breakthroughs in the energy transition in order to facilitate the leap to a genuinely sustainable Netherlands in 2050. This represents a formidable challenge, which will require radical changes to our economy, society and energy supply. AWTI has three recommendations for making the energy innovation policy more effective: make clear choices and focus on them; make the policy more suitable for breakthrough innovations; and improve the policy through evaluations which take into account the need for broader system change. Since system breakthroughs take a long time, AWTI stresses the need for rapid action: adapt the policy now and promote the required breakthroughs.

As well as incremental improvements in the existing energy system, a number of robust breakthrough innovations are also needed: radically different technologies or processes in industry, different modes of transport or entirely new ways of organising the energy supply.⁷³ These breakthroughs generally demand a great deal of technological development⁷⁴ and face considerable social and institutional barriers. But if they lead to system changes, their impact can be great, especially if they are ready to deploy early enough and on a large enough scale to achieve the energy transition goals. Breakthrough innovations are in many cases high-risk, but also potentially high-reward, for example bringing opportunities for international leadership. They also have the potential to become game-changers which make it easier for the Netherlands to achieve its climate ambitions.

Government support for breakthrough innovations is essential,⁷⁵ not just because of their great potential, but also because the great risks and uncertainties that are inherent in them mean they are often not picked up directly by the market. Moreover, developments in non-technological dimensions (such as legislation and regulations, market formation

73. The IEA, for example, estimates that at least 35% of the technologies needed for a sustainable 2050 have still to be developed from scratch (see: IEA (2025a), *The State of Energy Innovation*, Paris: IEA Publications); see also: A. Kooiman & M. van Tuyll (2025), *Technologieradar: Welke disruptieve technologieën gaan impact hebben op ons energiesysteem?*, TNO2025 R10049, The Hague: TNO Public.

74. The IEA (2025a), for example, identifies 18 'races' around new breakthrough technologies.

75. See AWTI (2016), *Grasp the challenge. Daring to go for energy innovation (Oppakken en doorpakken, Durven kiezen voor energie-innovatie)*, The Hague, pp. 20-23, for a detailed discussion of the role of the government in energy innovation.

and social aspects) and enabling conditions (such as infrastructure) are often crucial for the success of innovations, and especially breakthrough innovations.⁷⁶ These are aspects of the innovation process that often fall under the responsibility of the government.

In AWTI's view, improvements in the existing energy system, i.e. incremental innovations, can already be stimulated reasonably well through the smart deployment of the general innovation policy as a national and European energy and climate policy, though that policy will need to provide more incentives for innovation in some areas.⁷⁷ Promoting incremental innovation is still important, because it not only contributes to reducing emissions, but also to containing the costs of the transition.

The specific policy aimed at energy innovation should preferably focus on breakthrough innovations. Support for specific energy innovation policy is essential because breakthroughs will not be achieved with general innovation policy and the energy and climate policy alone, as these policies are not effective enough to overcome the specific barriers facing breakthrough innovations, such as their distance from the market, the complexity of the broader transformation to which the breakthrough is intended to lead, and the reticence of the market to invest in such risky projects. Specific policy support is needed to achieve the necessary breakthroughs.

Moreover, the resources for energy innovation are under pressure at a time when the challenge is considerable. That makes it all the more important to ensure that the energy innovation policy is as effective and efficient as possible. For this reason, AWTI advises the government and parliament to **focus the energy innovation policy on breakthrough innovations that will help achieve the transformation to a sustainable Netherlands in 2050** by making clear choices, by making the policy more suitable for breakthroughs and by evaluating the policy in the context of its contribution to the envisaged transformation. This needs to be based on a broad vision for a sustainable economy, society and energy supply in 2050. That broad vision is a necessary basis for the policy.

AWTI makes three recommendations for translating this advice into practice:

- ▶ Instil direction and focus in the energy innovation policy.
- ▶ Make the policy suitable for breakthrough innovations.
- ▶ Include the context in evaluations and ensure that evaluations are geared to learning for system change.

76. This is a complicating factor for 'green innovations' in general, but especially for breakthrough innovations (see: C. Paunov *et al.* (2025), and: IEA (2025a), p. 12). See also: AWTI (2023), *Shaping The future. From optimization to transformation*; The Hague.

77. Cf. Recommendations 2 and 3 in AWTI (2016), 'Grasp the challenge' (*Oppakken en doorpakken*), p. 65.

System change takes time. It is therefore essential to make a start now on the breakthrough innovations that we need in the run-up to 2050. The development of such innovations, together with the required adaptations to the system, will easily take 15 to 20 years, and it is therefore of the greatest importance that AWTI's recommendations for the energy innovation policy are implemented as quickly as possible. Policy adaptation is urgent, paradoxically enough because we are talking about processes which take a long time to complete.

In making these recommendations, AWTI is also addressing the focus areas set out by the government in the request for advice (priorities, breakthroughs and measurability). The first recommendation will help in setting the priorities in the energy innovation policy more effectively, whilst at the same time creating more focus in the policy. The first and second recommendations will together ensure that 'breakthroughs' receive the appropriate attention in the energy innovation policy and that the policy mix is able to promote breakthroughs more effectively. The third recommendation is concerned with measurability and examines of how the impact of the innovation policy on the transformation can be made more visible.

3.1 Recommendation 1. Instil direction and focus in the energy innovation policy

AWTI advises the government to play more of a leading role in energy innovation. Concentrating attention on a limited number of innovation programmes will increase the impact of the policy. It is important that innovation programmes are a good fit for the Netherlands and for the broad vision for a sustainable economy, society and energy supply in 2050.

Instilling more direction and focus in the energy innovation policy begins with formulating a broad vision for a sustainable economy and society in 2050 and the energy supply that goes with that. Which actors play a role in this and how do we organise the energy supply of the future? A cohesive picture of what the transformation to sustainability by 2050 will look like is an essential basis for the policy. Current policy takes the present economy and society as a starting point; that is problematic because it will be too big a challenge to make all of that fully sustainable by 2050. AWTI advises the government to make use of earlier advisory reports published among others by AWTI and the Netherlands Scientific Climate Council to develop a broad, inspiring and adequate vision for a sustainable

economy, society and energy supply for the Netherlands in 2050.⁷⁸ That vision should incorporate strategic autonomy.

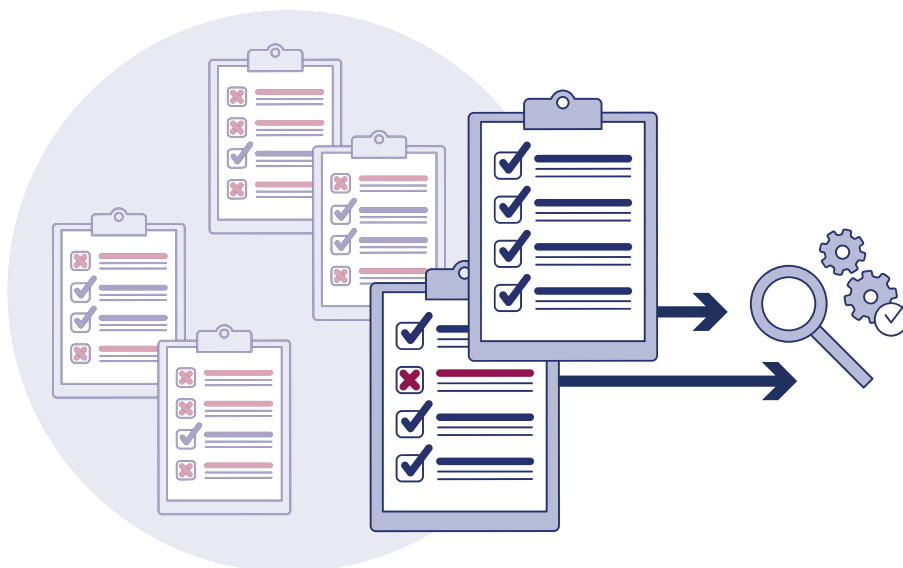


Figure 11. Recommendation 1: Instil direction and focus in the energy innovation policy by selecting a limited number of priorities based on an assessment framework for which mission-driven innovation programmes are set up

To instil more direction and focus in the energy innovation policy, AWTI proposes the following three interrelated actions: (1) choose priorities based on an assessment framework; (2) develop multi-year innovation programmes for those priorities; (3) organise the right governance to enable those clear choices to be made.

Action 1. Choose the priorities in the energy innovation policy based on an up-to-date assessment framework.

To enable a considered choice of the priorities for the energy innovation policy, AWTI proposes using an assessment framework. This would help in choosing the innovation

78. AWTI (2016), *Grasp the challenge. Daring to go for energy innovation (Oppakken en doorpakken. Durven kiezen voor energie-innovatie)*; AWTI (2020), *Strengthen the role of science, technology and innovation in societal transitions*; AWTI (2023), *Shaping the future. From optimisation to transformation*; Wetenschappelijke Klimaatraad (2025), *Vaart maken met visie*.

projects on which Dutch innovation policy should focus as a priority. It is important to make an assessment of the following factors:

- ▶ *Alignment*: How well the innovation aligns with the future sustainable energy system.
- ▶ *Impact*: The impact of the innovation in question, both in terms of its contribution to achieving the sustainability objectives, and its social and economic value.
- ▶ *Strategic autonomy*: How important do we believe it is – strategically – to develop the innovation in question in the EU or the Netherlands?⁷⁹
- ▶ *Chance of success*: The degree to which the Netherlands meets the conditions to make this innovation project a success. Does the Netherlands have a relative advantage to enable it to push through this innovation successfully?

The better the alignment between the innovation and the future system, the greater the (expected) impact, the more weight is assigned to strategic autonomy and the greater the chance of success, the more attractive it is to take up the innovation project in question in the Netherlands.

Table 1 presents the assessment framework proposed by AWTI, based on the framework in its 2016 advisory report. This updated version incorporates several new developments, such as strategic autonomy, EU policy and the emergence of civic initiatives. Appendix 3 explains how these points have been incorporated in the earlier framework.

The alignment with the broad vision is encapsulated in the first criterion, in which the vision will also need to take into account a strategic autonomy in relation to aspects such as energy resources and the future economic structure.

The second and third criteria in the assessment framework are concerned with the (expected) impact of the innovation. What contribution do we expect the innovation to make to the energy transition and what environmental gains are likely? What will be the economic and social impact of the innovation? The economic impact need not always mean that a large new factory arises as a result of the innovation; An innovation can also be highly successful if it is easily scalable and reproducible.

The fourth criterion concerns strategic autonomy in relation to the innovation project in question: are their strategic reasons for wanting to develop the innovation in the Netherlands? It is relevant here to assess the international position of the Netherlands and the acceptable vulnerabilities and desired strategic independence. Strategic (in)dependence is not only concerned with geopolitical aspects, but also the autonomy of citizens and the possibility of dependence on a small number of large players.

79. This takes into account the perspective of the customer/citizen and the extent to which they retain freedom of choice and freedom of action, and how stable prices are expected to be.

Table 1: Assessment framework for determining priorities for energy innovation

<i>Aspect</i>	
Criterion	Question
<i>Alignment</i>	
Alignment with broad vision	How well does the innovation align with the (vision for the) future sustainable economy, society and energy supply?
<i>Impact</i>	
Expected impact on sustainability	What is the innovation expected to contribute to the energy and climate goals?
Expected impact on economy and society	What is the expected impact of the innovation on the economy and society? Will it contribute to earning capacity, the phasing out of undesirable dependencies and the achievement of social objectives? How reproducible and scalable is the innovation?
<i>Strategic autonomy</i>	
International context	Are there strategic reasons to take on this innovation in the Netherlands? Will it contribute to our autonomy? What is being done in other countries and what are our relations with those countries: are they countries we 'trust', or on which we would rather not be dependent?
Economic relationships	Will the innovation contribute to (maintaining) the autonomy and/or freedom of choice of citizens, organisations and businesses?
<i>Chance of success</i>	
Knowledge position of the Netherlands	Is the necessary knowledge present in the Netherlands? To what extent does the Netherlands have a world-leading knowledge position, among 'friendly countries' and in the EU?
Stakeholder willingness	Are companies/civil-society organisations available and willing to invest?
Market potential	Is there a market, or can one be created (in the Netherlands, the EU or worldwide), possibly with help from the government?
Social potential	Is there is social driver (for example civic initiatives) or public support, or can that be created?
Linkage opportunities	Can the initiative be linked to other initiatives or policy? (such as Technology Strategy, EU or civic initiatives)
Obstacles	Are there any (other) barriers to certain innovation steps, such as a lack of infrastructure or legislation?

The remaining criteria are concerned with aspects that influence the likelihood of the innovation project being successfully picked up in the Netherlands. Relevant aspects here are the (relative) knowledge position of the Netherlands, the presence of relevant stakeholders (such as businesses) and their willingness to invest in the innovation project, the societal potential (is there a civic initiative or public support), the possibility of linking the innovation to other policy goals and the presence or absence of obstacles.

The assessment framework presented here can help the government determine the substantive priorities within the energy innovation policy. The Council believes that breakthrough innovations are better match for the criteria in the assessment framework than incremental innovations in the bid to achieve the energy transition objectives. Those breakthrough innovations may stem more from technological innovation, driven by innovations that are non-technological or which take place together with technological innovations. It is important that these breakthroughs ultimately lead to a change in the system, and this therefore requires a perspective based on the system (see also Recommendation 2).

Action 2 indicates *how* the government can best focus on those priority innovations.

Action 2. Select a limited number of mission-oriented innovation challenges (suited for the Netherlands) and set up multi-year innovation programmes for them, based on a planned approach and strong internal cohesion

AWTI recommends using the assessment framework presented here to select a limited number of mission-driven innovation challenges and to set up innovation programmes for them. Achieving a major transformation within the relatively short time span from now until 2050 will require many innovations. The Netherlands is not a large country and can only be involved in a proportion of these innovations. AWTI therefore recommends that clear, strategic choices be made for innovations that are a good fit for the Netherlands, given the envisaged future economy, society, energy supply and strategic autonomy. That will increase both the chance of success and the impact. It is important when making choices to maintain the focus on the long term goals. The assessment framework presented here will help with this.

AWTI recommends that the mission-driven innovation programmes be focused as a priority on breakthrough innovations. Such innovations benefit from a mission-driven, multi-year approach. This is moreover in line with AWTI's overarching advice to focus the energy innovation policy on breakthrough innovations.

The next action focuses on the governance needed to enable clear choices to be made.

Action 3. Organise the governance to enable clear choices to be made.

AWTI recommends that the governance of the energy innovation policy be configured in such a way that clear choices can be made. The structure used in recent years has led to attention being divided across many topics. AWTI recommends that an independent, autonomous governing body be set up with sufficient substantive expertise and authority to make clear choices for innovations.⁸⁰ This body can be given the power to make its own choices or to issue influential advice to the government decision-makers (as happens now, for example, with the National Growth Fund Advisory Committee). This governing body should be given a clear assessment framework (see Action 1 above) which also links up to the broad vision for the energy system. It is recommended that the governing body also include a number of experts from other countries.

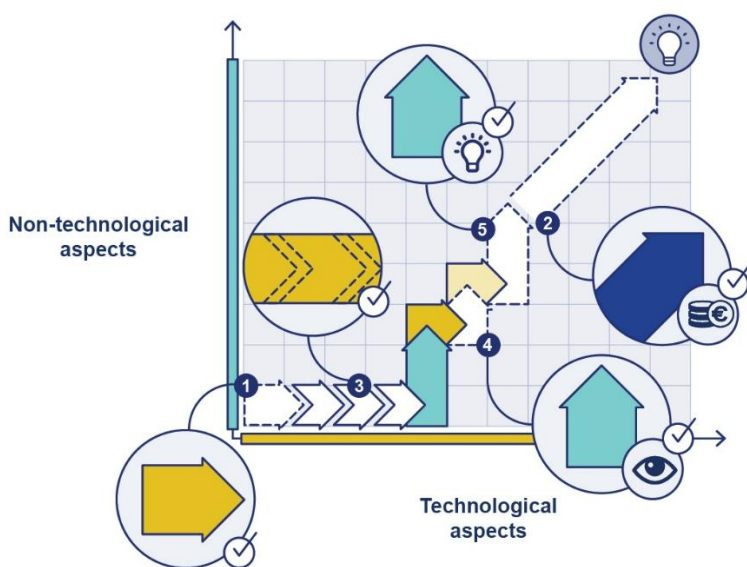


Figure 12. Recommendation 2: Make the policy suitable for breakthrough innovations. AWTI believes that a number of adaptations can improve the cohesiveness of the policy, thereby boosting the chance of success of innovations. The numbers refer to the proposed actions in Recommendation 2.

80. Such as the Energy Innovation Task Force previously recommended by AWTI: AWTI (2016), *Grasp the challenge. Daring to go for energy innovation (Oppakken en doorpakken. Durven kiezen voor energie-innovatie)*, The Hague: AWTI, pp. 40-42 and pp. 66-67.

3.2 Recommendation 2.

Make the policy suitable for breakthrough innovations

Breakthrough innovations are essential to achieve the transformation to a sustainable 2050, but they also face the biggest obstacles. AWTI therefore has a number of proposals to improve the energy innovation policy further to make it more suitable for ensuring the success of breakthrough innovations. Our analysis revealed a number of shortcomings in the current policy mix for the energy innovation chain, creating obstacles which impede the success of breakthrough innovations. Eliminating all of these obstacles would give breakthroughs a better chance of success. If only a few of them are addressed, there is a danger that an innovation process will subsequently run aground on another obstacle. AWTI therefore recommends six actions, which will not only help breakthrough innovations, but also other energy innovations. Figure 12 presents a schematic overview of where the first five actions influence the policy mix for the innovation chain; their purpose is to fill gaps and create more cohesion.

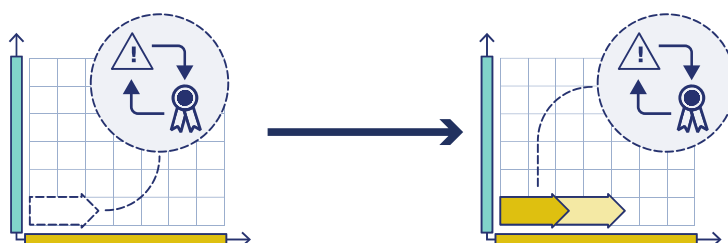


Figure 13. Action 1: Establish a high risk/high reward programme for energy innovations

Action 1. Establish a high risk/high reward programme for energy innovations: the SPRIND programme in Germany or the American ARPA-E programme can serve as sources of inspiration here.

AWTI proposes that a specific high risk/high reward programme be set up for energy innovation. The purpose of this programme will be to provide support at the start of the innovation chain for ideas which could potentially have a very large impact but which still carry high risk. There is currently no such instrument in the Dutch ecosystem for energy innovation.⁸¹ Figure 13 illustrates this recommendation.

81. The recent 3% R&D action plan announced that a study would be carried out into the feasibility of setting up a National Agency for Disruptive Innovation (NADI), based on the example of

AWTI also advised launching a high risk/high reward programme in 2016, in which around ten potentially promising ideas could be funded.⁸² The proposal was to select those ideas in an open competition. During this selection process, attention would need to be given to the impact (such as CO₂ reduction, economic contribution) and to the (potential) technical feasibility. The added value from an international perspective is also relevant (including in relation to strategic autonomy).

The Netherlands could draw inspiration for the design of such a high risk/high reward programme from SPRIND in Germany, ARIA in the United Kingdom or ARPA-E in the United States. The Dutch Research Council (NWO) does have the 'Open Mind' research funding programme for 'out-of-the-box' ideas, but this is limited to 50,000 euros per idea, an order of magnitude smaller than in the ARPA-E programme.⁸³ The NWO programme is moreover only accessible for universities. Creating a high risk/high reward fund within the context of EU regulation is not simple (partly because of EU rules on state aid) but the German example of SPRIND shows that it can be done with the right political will. The Dutch government is pervaded by a risk-averse culture, which needs to be overcome. It is important to build a solid ecosystem around such potentially impactful ideas, comprising knowledge partners, talent, infrastructure and industrial activity. It is also key to ensure that there are adequate funding opportunities in the Netherlands and the EU to support the continued development of an innovation so that, if it proves successful, the industrial activity will also remain in the Netherlands (or the EU).

ARPA-E. The Council sees this as a promising development, and hopes the study will lead to the actual establishment of such a high risk/high reward programme. See: Minister van Economische Zaken (2025), *Kamerbrief 'Investeren in een weerbare en toekomstbestendige economie: het 3%-R&D-actieplan'*, Letter to Parliament 11 July 2025.

82. See AWTI (2016), *Grasp the challenge (Oppakken en doorpakken)*, The Hague: AWTI, p. 67.

83. Projects funded by ARPA-E typically receive amounts ranging from 500,000 to several million USD.

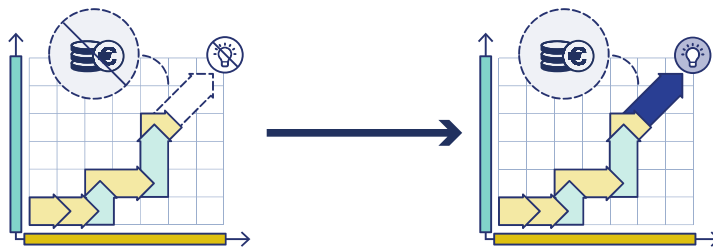


Figure 14. Action 2: Create a specific financial instrument to support upscaling

Action 2. Create a specific financial instrument to support upscaling. Investigate the possibilities of organising this at European level or creating leverage with EU policy instruments.

AWTI advises that a (financial) instrument be created to support upscaling (see Figure 14). Attempts at upscaling often encounter obstacles which prevent the associated transformation of the energy system from succeeding.⁸⁴ The biggest obstacle is often a lack of finance for upscaling. Large ‘funding packages’ to finance continued growth are scarce in the EU and the Netherlands, especially compared with the US.⁸⁵ The government can take the lead in setting up public-private funds specifically to finance upscaling of (breakthrough) innovations around energy. Funds at EU level have even more impact, enabling more capital to be raised. The (European) scale also makes setting up thematic funds more viable.⁸⁶

As well as financial obstacles, availability of labour and knowledge are also potential obstacles to upscaling. Established parties, such as network operators, can play a role here, given their access to both knowledge and labour. Obstacles such as existing regulations (which may stand in the way), lack of clarity about the market (business case) or lack of necessary infrastructure can be eliminated by devoting attention in good time to enabling parameters and the non-technological dimensions of innovation (see Action 4).

84. Cf. AWTI (2023), *Shaping the future. From optimisation to transformation (In dienst van de toekomst. Van optimalisatie naar transformatie)*, The Hague: AWTI, pp. 48-50.

85. AWTI (2020), *A better start. The key to growth of knowledge-intensive start-ups (Beter van start. De sleutel tot doorgroei van kennisintensieve start-ups)*, The Hague: AWTI, pp. 30-31.

86. See also: AWTI (2020), *(A better start. The key to growth of knowledge-intensive start-ups) Beter van start. De sleutel tot doorgroei van kennisintensieve start-ups*, The Hague: AWTI, section 3.6 (pp. 50-52).

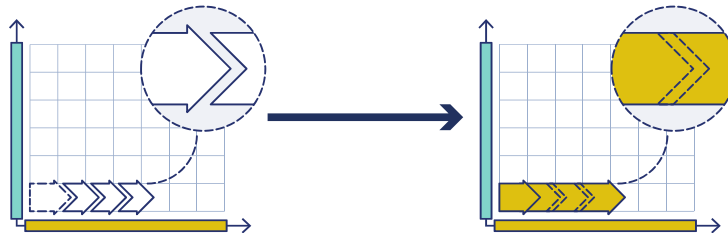


Figure 15. Action 3: Improve the connectedness between policy instruments

Action 3. Improve the connectedness between policy instruments for the different stages in an innovation project by setting up programmes which allow for automatic progression to the next step when one stage is completed successfully.

A frequently voiced complaint concerns the need to apply for new funding for each successive step in an innovation project. Applicants have to deal with a new funding body for each step, each with its own committee and its own criteria. That not only creates lots of red tape, but also means that applicants for each subsequent step in the process have to compete against other projects once again (see left-hand illustration in Figure 15). To avoid this, AWTI advocates integrated programmes with clear criteria for progressing to the next innovation step *within* a programme. Once a party has met the objectives in a given innovation step, they are assured of funding in the next step (right-hand illustration in Figure 15). This avoids them having to compete with other proposals each time. This could lead to a reduction in the number of innovation areas to which the government provides funding, but the available funding will be used more effectively and have greater impact. In Recommendation 1, AWTI proposed the setting up of multi-year mission-driven innovation programmes; these should operate in this way.⁸⁷ Another example of a more integrated programme is the National Growth Fund, but there are also other ways of addressing the fragmentation in policy.⁸⁸

It is therefore important that the consortia and the programmes focusing on breakthrough innovations all continuous, but they must also be adaptable. Because transformative system innovations, which are often high risk/high reward in nature, are characterised by

87. Cf. also AWTI (2016), *Grasp the challenge (Oppakken en doorpakken)*, The Hague: AWTI, pp. 38-42.

88. See examples in Dialogic & SEO (2023), *Evaluatie Energie-Innovatieregelingen 2012-2021*, section 4.1 (pp. 57-61) and section 6.2 (pp. 80-81).

great uncertainties in their development. Future programmes can be made more adaptable than today's programmes through less detailed planning and more rapid assessment procedures, and by ensuring that consortia are formed in a transdisciplinary way and more dynamically across innovation cycles. This makes the quality of governance throughout the programmes more important. An assessment should be made when a programme is set up to determine whether competition is the appropriate way to divide funding and attention, or whether collaboration is more effective. Another possibility would be still to have competition, but with the attached condition that solutions must be interoperable so as to guarantee collaboration at the level of implementation.

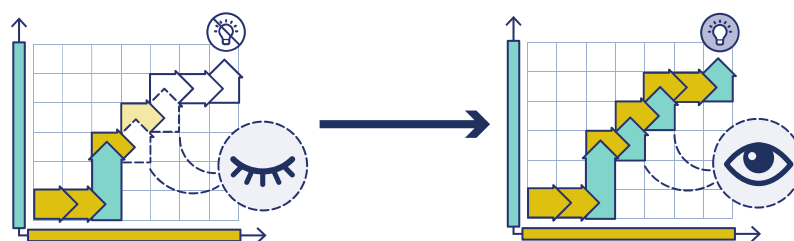


Figure 16. Action 4: Consider non-technological aspects and enabling parameters from the beginning. Make these aspects an integral part of the innovation policy.

Action 4. In the case of technological developments, consider non-technological aspects and enabling parameters from the beginning. Make these aspects an integral part of the innovation policy by ensuring that the policy on those other aspects keeps pace with the technological innovation policy.

AWTI urges that the policy for relevant non-technological aspects of innovation be included in the policy mix for innovation. At present, innovation policy is focused too much on the technological aspects, with the non-technological aspects often being seen as merely a secondary parameter (see left-hand illustration in Figure 16). For breakthrough innovations, in particular, the non-technological aspects are an essential condition for success or failure. They must be systematically incorporated from the start (see right-hand illustration in Figure 16). If regulations stand in the way, or if there is no market, or if the supporting infrastructure is absent, an innovation programme quickly grinds to a halt, even if the technological aspects are developing as planned.

The legislator therefore needs to create clarity regarding the legal status of electricity storage, for example, so that the different players involved in developing storage options know where they are and how they need to structure their business case. It is also important that measures aimed at the non-technological aspects are taken early, so that the technological and non-technological steps are sufficiently aligned during the innovation process and that no barriers arise.

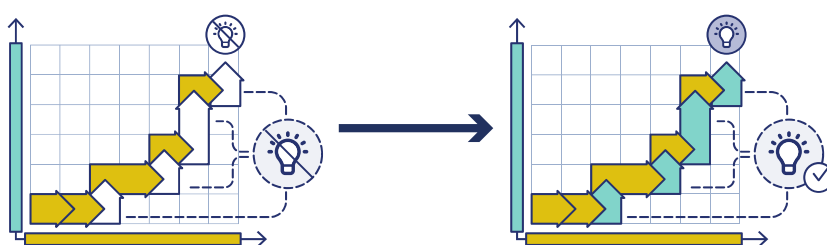


Figure 17. Action 5: Acknowledge that non-technological dimensions are also an independent source of innovation

Actie 5. Acknowledge that non-technological dimensions are also an independent source of innovation and develop innovation policy aimed at eliciting and encouraging such innovations.

AWTI proposes that the energy innovation policy also focus on non-technological aspects as an *independent* source of innovation (see Figure 17), in order to promote institutional and social innovations in relation to energy. This supplements Action 4, which argues that technological and non-technological developments *together* ensure a successful innovation process (whereas innovation policy currently focuses mainly on promoting the technological innovation steps).

Non-technological innovation is of particular importance for achieving breakthroughs, because breakthroughs often do not fit in easily with the existing system; Their success accordingly depends on how successfully system barriers can be demolished. But that also means that success in changing ‘the system’ enough to more easily accommodate all kinds of innovations, can provide a serious boost to those innovations. An example of such an institutional innovation is a change in regulation, organisation or market formation, creating an environment in which implementing entirely new technological innovations is made possible or even encouraged. Focusing on non-technological innovations thus enables breakthroughs to be achieved which contribute to the transformation of the energy system as a whole.

A practical example of this is issuing a call for a completely new organisation of the electricity market, which is better aligned than the existing market rules to self-generation using solar panels or wind turbines, and to the emergence of energy cooperatives. Social or institutional energy innovations such as these can in turn stimulate technological innovations, for example the development of equipment which facilitates the sharing of energy between members of an energy cooperative.

Action 6. Develop policy aimed at the phasing out of practices which are or will become undesirable. Ensure that this policy is properly aligned with the policy on developing alternatives, and also treat 'phasing out' as a topic for of innovation.

At present, the emphasis in the innovation policy is mainly on promoting the *development* of new alternatives. Just as important, however, is the phasing out of practices we wish to abandon based on our vision for a sustainable 2050.⁸⁹ This phasing out is necessary to create space for new (sustainable) alternatives. The policy for phasing out existing but ultimately undesirable practices should run in parallel with the development of (sustainable) alternatives. To some extent, this is comparable with our recommendation that the policy for non-technological aspects should run in lock-step with the technological progress of the innovation (Action 4). Phasing out existing practices moreover creates traction for the development of alternatives, and in that sense can be a major stimulus for innovation.

Phasing out can also be a topic for innovation. An example is the Gas-free Neighbourhoods Programme (*Programma Aardgasvrije Wijken*), in which all kinds of possibilities were investigated and tested to see how neighbourhoods could end their dependency on gas, and what impact that has.⁹⁰ The starting point was the phasing out (ending the dependency on gas) and the programme was intended to generate ideas to achieve that.

The Council would also draw attention to another relevant role of 'phasing out', namely the importance of considering at an early stage how the policy promoting innovations (or new alternatives) can itself be phased out over the longer term, once those new developments are being applied more widely. Creating clarity on this enables stakeholders to anticipate ways of incorporating those new alternatives in the 'new' system.⁹¹

89. See also: AWTI (2023), *Shaping the future (In dienst van de toekomst)*, The Hague, pp. 28-30.

90. See Ministerie van Binnenlandse Zaken en Koninkrijksrelaties (2022) for an evaluation of the Gas-free Neighbourhoods Programme (Programma Aardgasvrije Wijken).

91. An example of where there was a failure to grasp this opportunity to provide clarity at an early stage was the phasing out of the netting off scheme for solar power. The government knew for a very long time that this method of incentivising customers to produce their own electricity, mainly

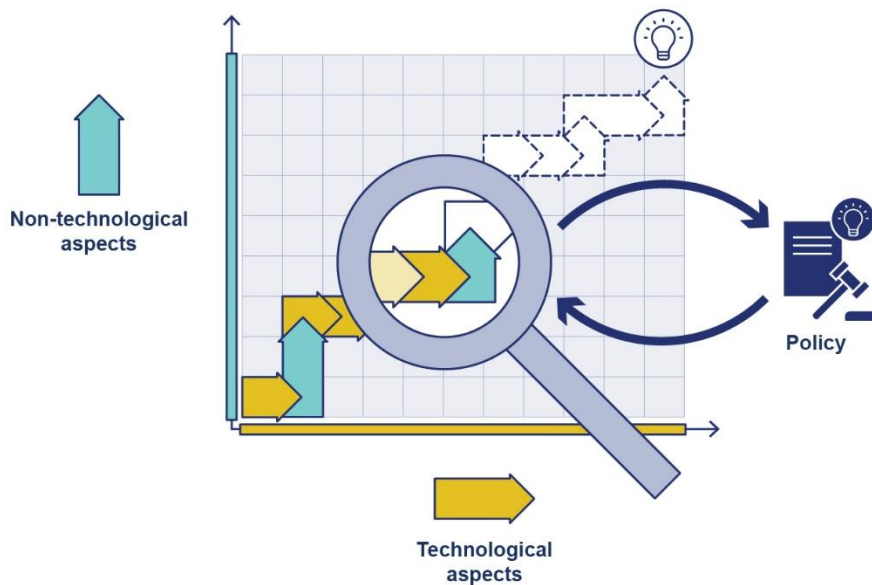


Figure 18. Recommendation 3: Include the context in evaluations and ensure that evaluations are geared to learning for system change

3.3 Recommendation 3. Include the context in evaluations and ensure that evaluations are geared to learning for system change

The broader view of energy innovation policy recommended by AWTI also applies for the evaluation of that policy. The context of the policy instrument and the promoted innovations is very important here; evaluation of innovation processes is most useful when it takes into account the different dimensions that are relevant for the innovation and for the accompanying policy, as well as for the underlying objective: transformation towards a sustainable system in 2050. The ‘success’ of the innovation policy therefore has to be judged in the light of the desired effects on the system and the (envisaged) transformation. Put differently: has the envisaged system change been brought closer? AWTI proposes the following two actions to ensure effective evaluation:

using solar panels, was not sustainable financially, but the lack of clarity on how the scheme would be phased out continued for too long.

Action 1. Ensure that evaluations do not focus solely on individual policy instruments and the 'direct' results (output and outcomes), but also on the context and process of which the policy instrument forms part. Use a broad array of evaluation frameworks and methods for this purpose.⁹²

AWTI recommends not only evaluating each individual policy instrument, but also the context and the process of which that instrument forms part. Figure 18 illustrates this by showing the magnifying glass viewing the policy instrument together with the context. A project may be a technological success, but the innovation can still run up against the buffers of a lack of enabling parameters. Identifying these 'system bottlenecks' is important, because it offers pointers for improvement and therefore also raises the effectiveness of the policy mix intended to promote innovation. By 'context' we mean made aspects such as the governance around policy instruments; to what extent does this governance offer opportunities to introduce changes in the policy mix? Other topics which could be included in an evaluation are the interaction between technological and non-technological policy instruments, the degree to which high risk/high reward ideas are encouraged, or the extent to which the policy instrument has actually contributed to genuine system change.

An evaluation which takes as its starting point mapping the impact at system level must therefore also incorporate relevant aspects from a system perspective. These cannot always be translated into strictly measurable terms of output and outcome, making it difficult to draw conclusions about the effectiveness and impact of policy instruments (particularly in the short term). To establish the effects of policy instruments at system level, different evaluation methods have to be used, and it is important to make the underlying assumptions explicit.⁹³

Action 2. Use evaluations mainly as learning exercises with the aim of improving the policy or supporting portfolio management. Organise the evaluation-based learning process as a continuous process, enabling adjustments to be made during the implementation phase.

AWTI recommends that evaluations be used primarily as learning tools with a view to improving policy or for portfolio management within large innovation programmes.

92. For a full overview of different evaluation perspectives, methods and decision schemes, see Commissie Evaluatiemethoden Systeem- en Transitiebeleid (2022), *Durf te leren, ga door met meten*. The Hague: Ministerie van Economische Zaken en Klimaat.

93. We would stress the importance here of formulating a theory of change, which makes explicit the relationship between policy interventions and desired outcomes. Mapping these assumptions enables policymakers to systematically determine which specific mechanisms need to be effectuated and where stagnation sets in. It thus forms a benchmark against which policy practice can be compared.

Evaluations must be a tool for continuous learning and making improvements based on the lessons drawn. This is illustrated in Figure 18 by the interaction between the evaluation (magnifying glass) and the policy. One way of learning from evaluations would be to ensure that the enabling parameters are in place in good time, or improving the policy or its cohesiveness to make it more effective. This requires that the underlying evaluations take account of the context of related policy domains and the system within which the innovation has to operate (see Action 1). In addition to lessons from evaluation(s) of Dutch policy, lessons can also be drawn from the way other countries arrange the cohesion of their energy innovation policy and what lessons this could offer for the Dutch context.

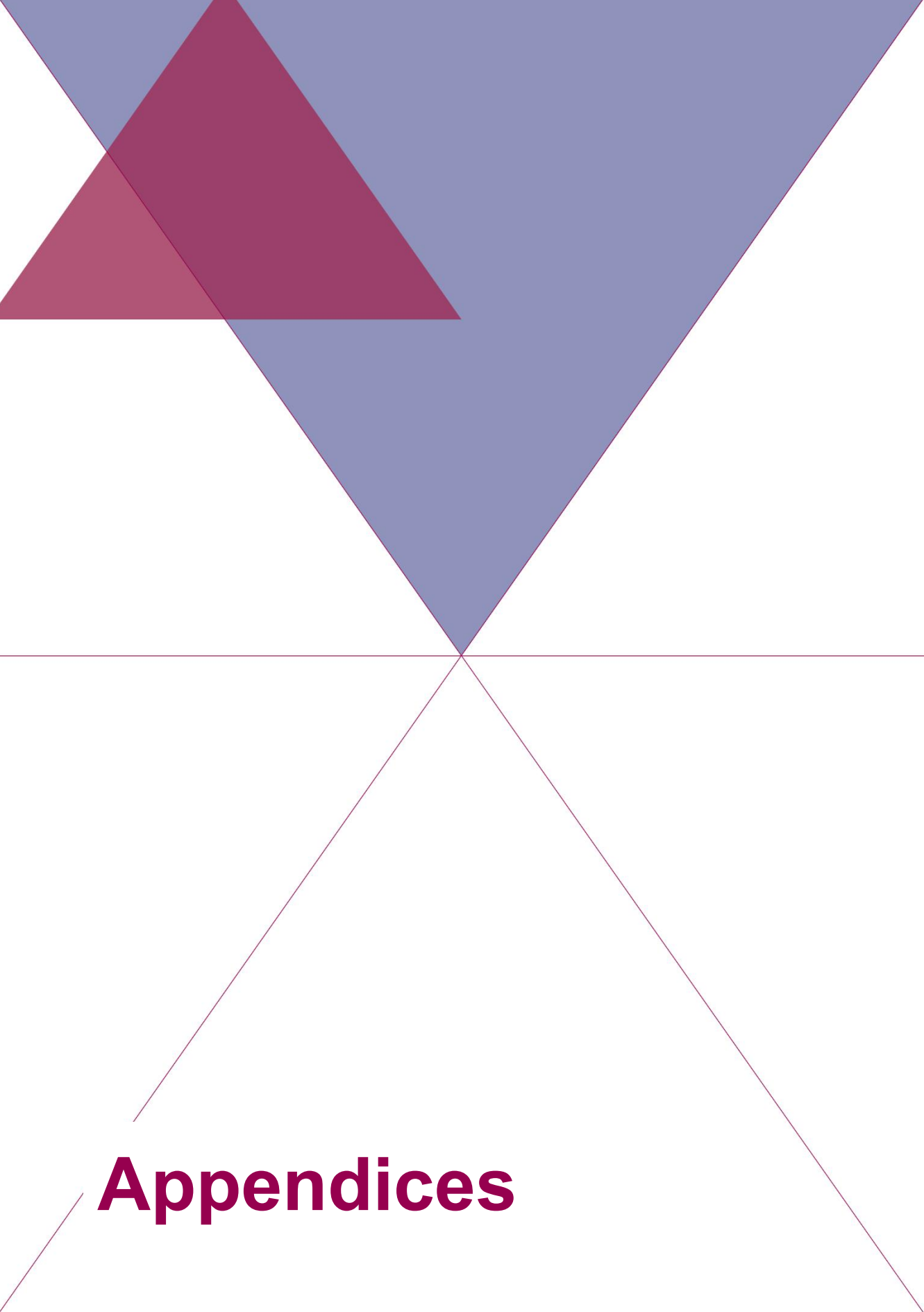
As regards portfolio management in innovation programmes, using the aforementioned methods and evaluation frameworks can promote a sensible development of the innovation portfolio. Here again, the system perspective must be the starting point in evaluating the portfolio, not the sum of the successes of the various programmes or activities.⁹⁴

A characteristic of system changes is that they are often not linear processes. Moreover, many developments are linked in complex ways, making it difficult to establish causality. To accommodate the complexity and variability of system change, a form of evaluation research should be configured during the implementation of the policy. This should provide insight into the functioning and steering of policy, making it possible to make adjustments early in order to improve the policy on the hoof.⁹⁵ Finally, it is very important that there is sufficient knowledge within government at all times about energy innovation and the enabling policy.⁹⁶

94. OECD (2025), 'Proactive Portfolio Management in Mission-Oriented Innovation Policy', *OECD Science, Technology and Industry Policy Papers*, No. 173. Paris: OECD Publishing.

95. See the literature on 'learning-oriented evaluation'. See: L. Verwoerd & E. Kunseler (2025), 'Lerend evalueren: een methode voor beleidsevaluatie van complexe veranderopgaven'. In: D. Hanemaayer, J. Mevissen & V. Patyn (eds.), *Themareeks Methoden en benaderingen in de beleidsevaluatie*. Beleidsonderzoek Online.

96. Cf. also AWTI (2021), *State of knowledge - Restoring the value of knowledge and expertise in policy and politics*, The Hague: AWTI.



Appendices

Appendix 1 AWTI advisory report from 2016

AWTI also published an advisory report in 2016 advising on the desired policy for energy innovation.⁹⁷ In that report, AWTI carried out a very extensive analysis of the policy framework relating to energy innovation. The Council also looked at a number of examples from other countries. AWTI concluded that energy innovation in the Netherlands was lagging behind what was possible and needed. The chief causes of this were:

- ▶ *The need for further strengthening of the energy innovation system*
Whilst there was a great deal of knowledge present in the Netherlands, it was dispersed and fragmented. There were also some missing links in the innovation chains, and the connections between links could be strengthened further, although the Top Sector Energy had brought major improvements here. There was also a lack of clarity about the shape of the envisaged energy system, due to the absence of a broadly shared vision for the long term.
- ▶ *Too little attention for innovation within **energy** policy.*
Although money was available for the roll-out of sustainable energy (targeting the cheapest currently available technologies), the existing energy policy provided virtually no incentives to improve existing or develop new technologies, or to limit emissions in other ways (e.g. through energy-saving).
- ▶ *Too little encouragement of radical energy innovation and its implementation.*
The policy (in 2016) focusing specifically on energy innovation mainly provided incentives for incremental innovations. Instruments such as the Energy Innovation Demonstration scheme or the Top Sector Energy were mainly aimed at incremental improvements and were inadequately equipped to bring about radical (system) changes. There was no nationwide agenda to promote radical innovation. Moreover, compared with other OECD countries, the Netherlands was investing little in research, development and demonstration of new energy technologies.

To turn this situation around and ensure that the Netherlands was in a better position to grasp the opportunities around energy innovation and make a bigger contribution to the energy transition, AWTI advised the government to adopt more of a leadership role.

97. AWTI (2016), *Grasp the challenge. Daring to go for energy innovation (Oppakken en doorpakken. Durven kiezen voor energie-innovatie)*, The Hague.

AWTI made the following recommendations in 2016:

- a)** First, develop a clear, internationally embedded vision for the future energy system.
- b)** Focus Dutch and European *energy policy* more on innovation (as a secondary objective).
- c)** Focus (Dutch) generic innovation policy more on energy innovation.
- d)** Focus the energy innovation policy first and foremost on promoting a small number of *radical* innovations (six mission-driven innovation programmes which are characterised by their long term, planned approach, strong internal cohesion and adequate funding; use an assessment framework to make this choice – AWTI presented a proposal for such a framework).
- e)** Ensure that the broad knowledge base is properly developed and support new ideas (including a high impact/high risk programme for new ideas);
- f)** Around 300 million euros per annum would be needed for the proposed new policy (points *d* and *e*), and to keep pace with comparable countries, an annual total budget of 400-450 million euros would be advisable for energy innovation (in 2016, the budget was around 250 million euros).

A central notion in the AWTI advisory report from 2016 was that incremental innovations can be promoted with help from energy and climate policy (both national and European) and general innovation policy. Energy and climate policy could be reshaped to foster innovations more, while the general innovation policy could be focused on socially desirable innovations. These actions alone could provide a substantial boost for incremental energy innovation, and it would therefore make sense to utilise the specific *energy* innovation policy to promote radical innovations.

A few elements from the 2016 advisory report have been adopted in recent years, such as the vision formulated in the National Plan for the Energy System (NPE) (December 2023) for what the Dutch energy system should look like in the future. Several parts of the general energy policy have also been updated to make them more innovation-friendly. An example is the SDE++ subsidy programme, which now incorporates several different categories; the most viable technologies within the programme receive subsidies, so that funding is also able to promote innovation in categories that are closer to the beginning of the innovation chain (the programme's predecessor, SDE+ was essentially a single pot of money from which only the very cheapest technologies received financial support).

A number of points from the 2016 advisory report have *not* been adopted. The proposed fund for high impact/high risk projects has not yet materialised in the Netherlands (the UK and Germany did recently establish funding programmes for this purpose).⁹⁸ Another

98. The UK programme is ARIA (Advanced Research and Invention Agency), while Germany has SPRIND (Bundesagentur für Sprunginnovationen SPRIND).

recommendation from AWTI in 2016 was to exclude R&D focusing on non-sustainable options from support from generic programmes in the innovation policy, and to devote the budget for generic support more emphatically to socially desirable innovations. This is another development that has *not* taken place in recent years: generic innovation policy still supports sustainable and non-sustainable innovations equally.

Other proposals put forward by AWTI Have been adopted to a lesser extent. The energy innovation policy was configured on a mission-driven basis after 2016 with the establishment of an Integral Knowledge and Innovation Agenda (IKIA). An assessment framework was also used for (some) agendas, seemingly based on that proposed by AWTI; this certainly marks a first step in line with the 2016 advisory report.

However, these initiatives have not been followed through: the number of multi-year mission-driven innovation programmes is double that advised by AWTI in 2016 (13 as opposed to six). That has led to a fragmented focus. Moreover, the focus in the IKIAs and the programmes is not on *radical* innovation as advocated by AWTI: while there is some attention for radical innovations, this is ranged alongside attention for incremental innovations.⁹⁹ The development of the agendas is also still embedded in the Top Sector Energy. AWTI was critical of this in 2016, because the Top Sector mainly represented established parties, making it less likely that radical new alternatives would be placed on the agenda. This also makes it more difficult to place innovation needs generated by civic initiatives on the agenda.

Although the Dutch budget for energy innovation initially increased after 2016 (until 2021), this money did not prioritise radical innovation, contrary to AWTI's advice in 2016. In the years since 2021, the public budget for energy research and innovation has actually fallen steadily, from 290 million euros in 2022 to just 151 million euros in 2023.¹⁰⁰

The Council thus notes that some of the weaknesses identified in the Dutch policy around energy innovation still exist. At the same time, a number of new challenges have emerged to which the energy innovation policy has to find an answer. All in all, the energy innovation policy is (still) not optimal, particularly given the position assigned to *breakthroughs* within that policy.

99. See e.g. the IKIA for offshore wind power.

100. RVO (2024), *Monitor publiek gefinancierd energieonderzoek 2023*, p. 5.

Appendix 2 Strategic autonomy

Strategic autonomy has become enormously important in recent years, including within the field of energy. The war in Ukraine has exposed the risks and dependencies for the EU in the supply of energy. The change in the stance of countries such as China and the US also has an impact on the price and availability of certain energy resources. Strategic autonomy is therefore becoming increasingly important, including in the context of energy innovation. Innovations which lead to the use of new energy resources or to the preservation of existing resources contribute to strategic autonomy by reducing the dependence on specific partners.

Strategic autonomy is a diffuse concept. This appendix first describes what strategic autonomy entails, before examining how innovation can contribute to increasing autonomy and how this aspect can be incorporated in the optimal prioritisation of Dutch energy innovation policy.

Definition and dimensions of strategic autonomy

Although a much discussed topic, strategic autonomy remains an ambiguous term, as acknowledged in a study carried out for the European Parliament.¹⁰¹ The European Commission coined the term 'Open Strategic Autonomy', but discussions show how differently member states interpret what this means in practice. In the scientific literature, European strategic autonomy within the energy domain has been defined as *'the EU's political, institutional and material ability political, institutional, and material ability to pursue its own, viable path towards a decarbonized energy mix'*.¹⁰² Both security of supply and affordability of energy are crucial concepts here.

External dependencies are found in the value chain in several dimensions: first, with respect to raw materials. Having sufficient access to minerals and metals such as copper, lithium and rare earth metals is essential to be able to produce renewable technologies. The EU defines a raw material as 'critical' if it has great economic value and there is a potential risk to its supply. No significant reserves of the materials used in sustainable technologies are present in the territory of the EU, and there is heavy dependence on countries that are rich in these resources, such as Congo and China.

There are also dependencies for the components needed for green energy technologies in the different phases of the production process. At present, for example, China is the biggest manufacturer, exporter and installer of solar panels, wind turbines and electric

101. European Parliamentary Research Service (2022), *"EU strategic autonomy 2013–2023: From concept to capacity"*, Briefing EU Strategic Autonomy Monitor. Brussels: European Parliament.

102. Hancher, L., & A. de Hauteclocque (2024), *'Strategic Autonomy, REPowerEU and the Internal Energy Market: Untying the Gordian Knot'*, *Common Market Law Review* **61**, Issue 1, pp. 55-92.

vehicles. Judging from the direction recently taken by the current Trump administration with regard to the energy transition, that is likely to remain the case. Trump's Big Beautiful Bill, for example, involves the phasing out of the tax breaks in the coming years for solar and wind energy and green hydrogen.¹⁰³

Another dimension is strategic autonomy within the *innovation process* itself. What influence/position do external parties have in respect of the innovation process, for example because the intellectual property rests in foreign hands? Strategic autonomy in the innovation process means that a higher proportion of the process and the relevant intellectual property is in 'domestic' (European) hands.¹⁰⁴

Before going talks mainly about the geopolitical aspects of strategic autonomy: which countries are we willing or reluctant to depend on? But strategic autonomy can also be viewed from another perspective: how much autonomy do stakeholders have regarding their own position, or are they dependent on one or a small number of parties? Compare developments in information technology, where a few large companies dominate and control 'our' data. The broad vision for the economy, society and the energy supply of the future (a sustainable 2050) must also include this aspect. If autonomy of citizens is considered important, different demands will need to be placed on the organisation of the energy supply than if that autonomy is considered less important.

European strategic autonomy for the energy system in practice

For the EU, strategic autonomy means an energy system which offers security of supply and is not dependent on importing primary energy resources, electricity or other carriers, or on raw materials from a small number of countries, or a supply chain that is unstable in any other way. The phasing out of fossil fuels such as coal, oil and gas, which are presently largely imported into the EU, reduces the dependence on countries outside the EU - but only if they are replaced by more local resources such as wind power and (local) solar energy.¹⁰⁵

Energy storage will be an important component of the stability of the energy system. It is still uncertain how much green hydrogen Europe can produce itself and how much will have to be imported. At present we are heavily dependent on countries outside the EU, such as China, for the production and import of batteries.

103. The Economist (2025), 'Donald Trump's war on renewables'. In: The Economist. Accessed on 5 August 2025 <https://www.economist.com/briefing/2025/07/31/donald-trumps-war-on-renewables>.

104. H. Kroll (2024), *Assessing Open Strategic Autonomy*, Luxembourg: Publications Office of the European Union, <https://data.europa.eu/doi/10.2760/767279> (JRC136359).

105. If reliance was placed for a substantial proportion of the necessary primary energy on solar power from the Sahara, for example, which is then converted into a fuel that is transported to the EU, this would create a new dependence.

There are also sectors where the EU is itself a producer but is dependent on other countries for essential raw materials. This is the case particularly for technologies such as hydrogen-powered vehicles, electric vehicles and energy storage (e.g. batteries). There are also sectors in which the EU is almost entirely dependent on China for essential raw materials, for example for photovoltaic energy generation. International cooperation will also be essential for CCS projects, for example setting up a network for carbon storage to enable industrial CO₂ emissions to be captured and stored in empty gas fields under the North Sea.

Some options merely move dependencies around. For example, nuclear energy has the potential to reduce dependence on (imported) fossil fuels, but the uranium that serves as a 'fuel' is a critical raw material which is currently sourced primarily in Canada, Kazakhstan, Niger and Russia.

Significance of strategic autonomy for policy

There are two considerations when incorporating strategic autonomy in policy. First, it is important to think about how to deal with dependencies on others; Second, a decision needs to be made on where we are able and want to be autonomous, and on what scale.

Dependence

Numerous strategies are possible as regards dependence. Full autonomy (and thus independence) is at one extreme, but is often not very realistic. Researchers at Clingendael (Netherlands Institute of International Relations)¹⁰⁶ have concluded that full independence for the European energy supplies unattainable and that strategic autonomy will therefore likely be largely about differentiation of sources, raw materials and components.

At European level, we see this for example in the European 'Critical Raw Materials' Regulation which was adopted in 2024.¹⁰⁷ This Regulation sets conditions for the supply chains of critical raw materials in order to increase and diversify them.

Other, more generic instruments within trade policy include the Export Control Regulation, Foreign Direct Investment Screening and the recently adopted Single Market Emergency Instrument, with which the EU is attempting to control imports and exports and secure the supply of critical products. The EU is also using budgetary instruments in an attempt to drive the EU towards European strategic autonomy, including by funding Important

106. S. Lokenberg, G. Cretti & L. van Schaik (2023), 'A Tale of Two Dependencies: European Strategic Autonomy in the Field of Energy'. *European Foreign Affairs Review* 28, no. 4, pp. 417-438.

107. Regulation (EU) 2024/1252 of the European Parliament and of the Council of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials, *PbEU* 2024 L.

Projects of Common European Interest focusing on studying researching and creating multinational supply chains in the EU. Another example is the recently established Strategic Technologies for Europe Platform (STEP). This Platform Draws on existing funds and aims to attract public and private investment for the development and production of critical technologies.

The Dutch government has endorsed the importance of European strategic autonomy and aims to play a leading role in related EU programmes and in developing policy in close alignment with European policy. The government has for example published its own raw materials strategy, introducing five trade parameters aimed among other things at more sustainability, improved circularity and diversification of raw materials use. Strategic autonomy can also be influenced through consumption. The most direct way to make the EU and the Netherlands less dependent on energy is energy conservation; accordingly, the NPE focuses heavily on this, in addition to maximum energy production and security of supply.

Autonomy

Securing a leadership position in green technology is another strategy for optimising the use and recycling of critical raw materials. This could also lead to a stronger international negotiating position. At European level, this works through into the way in which the EU is trying to make its own industry more competitive, but at the same time with more 'open strategic autonomy'. The EU plans to combine this in the Net Zero Industry Act, a regulatory framework intended to make industry more sustainable whilst retaining its competitiveness. This can be seen as a response to the US Inflation Reduction Act. The 2024 Draghi report also fits in with this context.

Aiming for a leadership position in green technology will require radical innovation by present-day industry. In a report on the status of open strategic autonomy in the EU, the Joint Research Centre highlights two dimensions as being of great importance:¹⁰⁸ autonomy in innovation and economic autonomy. Autonomy in the innovation process is concerned with the influence of external stakeholders on innovation processes (the more external influence, the less autonomy). Economic autonomy is characterised by the absence of material and production dependencies in the relevant value chains. Economic autonomy is important for prosperity today and in the near future. Autonomy in innovation, by contrast, is plays a role in prosperity in the longer term, because it has a decisive influence on the socio-economic model of the future.

108. Kroll, H. (2024). *Assessing Open Strategic Autonomy*, Luxembourg: Publications Office of the European Union, <https://data.europa.eu/doi/10.2760/767279> (JRC136359).

Relationship between dependence and autonomy

The two strategies often go hand in hand. A strong position in the production and innovation of green technologies can not only reduce dependence on raw materials or production processes, but can also make other partners dependent on home-grown technology. For example, China and (until recently) the US focus on innovation in order to become leaders in key technologies. By doing so, they are safeguarding their own strategic autonomy. Examples include the 'Made in China 2025' strategy and the US Chips Act.

Within the EU, by contrast, efforts are directed towards integration of the Dutch energy market with that of other EU member states in order to increase stability, for example through cross-border infrastructure projects and joint investments in renewable energy (specific reference is often made here to the linking of networks with Germany and Belgium), knowledge-sharing and policy coordination and harmonisation of regulations within the EU. In addition, the Netherlands is already working with other EU member states to develop joint offshore wind energy projects in the North Sea.

Strategic autonomy in international partnerships

How are the forgoing considerations incorporated in strategic choices around energy innovation in international partnerships? A conversation with the Ministry of Economic Affairs and the Ministry of Climate Policy and Green Growth revealed that strategic autonomy plays only a limited role in the strategic decision-making around energy innovation. Strategic autonomy is still principally linked to critical raw materials, with little or no critical review of dependencies in production processes or in the resultant energy supply. A start is being made on efforts directed towards bilateral cooperation, European and international funds, with the Integral Knowledge and Innovation Agenda (IKIA) – a working up of Dutch priorities in energy innovation – but in reality the decision on which international projects the Netherlands signs up to is based more on a degree of opportunism. International funding is so difficult to organise that strategic autonomy can be an obstacle to potential collaborations. In practice, the Netherlands generally collaborates with partner countries which are (currently) reliable, making testing less essential. There is an awareness at the Ministry of Economic Affairs and the Ministry of Climate Policy and Green Growth of the risk of dependence, but this is not yet a serious focus area. The impression is that the same applies at local government level.

Implications for energy innovation policy

Strategic autonomy thus has a number of implications for Dutch energy innovation policy.

First, strategic autonomy underlines the importance of radical innovation or breakthrough innovations. There is an enormous challenge in making industry more sustainable. It is also vital to make industry as circular and independent as possible.

Total independence is neither feasible nor desirable. The best way to reduce vulnerable energy dependencies is by working at EU level. The Netherlands can contribute to this anyway that benefits it as well. On the innovation side, acquiring a leadership position in a particular technology or other innovative solution can reduce or positively influence vulnerable dependencies. The Netherlands could aim to play a leading role in one of the value chains that are considered important for the European energy system. Integrating the European energy system would enable value chains to be split across several countries, with individual countries taking ownership of part of a value chain, for example transport or hydrogen. This implies that the Netherlands needs to specialise more and may have to choose which innovation challenges to focus on in order to acquire a position of strength.

In creating the NPE, it is clear that consideration was given to the opportunities for the Netherlands to exploit its own strengths and utilise them to support the European energy system, for example by acting as a hydrogen hub or by concentrating storage, conversion and distribution within and between the different energy chains in the Netherlands. It therefore does appear that the Dutch government is aware of the opportunities.

Some of these plans will require a great deal of innovation, and the Netherlands can only assume a leadership role here if it sets clear priorities. Which are the innovation needs or parts of the chain on which the Netherlands/Dutch players wish to focus? It is precisely on this issue of prioritisation, however, that the focus appears to be too diffuse. The present mission-driven innovation policy is based on five missions which together effectively describe which societal challenges need to be overcome to achieve a zero-emission energy system. These missions are divided into several Multi-year Mission-driven Innovation Programmes (MMIPs).¹⁰⁹ The question is whether these missions will lead to the convergence of efforts which would enable the Netherlands to genuinely achieve a leadership position in a particular technology or domain. That requires more than simply offering space for good ideas; It also requires a transformation of the entire surrounding ecosystem, with institutional and social innovations. Thinking in terms of missions is a good way of eliciting creativity, but must not turn into a way of avoiding strategic choices. Moreover, the Netherlands will have to learn to exploit its position of strategic autonomy vis-à-vis other partners. Having ownership of one point in the network can deliver an advantage, but can also result in the risk itself being played out between other superpowers, as in the case of ASML.

109. M. Janssen (2023). *Adviesnota monitoring en evaluatie missiegedreven innovatiebeleid*. Utrecht: Copernicus Institute of Sustainable Development - Utrecht University.

The Netherlands is making good strides in reducing dependence with its raw materials strategy, which aligns with the European Critical Raw Materials Regulation. However, the question is whether this is filtering down to all administrative layers. Many choices relating to raw materials are taken at provincial or local level, for example when it comes to the methodology used for storing energy.

Appendix 3 Assessment framework

Assessment framework from earlier AWTI advisory report (2016)

AWTI's 2016 advisory report 'Grasp the challenge' ('Oppakken en doorpakken') presented an assessment framework to help decide the best innovation missions for energy for the Netherlands to focus on. There were two levels to the framework: the first was intended to help in deciding which options for energy were promising and desirable for the Netherlands (which fuels or energy conservation options). The second level was intended to help decide which knowledge and innovation needs the Netherlands should focus its attention (and money) on as a priority for the options selected in the first level of the framework. Those would be innovation missions which were a good fit for the Netherlands.

The assessment framework from 2016 is summarised below.

Two-stage assessment framework from AWTI advisory report 'Grasp the challenge' (2016)

In the first stage of the assessment framework (options) the following were listed as relevant issues:

- ▶ What is the expected impact of this option (how much does it contribute to the goals)?
- ▶ To what extent does the Netherlands have a relative advantage with this option?
- ▶ How well does this option align with (the vision for) the future energy system?

In the second stage (selection of innovation challenges on which the Netherlands should focus as a priority), the following aspects were regarded as relevant:

- ▶ Is the same thing already being done elsewhere?
- ▶ Is the necessary knowledge present in the Netherlands, and does the Netherlands have a world-leading position?
- ▶ Are relevant companies available and willing to invest?
- ▶ Does a market exist, or can one be created, possibly with help from the government?
- ▶ Are there opportunities to link with other innovations, sectors or developments?
- ▶ Is there public support, or can that be created?
- ▶ Are there (other) barriers to certain innovation steps, such as a lack of infrastructure?

Update needed to accommodate new developments

All kinds of things have of course taken place since 2016, for example the growing importance of strategic autonomy, the greater role for the EU in the field of energy and climate, and the emergence of civic initiatives in the energy domain. These developments were not included, or to only a limited degree, in the 2016 assessment framework. It is therefore high time it was updated.

Towards a single-stage assessment framework

The first important update is to create a single-stage assessment framework. There was not yet a vision for the future energy supply in 2016 and it was therefore logical that the assessment framework also homed in on the underlying question of which energy resources the Netherlands would need to use in the future. Since then, a vision has been set out in the NPE for the energy system of the future. Although AWTI has called for this vision to be more broadly embedded in the vision for the sustainable economy and society in 2050, we can now assume that the underlying question of which energy options the Netherlands has been answered wishes to choose in that vision. When answering this question via the broad vision, strategic autonomy will also need to be explicitly included as a relevant focus area. The shift away from fossil fuels, which predominantly come from outside the EU, to alternative fuels, offers an opportunity for the EU to become more autonomous in its energy supply. If this broad vision provides clarity on which fuel options the Netherlands wishes to choose in the future, the assessment framework can then focus on the selection of the innovation missions on which the Netherlands should focus as a priority. They are closely related to the fuel options chosen.

The key issues

Yet the questions posed in the first stage of the 2016 assessment framework are still highly relevant for the updated framework, since they play a major role in determining how attractive it is for the Netherlands to take on a particular innovation challenge:

- ▶ The *alignment* of the innovation with the future sustainable energy system.
- ▶ The *impact* of the innovation, both in terms of achieving the sustainability goals and its social and or economic value.
- ▶ The *chance of success*: the degree to which the Netherlands meets the conditions to make the innovation a success; does the Netherlands have a relative advantage to enable it to make a success of this innovation?

The closer the alignment with the future system, the greater the (expected) impact, and the greater the chance of success, the more attractive it is for the Netherlands to take on the innovation mission in question. To what extent does a further aspect needed to be added based on current developments?

Strategic autonomy in an assessment framework?

Strategic autonomy was not *explicitly* included as a point for consideration in the 2016 version of the assessment framework (see box). At that time, there was more optimism about the degree to which knowledge, raw materials and materials could be ‘freely’ obtained from elsewhere. Yet it could be said that the importance of autonomy was already implicitly included where the assessment framework assigned a clear preference for chains in which the Netherlands was active in many links, i.e. chains in which there was limited dependence on other countries and thus a fairly high degree of autonomy.

Today, in 2025, strategic autonomy undoubtedly warrants a place in the assessment framework. First, strategic autonomy works through into the broad vision of the economy, society and energy supply in 2050: which fuel options do we foresee in that sustainable future? How (in)dependent does the Netherlands wish to be? Which dependencies are still considered acceptable? This aligns with the second point in the 2016 assessment framework relating to fuel options: ‘the relative position of the Netherlands’. Questions can be included in the new version relating to the degree of dependence or autonomy for each option. The less dependent the Netherlands is on external parties, the more attractive the (fuel) option is, and with it the associated innovation missions. Since geopolitical developments are difficult to predict on a time scale up to 2050, it is crucial to make an assessment now regarding the areas where the Netherlands wishes to be autonomous (‘critical’ elements of the energy supply, infrastructure or economy), where autonomy is desirable but not essential, and where it is less vital. This layered structure will then itself work through into the broad vision and subsequent policy choices.

The second level of the assessment framework homes in on the prioritisation of innovation missions (and the associated technologies). The first questions relate to the (relative) position of the Netherlands. Is the same innovation mission also being worked on elsewhere, and with what progress? Where is the knowledge available, where are the relevant companies? Whereas in 2016 it would have perhaps been logical for the conclusion to be ‘don’t do it here’ if other countries have progressed further in terms of knowledge or available companies, in 2025 the situation is more nuanced. Suppose we are talking about critical technologies in chains which are important for Europe or the Netherlands, but for which the expertise or industrial activity currently lies outside the EU. That could well be a reason to develop that knowledge or industrial activity *within* the EU. The Netherlands could then be in the picture if it has a position of *relative* leadership within the EU.

Including the aspect ‘strategic autonomy’ in the assessment framework essentially concerns the question of whether there are strategic reasons for taking on a particular innovation mission in the Netherlands. There may be geopolitical reasons for this, for

example that we do not wish to be dependent on other regions, or that we believe we are in such a relatively good starting position that it makes absolute sense for the Netherlands to take on the innovation in question. But a desire to protect the autonomy of citizens, organisations and businesses can also be a reason to take on an innovation here in the Netherlands. If we do not wish them to be made dependent on one or more large players for crucial services or data, that can be a reason to choose to develop or at least certain innovations (intended to prevent that happening) in the Netherlands.

The assessment framework also covers the opportunities for linking to other developments. Strategic autonomy can play a role here, too. What impact does the innovation mission concerned (and the underlying technology) have on the dependence of the Netherlands and/or the EU in terms of raw materials, chain or economy? Does it reduce our dependence (a good thing) or make us more dependent on others (a bad thing)? To what extent does (the expected effect of) the innovation contribute to EU or Dutch policy in relation to (critical) raw materials?

To incorporate strategic autonomy, the first two questions in the second stage of the assessment framework need to be made more specific. In the updated framework, they are split into three questions: first, a question about the international context (the geopolitical dimension of strategic autonomy); second, a question focusing on economic aspects (the economic dimension of strategic autonomy); and third, an update of the earlier question from the 2016 framework about the knowledge position of the Netherlands, including the idea of strategic autonomy. The updated questions are as follows:

- ▶ Are there strategic reasons for wanting to take on this innovation in the Netherlands? Does it contribute to our autonomy? What is being done in other countries and what are our relations with those countries: are they countries we ‘trust’ or on which we would rather not be dependent?
- ▶ Does the innovation contribute to (maintaining) the autonomy and/or freedom of choice of citizens, organisations and businesses?
- ▶ Is the necessary knowledge available in the Netherlands? To what extent does the Netherlands have a world-leading knowledge position, among ‘friendly countries’ and in the EU?

Other developments in the new assessment framework: civic initiatives

Another important development since the 2016 advisory report is that many citizens, businesses and organisations are taking steps, individually or in collective initiatives, to increase their sustainability (for example by installing solar panels on their homes or business premises) and moving together towards greater sustainability. These are valuable contributions on the road to the ultimate objective of a sustainable energy

supply. This social driver was not fully incorporated in the 2016 version of the assessment framework.

The original assessment framework did look at whether there was public support, or whether that could be created. This was perhaps a somewhat 'passive' approach: first innovating and only then seeking public support, and thus failing to acknowledge the social 'driver' behind a number of initiatives. In these bottom-up civic initiatives, public support is an active source of innovation(s). Our proposal is therefore to reformulate this aspect of 'public support' as follows, and in doing so to acknowledge the relevance of a 'bottom-up' driver:

- ▶ Is there is social driver (for example civic initiatives) or public support, or can that be created?

Links to other policy

The original assessment framework contains a question on opportunities to link with other innovations, sectors or developments. The Council now also believes it is important to look at the opportunities to link with other policy, such as general, non-energy-specific policy on technology or EU policy around energy and energy innovation, for example alignment with the National Technology Strategy.

As regards the link with EU policy, in its advisory report *Strategic interplay* (2023) AWTI recommended establishing a carefully considered link between European policy for research and innovation. The Council recommended always carrying out an 'EU-check' before introducing a national measure or policy. Does the national policy strengthen the European choices or priorities? Or, by introducing national measures, is the Netherlands deliberately focusing on topics that are not on the EU's radar? If it is decided at national level to strengthen the chosen policy in the EU, this could be leveraged to increase the success of the Dutch efforts. On the other hand, the Netherlands could consciously choose to develop a niche on which the EU as a whole is not focused. It is important that these (national) choices are made in a considered way. The same applies for choices around energy research and innovation.

The Council therefore proposes modifying the original question about linkage to explicitly include opportunities for linking to other policy, whether that be related national policy (such as a Technology Strategy or policy for strategic autonomy around raw materials), or EU policy. The question in the assessment framework then becomes:

- ▶ Can links be made to other innovations or policy?
(Such as the National Technology Strategy, EU policy or civic initiatives)

An updated assessment framework

an updated assessment framework will help the government and stakeholders to select those energy innovation challenges on which the Netherlands wishes to focus as a priority.

In this context, it is important to make an assessment of the following aspects:

- ▶ *The alignment* of the innovation with the future sustainable energy system (as ideally set out in a broad vision for a sustainable economy, society and associated energy supply in 2050, which takes account among other things of strategic autonomy for fuels, raw materials, etc.),
- ▶ *The impact* of the innovation in question, both in terms of its contribution to achieving the sustainability goals and its social and/or economic value, acknowledging the importance of how easily that innovation can be produced or upscaled elsewhere?
- ▶ *Strategic autonomy*: how important do we think it is – strategically – to develop the innovation in question in the EU or the Netherlands?
- ▶ *Chance of success*: the degree to which the Netherlands meets the conditions to make a success of this innovation challenge: does the Netherlands have a relative advantage to help this innovation succeed?

The closer the alignment with the future system, the greater the (expected) impact, the greater the importance of strategic autonomy and the greater the chance of success, the more attractive it will be to take on the innovation mission in question in the Netherlands. These four aspects are worked up in more detail in the following questions, which together form the updated assessment framework (which is based on the 2016 framework with the adjustments described above):

Table 2: Updated assessment framework to determine priorities for energy innovation

<i>Aspect</i>	
Criterion	Question
<i>Alignment</i>	
Alignment with broad vision	How well does the innovation align with the (vision for the) future sustainable economy, society and energy supply?
<i>Impact</i>	
Expected impact on sustainability	What is the innovation expected to contribute to the energy and climate goals?
Expected impact on economy and society	What is the expected impact of the innovation on the economy and society? Will it contribute to earning capacity, the phasing out of undesirable dependencies and the achievement of social objectives? How reproducible and scalable is the innovation?
<i>Strategic autonomy</i>	
International context	Are there strategic reasons to take on this innovation in the Netherlands? Will it contribute to our autonomy? What is being done in other countries and what are our relations with those countries: are they countries we 'trust', or on which we would rather not be dependent?
Economic relationships	Will the innovation contribute to (maintaining) the autonomy and/or freedom of choice of citizens, organisations and businesses?
<i>Chance of success</i>	
Knowledge position of the Netherlands	Is the necessary knowledge present in the Netherlands? To what extent does the Netherlands have a world-leading knowledge position, among 'friendly countries' and in the EU?
Stakeholder willingness	Are companies/civil-society organisations available and willing to invest?
Market potential	Is there a market, or can one be created (in the Netherlands, the EU or worldwide), possibly with help from the government?
Social potential	Is there a social driver (for example civic initiatives) or public support, or can that be created?
Linkage opportunities	Can the initiative be linked to other initiatives or policy? (such as Technology Strategy, EU or civic initiatives)
Obstacles	Are there any (other) barriers to certain innovation steps, such as a lack of infrastructure or legislation?

Appendix 4 Innovation case studies

Three Innovation cases were studied in the energy domain to gain a better understanding of the main obstacles and the most difficult steps in ensuring a successful innovation. These case studies illustrate which (enabling) conditions need to be met for the successful facilitation of such an innovation.

The innovation case studies

Offshore wind: This was identified by AWTI in 2016 as a promising opportunity. In fact it is one of the few options that the Netherlands has to produce renewable electricity on a large(r) scale. It has now become an example of a successful breakthrough: within a limited number of years a major leap in capacity has been achieved. Technical steps have been taken (ever larger turbines) and the cost has fallen sharply. This is due in part to efficiency gains in installation and maintenance, while the government has also ensured the enabling conditions are met (such as the infrastructure needed to bring the electricity ashore, streamlining the licensing procedures and operational subsidies). That has also lowered the price to consumers. Despite this, an even bigger leap and larger scale will be needed in the future (from 2 GW to 70 GW installed capacity).

Steam from electricity: Steam is used in industry in large quantities in a variety of processes. At present, steam is generated using gas. If we stop using gas, generating steam from electricity will be the only clean alternative remaining (unless alternatives emerge to the use of steam). Technically, this is already perfectly possible (by using an e-boiler), But it is currently too expensive to generate steam.

Realising this option in practice will therefore require essential steps to be taken both in the market and in the institutional organisation. In the market, a shift would be needed in the relationship between the prices of electricity and gas. At institutional level, the right contracts need to be created for users of steam. One possibility would be for such a contract to enable users of steam to provide services to (local) network operators. Another option would be for several users of steam within the same area to forge some kind of partnership to lower the costs of switching to steam from electricity. This is an example of an innovation case study where the required developments are not so much technical, but lie primarily in other dimensions (especially institutional).¹¹⁰

110. At times when the electricity price is low, it is already feasible to generate steam using electricity; see: H.P.A. Knops, A.C. Patil & R.M. Stikkelman (2014), "Power-to-value": Converting Excess Wind Power into Valuable Products or Processes', *Proceedings of IAAE Conference*, IAAE: Rome. Knops *et al.* (2014) refer to the Port of Rotterdam as a cluster where there was a good chance of implementing this option. However, institutional obstacles mean this has not yet happened. The Maastricht-based paper manufacturer Sappi has however recently announced plans to produce steam from electricity and to provide services to the network operator (see B.

A further pitfall is that focusing on the option which might appear the most valuable *now*, namely a hybrid steam plant fuelled by gas and electricity, means deferring the full phasing out of gas as an energy source for generating steam.

Salt batteries: New ways of storing energy will be an essential part of the future (sustainable) energy system. One disadvantage of traditional batteries is the need for rare minerals in their production, which largely come from outside the EU. Using salt to store energy is therefore an interesting option, given the plentiful local supply of this mineral. Various energy storage technologies based on salt are currently being developed in the Netherlands (see Appendix 4 for two examples, and an article from the *Financieele Dagblad* newspaper from 2024 for further examples)¹¹¹. What these options have in common is that the technology is still being developed, while at the same time work is ongoing to determine precisely what their business case will be and how they can be aligned with the regulatory and market systems. An example is the technology being developed by Aqua Battery, using membrane technology. Another initiative is a joint project by TNO (Netherlands Organisation for Applied Scientific Research) and TU/e (Eindhoven University of Technology) involving thermochemical storage, i.e. storage of heat, in a salt battery, something now being worked on by a spin-off (Cellcius). The essence of these projects is the interplay between technological progress and the development of potential applications and business cases, as well as clear parameters around regulation and licensing. It is also striking that there is currently no financial incentive ('premium') for contributing to strategic autonomy. Everyone sees the strategic benefits of salt batteries (the ingredients needed are obtainable locally), but no one is yet 'paying' for them.

Below we describe the main lessons regarding the obstacles in the innovation process, subdivided into relevant dimensions of technology, institutions and social aspects.

Technological dimension:

The technological steps around an innovation are usually clearly expressed in the innovation policy. Using a variety of policy instruments, the development is promoted via the ladder of Technology Readiness Levels. Yet we do see obstacles with technology development.

Obstacles:

System dimension of technology. Each new technology/innovation becomes part of a technical system and has to fit in with it. This might be a matter of alignment, compatibility

van de Weijer (2024). 'Vol stroomnet? Een elektrische reuzenboiler kan wonderen verrichten', in: *de Volkskrant* 25 June 2024).

111. Selderbeek, E. (2024). 'Elk type batterij telt in zoektocht naar langdurige energieopslag', in: *Financieele Dagblad* 24 June 2024.

or the underlying capacity of the system to integrate an innovation. This often requires adaptations to the existing (technical) system, and the policy does not always take this into account early enough. This can then form an obstacle to the innovation. Here, too, issues around strategic autonomy can be relevant: who is the owner of the infrastructure and does this generate undesirable dependencies?

The market. If a technology is not efficient or cheap enough compared with alternatives, bringing it to market will have little chance of success. As a result, the innovation will not readily be taken into use. The government can play a steering role using corrective mechanisms such as pricing of the alternatives (and their external effects) or by subsidising the innovation. Measures to phase out existing practices (for example through standardisation or prohibition) can help the new technology gain ground.

Technological path dependency. Certain technological choices may be necessary for the purpose of continued development or profitability, but can subsequently lead to a 'lock-in', possibly preventing the new technology from achieving its full sustainability potential. A hybrid system for generating steam from electricity is a good example of this: a hybrid system involves installing a gas-fired and an electrical steam generator. This combination has a shorter payback time than an electrical steam generator alone, but the hybrid installation means that gas continues to be used for longer.

Institutional dimension:

Institutional changes are often necessary to accommodate innovations in the system, but the institutional domain itself is also a source of innovation. New types of collaboration around energy, for example in energy cooperatives, or new types of contract which enable subscribers to contribute to the network management, are examples of institutional innovations. Climate objectives give direction and stimulate developments. Yet there are also institutional obstacles to breakthroughs in the energy domain.

Obstacles:

Public funding structures. The way the government gifts support can hold back innovations with lots of potential, because the government programmes (at that moment) make cheaper alternatives more appealing. An example was the original design of the SDE subsidy programme, in which subsidies were only given to the energy option which was the cheapest at that time. No allowance was made for the possibility that other options might in time be much more attractive (and cheaper). The focus was on short-term financial aspects rather than sustainability aspects in the longer term which would or could be achieved using future breakthroughs.

Poor fit for the system. The way in which sectors or markets are organised can be explicitly or implicitly disadvantageous for potential breakthroughs, because those

breakthroughs do not fit in with the existing system. In the most extreme case, the existing regulation or structures will mean an innovation is not possible at all. Less extreme, but still an inhibiting factor, is lack of clarity about whether or not a licence must be obtained for something, and if so, which. We see that in the case study with energy storage using salt batteries. Not only is the economic status of such storage not fully crystallised, but local authorities often have no idea at all which licences apply.

Interests. Existing parties sometimes have different interests than the 'extrapolated' innovation. These vested interests then stand in the way of sustainable innovations. They prevent barriers in the process from being overcome or impede the ability to upscale such innovations.

Social dimension

There are two forces in the social dimension, which can act as a stimulus or an obstacle to (leaps in) the innovation process.

Societal embedding. There may be resistance or lack of support for certain innovations. In that case, public attitudes can form an obstacle, because resistance leads to delays in granting permits, or to political pressure against certain sustainable subsidies. On the other hand, forces can emerge from society which help get certain innovations off the ground. We are seeing all manner of initiatives being taken by citizens, businesses and organisations to move towards more sustainability themselves. These translate into numerous new institutional arrangements, and new innovations are applied. In this instance, society act as a driver of innovations.

Trust. Trust is a relevant factor for the successful progress of innovation processes. Lack of trust inhibits progress. Vacillating government policy, for example, reduces trust among market players, making them less inclined to invest in innovations. Trust between private parties is also important. That cannot always be taken for granted, for example because people have to agree on sharing data, trade agreements or shared management of installations. If that trust is present, is in line with the policy and regulation, or exists between businesses or organisations, this forms a solid basis for working together on developing new (institutional or technological) solutions.

Appendix 5 Interviewees

▶ Olaf Adan	TNO/Cellcius
▶ Marco de Baar	Differ
▶ Peter de Bock	ARPA-E/Eaton
▶ Mark Boneschanscher	Eindhoven University of Technology
▶ Martin van Breukelen	Differ
▶ Lisanne Brummelhuis	Ministry of Economic Affairs
▶ Hugo Buis	Noordzeker
▶ Jiajun Cen	Aqua Battery
▶ Fonz Dekkers	Ministry of Climate and Green Growth
▶ Floor Hooijman	Rebel Group
▶ Myrthe Hooijman	Techleap
▶ Lena Kitzing	DTU (Technical University of Denmark)
▶ Zofia Lukszo	TU Delft
▶ Peter Molengraaf	Top Sector Energy
▶ Jelle Nijdam	RVO
▶ Andrea Ramirez Ramirez	TU Delft
▶ Marjolein van Splunder	Ministry of Climate and Green Growth
▶ Wim Turkenburg	Utrecht University
▶ Jacqueline Vaessen	Top Sector Chemistry/NL Hydrogen
▶ Laurens de Vries	TU Delft
▶ Pascal Weijers	Windunie
▶ David van Walderveen	Differ
▶ Peter Maarten Westerhout	Techleap
▶ Christian van der Woude	Techleap

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