AI as an accelerator of the energy transitition
Opportunities for a carbon-free energy system

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AI AS AN ACCELERATOR OF THE ENERGY TRANSITION

Opportunities for a carbon-free energy system

NL AI Coalition

CONTENTS

1 AI AS AN ACCELERATOR OF THE ENERGY TRANSITION

During the next 10 years, the Netherlands is aiming to significantly increase production of renewable energy and to expand the electrification of heat demand and mobility. Such an ambition requires a complete and highly complex conversion of the energy system – the *energy transition* (GasUnie & TenneT, 2020 and 2021). An important part of this process is the involvement of the regions and the various stakeholders, which makes the decision-making processes more complex.

Artificial Intelligence (AI) can play a major part in accelerating the energy transition, among others by:

- Using AI to support regional planning and decision-making, while taking account of various factors, uncertainties, the many stakeholders, adaptive investments, and the impact of the energy system as a whole on the local environment.
- Making better use of existing energy infrastructures and the interaction between energy carriers, as more and more areas reach their limit as a result of congestion. With a modification to the rules, AI can ensure lower investments and shorter turnaround times in this regard.
- Offering AI support to various parties (businesses, prosumers, consumers) for supplying energy services (supply, storage, conversion, flexible consumption) or for consuming energy more smartly.
- Predicting and anticipating maintenance, and automating inspections and maintenance, especially in places that are difficult to access (for example, using drones for wind turbines far out to sea and small robots for gas network pipelines).

Worldwide, the fossil-based central energy system is set to change to a partly decentralised system based on renewable energy. As a result, the extraction of energy in the future will very much depend on fluctuating sources like the wind and the sun, which of course cannot be predicted or controlled to any degree of perfection. This variability creates a need for storing energy and for managing demand, with end-users playing a more active part in the energy system. New business models are essential in order to make this transition possible.

AI can play an important part in many of these worldwide developments – in predicting the yield of solar and wind energy and the demand for energy, for example, as well as in the use of data (real-time or otherwise (dena ANALYSIS: Artificial Intelligence – from Hype to Reality for the Energy Industry, 2020). Predictions and data are then used for both operational and strategic management: AI enables the autonomous control of adaptive and self-learning parts of a large-scale system, and it also helps support strategic decisions relating to such a system, where various interests are at stake.

Useful solutions that are being developed in the Netherlands can be used worldwide, and therefore exported. It is thus important to make sure that Dutch companies and knowledge institutions that have AI for these new challenges start pursuing this route.

Dutch companies are currently not making sufficient use of these opportunities. An explanation is that the energy transition is a highly dynamic process and that the successes of possible solutions very much depend on each other. Individual, local innovations are only of any value if the rest of the energy system has been transformed. The speed at which the changes will take place and the design and structure of the energy system in the future are not clear, which is causing great uncertainty among businesses in the energy sector. Nor is it clear to every party in the transition what is at stake, while the common interests of the energy transition override individual priorities. What is needed, therefore, is leadership to enable the development and integration of innovations until there is greater certainty regarding the form that an intelligent carbon-free energy system will take. However, there is no doubt that such an energy system will come.

This document describes the long-term vision of the opportunities and innovation tasks involving the use of AI for contributing towards the energy transition. It has been decided not to opt for a specific scenario or specific vision, but instead to look at a range of possibilities, among others derived from the integrated knowledge and innovation agenda for the energy transition. It is written as a starting point for discussions with stakeholders, as the basis for defining calls (in the context of the AiNed Investment Programme, for example (2019)), and for the formation of consortia.

This analysis starts with missions A and B of the integrated knowledge and innovation agenda (2019) – that is, a complete carbon-free electricity system and a carbon-free built environment by 2050 (Climate Agreement, 2019).[1]

In this document, we present our analysis of the knowledge and innovation tasks on the basis of, among other things, the descriptions in the long-term mission-driven innovation programmes 1-5 and 13, which are linked to missions A and B, and the possible contribution of AI and AI-related innovations to these missions. This concerns support for decision-makers with regard to investments in the energy system, making operational (and sometimes real-time) choices for operating the system (smart grids, for example), organising flexibility, automating maintenance, and reducing energy consumption.

After identifying the AI tasks related to these missions, we will analyse them on the basis of the following questions:

1. What are the challenges (that feature in these long-term mission-driven innovation programmes) that AI could have the most impact on, perhaps because the challenges in question cannot be met (or not met as well) without AI?
2. What are the AI-related challenges that come with these challenges? What AI technologies could be used or adapted for this purpose, taking relevant national and European frameworks and guidelines into account? What area of AI is relevant in this regard?
3. What is needed in order to accelerate the development of knowledge and innovation in relation to these AI challenges?

1. Missions C, D, and E will be included in future discussions on AI and sustainability.

2 THE IMPACT OF AI

The use of AI for the challenges referred to in the long-term mission-driven innovation programmes (see Appendix B) has major consequences for how the energy system is organised, the environment (how the energy system is physically integrated), and for the way in which energy is used (by industry and in the built environment). Although everything is ultimately interconnected, we discuss separately below the challenges relating to strategic choices (investment decisions, design, social considerations), operational optimisation, interaction with users, maintenance, and the reduction in energy consumption through AI methods.

When applying AI to a system that is such an essential part of our everyday lives, as the energy system is, it is important to take account of generic preconditions for AI such as privacy, security, reliability, explainability, accountability and resilience. In some cases, AI can actually help protect these processes. In this document, we focus our analysis on the tasks specific to the energy transition.

2.1 Support for decision-makers involved in complex strategic choices

The energy transition requires decisions (on investments, design, social considerations) in a complex and uncertain environment involving numerous stakeholders with differing and sometimes conflicting interests. Energy systems are generally created for the long term (30 years or more), are highly capital intensive, and in many cases have a significant impact on other decisions that have to be taken now or in the future (a large windfarm, for example, will affect the fishing industry, a heat network will affect nearby drinking water pipelines, and vice versa).

These considerations are becoming evermore complex because of the increasing integration between the energy systems of various energy carriers, the increasing pressure on space, and the increasing number of stakeholders in the decision-making process (Geothermal energy in the built environment, 2021). In this situation, decisions have to be taken using uncertain *data* (such as subsurface data) and *forecasts* (of future heat or energy consumption, for example) and sometimes structural uncertainties (which is the right model to use, such as in the case of social factors). These decisions have to be taken at different places in the chain of stakeholders, with the decision and consideration criteria depending on the respective stakeholder. AI can provide support in various ways when it comes to dealing with the complexity of decisions of this kind and with the extremely large scenario settings.

2.1.1 Assessment models and decision-making support tools

In order to reach robust decisions that enjoy general support, assessment models and decision-making support tools are needed that can highlight what solutions are possible in a specific situation. Taking decisions with the help of AI can contribute towards the energy transition through the presentation and interpretation of the great complexity of data and information, and by proposing solution options based on objectives, uncertainty analyses, preconditions, and risks.

Examples include (references to the relevant long-term mission-driven innovation programmes are in brackets):

- Decision-making support and tools for investments in an integrated energy system, such as where infrastructures for different energy carriers can be connected;
- Decision-making support and tools for chain communication concerning regional energy strategies, such as for the design of collective heat networks, in particular with sustainable heat sources like geothermal energy, biomass, and low-temperature sources in combination with the seasonal storage of heat, with both underground and above-ground aspects being of importance, including the creation of scenarios and sensitivity analyses and the balancing of interests in relation to space being used for multiple purposes (4.4-4.7, 5.2, 13.1, 13.2, 13.3);

- Decision-making support for the renovation of individual buildings (insulation, electrification, heat storage, ventilation), the validation and improvement of renovation concepts through the use of data, understanding the current condition of homes and of the practical costs of renovation, taking account of circularity ambitions such as carbon emissions and carbon in building materials and with possible problems regarding the availability of critical and non-critical materials (2.2a, 3.1-3.3, 4.2);
- Supporting investment and system-allocation issues in an uncertain and complex environment, with numerous stakeholders with differing and sometimes conflicting interests (5.3, 13.1), coordination and consideration of spatial planning, underground and above ground (5.4, 13.2); this could include, for example, decisions about the sites of renewable sources, storage (batteries) or conversion (hydrogen power plants), taking account of circularity ambitions and the availability of materials.

2.1.2 Data access and data sharing

Being able to take joint decisions in the chain makes access to reliable basic information essential (13.2). Examples include:

- An understanding of the space and condition of the subsurface for the infrastructure for new heat solutions, of the deep subsurface in relation to the potential for geothermal energy and energy storage;
- An understanding of data relating to the deep subsurface for the development of (offshore) wind farms;
- Real-time energy consumption and the most important parameters that affect it;
- Real-time and historic price information as the basis for price forecasts;
- Real-time (and predictive) awareness of the load on the electricity infrastructure as the basis for deploying smart energy services and for investment decisions related thereto (5.4);
- Combining satellite data, weather data, weather models, climate change, resource assessment (wind and sun), real-time network and consumption information in order to coordinate energy production and demand as effectively and efficiently as possible (2.2.1);
- Better understanding of practical costs of renovation for validation and improvement of renovation concepts (3.1-3.3);
- Availability and the certainty of supply of materials and components that are essential for the technical infrastructure needed for an energy transition;
- The joint scenario space and its use.

2.1.3 Predicting interaction between the energy system and the local environment

Far-reaching changes to the energy system can also have far-reaching consequences for the local environment, and vice versa. It is important to have a clear understanding of this. For example:

- Understanding and managing the subsurface and the environmental impact on soil and water caused by heat storage, geothermal energy, or thermal energy from water (4.5, 4.6);
- Predicting and responding to bird migration patterns;
- Monitoring, predicting, and responding to the environmental impact, both during installation and use;
- Investigation into sun and wind climate, and into wave and current movements, including their mutual effects (1);
- Effect on the liveability of the local environment (such as shadow flicker, noise nuisance);

- Effect of the local environment and subsurface on the costs of and the time taken to install new components of the energy system (such as the creation of a heat network, or the insertion of piles for wind farms);
- Understanding and predicting the behaviour of citizens and businesses.

2.1.4 Data analysis and support for improving designs

AI and data can help bring about further improvements to sustainable generation technologies. Possible examples include the simulation and automatic evaluation of designs. Among the areas where this could help are:

- Designing quieter turbines and more aerodynamic blades (2.2b, 2.2c);
- Improving the design of heat pumps and of thermal energy storage (4.1, 4.3);
- Optimising the design of solar and wind according to yield and location. This concerns radiation, the albedo effect, cooling, contamination aspects and the effect of wave movements on the yield;
- Optimising the solar and wind energy chain: from design tools and the use of visualisation software, the design of solar systems vis-à-vis their lifespan; reducing the costs of producing and assembling the building element, including the solar power function;
- Optimising the transport and installation costs of the system, the operational and maintenance costs, and the costs of disassembly and recycling the system (and its components) (2.1);
- Analysing the implications for the whole system of design choices, and optimising the design of the system in relation to the costs over the entire lifecycle and use of critical materials.

2.1.5 AI challenges

The horizon for *strategic choices* (both for the energy system and for individual users) is much further away; there are also major uncertainties and unknowns, there is more time to decide, while the interaction between human decision-makers and users is very important. Often, there is a wide range of interests to be balanced.

A large number of factors and criteria (such as manoeuvrability/no regret) needs to be taken into account to address the integrated considerations relating to the energy transition in an efficient manner. Uncertainty surrounding policies, cost movements, changes in demand, data uncertainty (such as subsurface), ownership of data, changes to business models and the uncertainty of predictions should be explicitly included in the decision-making process, which will also involve balancing complex social considerations.

These integrated considerations relate to various energy systems (electricity, hydrogen, (methane) gas, heat) and AI can help in the deployment of the models linked to the various systems in an effective and scalable way in the decision-making process. In some cases, there are different models that attempt to describe the same thing, but with another vision or at a different level of detail. AI can help here too, for example by comparing model outcomes and explaining them to users.

This requires the development of new knowledge and tools for supporting decision-makers, as well as reliable data and data interpretations, and tools for the efficient exchange of information in the development and user chains.

2.2 Operational optimisation of production, consumption flexibility and distribution

Until recently, it was demand for energy that was the key factor in the energy system. Supply was determined centrally, in a constellation of electricity markets, which meant that decisions about production in the power stations were taken by a limited number of large producers. The transition to renewable sources means that the centralised management of supply inevitably no longer predominates, but is being taken over by a partly distributed operational system that brings together changes in production, conversion, storage, and consumption instead. This makes accurate forecasting of these aspects and rapid responses very important. The continued electrification of part of our energy consumption (for heating, by industry, for mobility) is also resulting in greater demand for electrical energy that cannot easily be buffered. Control is shifting from a central location to multiple mechanisms (some of which are yet to be designed), more distributed (bottom-up), automated, with a market system that also ensures the efficient prevention of congestion in the distribution network. This bring fresh challenges for network operators, concerning the regulations for energy markets and new business opportunities.

2.2.1 Real-time monitoring and forecasts

Monitoring and forecasting the factors that influence energy production, energy consumption, the effect of the energy system on the local environment or on the costs and reliability of energy can result in improved coordination of energy production and consumption. These forecasts are important in relation to various time scales (seconds to days, to the forecasting of seasonal effects). It is therefore essential that the information about production and consumption is available.

Examples from the long-term mission-driven innovation programmes are related to the combining of satellite data, weather data, weather models, climate change, resource assessment (wind and sun), real-time network and consumption information in order to coordinate energy production and demand as effectively and efficiently as possible (2.1a); Or in relation to heat networks, which concerns the short-term (days) predicting of demand for heat, of heat loss through storage and heat networks, and of heat production through geothermal energy and the sun, as well as the prediction of seasonal influences (2.2a, 4.4-4.7).

2.2.2 Real-time optimisation

The energy system of the future will be multi-modal (a combination of a heat network and an electric heat pump, for example) and will consist of many small and large players, each with their own considerations and interests. For the right type of energy to be produced efficiently at the right time and place, and for it to be available, it will have to be possible for different systems to be aligned and coordinated, with rapid and autonomous decisions being taken and the whole thing functioning as a resilient and robust system. Examples include:

- Optimising energy systems and the links between the infrastructures of the various energy carriers, such as the optimisation of the operation/regulation of collective heat and cooling networks and large-scale heat and cooling storage (4.4-4.7), optimisation of (floating) renewable energy systems and wind farms, and of storage and conversion, by means of hydrogen or methane, for example;
- Monitoring the capacity and the balance in the electricity network;
- Being able to respond swiftly to changing circumstances.

Moreover, rapid methods for real-time optimisation can assist the decision-making support methods described in the previous section by calculating the effect of the strategic choices – those relating to capacity and balance in the electricity network, for example.

2.2.3 Coordination

For the electricity network, it is essential to have the right balance between consumption and production at any time and to take account of the capacity limitations of the distribution network. We have to prevent local optimisations (see the flexibility of users, below) from destabilising the whole system. Flexibility can be applied for different purposes and the interests of actors may run parallel to each other, but they can also collide. A greater understanding of the simultaneity – or lack thereof – of flexibility needs is required. For example, a neighbourhood battery may cause congestion if it is used to prevent an imbalance. There is also a risk here of improper use of mechanisms (gaming).

AI can help coordinate energy systems rapidly and accurately. This entails, for example, the development of new market mechanisms, network tariffs, and coordination systems for correct pricing and therefore using flexibility from the built environment and industry effectively, including the use of adaptable and flexible systems, the availability of information, and security (5.3). What coordination method will lead to an energy system that is not only safe, but also fair and exclusive?

2.2.4 AI challenges

Decisions in the context of *operational optimisation* have to be taken almost in realtime, and therefore automatically as much as possible. Human operators have to be able to monitor and understand these actions and, where necessary, adjust them, or to use the output of a support system in their own decision-making processes. The interaction through the market mechanisms is very important as this determines to a significant degree the efficiency of the whole energy system. In the limited amount of time available, AI can help both trading on the market and matching supply and demand. Uncertainties can be significantly reduced through the ready availability of data and predictions based on it. In addition, disruptive mechanisms on the energy market can be detected at an early stage.

AI solutions are highly suited for achieving this efficiently, even with large quantities of data, but without compromising agreements on privacy. At the same time, the development of embedded AI solutions that can be independent of cloud infrastructure, also known as Edge AI, is an important factor.

2.3 Interaction between users and energy system

Fluctuations in the production of energy (sun, wind) and the demand for energy will lead to bigger challenges when it comes to balancing supply and demand. This can be done by achieving real-time flexibility in the energy system, through load management (across multiple locations) of cloud services for example, flexibility in the use of electricity in industrial processes, households, commercial buildings, and electric charging. In turn, this can be achieved by making industrial production processes controllable (taking the price and availability of energy into account), by flexibilising the habits of consumers and supporting, monitoring, predicting and managing them. Without flexible electricity users, the operational optimisation of a sustainable energy system will be impossible. This flexibility will itself have a significant effect on how the infrastructure is used. In this section, we therefore look separately at supporting these users in their interaction with the energy system.

2.3.1 Increasing the energy flexibility of industry

Relatively small temporal shifts in high levels of electricity consumption can significantly contribute towards adapting levels of consumption to renewable and therefore variable production. This offers opportunities for existing large users of electricity, such as electric arc furnaces or producers of chlorine gas.

In addition, work is underway on the electrification or other modifications of industrial processes that emit large quantities of CO_2. This can be achieved by using different chemical processes by producing heat and steam in a different way, or by using, converting or storing CO_2 for use as bioenergy, for example. AI can help set this up flexibly, so that the industries involved can contribute towards the balance with renewable production. There are countless challenges in controlling or even completely redesigning sometimes highly complex industrial processes – from new optimisation methods to hybrid human-machine control or the design of new chemical technology, for example.

2.3.2 Smart energy services and flexibilisation of buildings and households

In order to achieve greater flexibility in the energy consumption of buildings and households, it is important to ensure that smart services help create comfortable environments in buildings. On top of that, interaction with these smart services should be agreeable and convenient (5.1).

- Optimisation of regulations for building-related and space-dependent smart heat facilities/storage/ventilation, perhaps in combination with electricity consumption and generation (4.1-4.3, 5.1), flexible and adaptable building energy management systems (5.1);
- This could also include all kinds of solutions for enhancing flexible and self-consumption (smart energy management of heating, cooling, and charging electric cars and bicycles) and for separating supply and demand, through the storage of heat or electricity or conversion, for example (2.2a).

Finally, AI can in some cases help reduce the energy consumption of buildings, households, and of industry as well. Possible examples include the smart deactivating of machinery when not being used.

2.3.3 Socio-organisational principles, revenue models, and legal parameters

Involving end-users as active participants in the energy system is essential, but entails a greater level of complexity in relation to the technical issues. The success of this approach depends largely on social norms and values (privacy, safety, power structures, control, autonomy, human dignity, and justice), having a sustainable revenue model, and the legal parameters to make this possible. As is illustrated in a pilot scheme in Helmond (EnergyMatch, (2021)). Factoring in these aspects may create new demands for the AI technology, such as:

- Safeguarding privacy when aggregating relevant end-user data;
- Optimising a fair distribution instead of minimising the sum of the social costs;
- Explaining and making transparent automated decisions, including those of algorithms that are used in a market.

2.4 Maintenance

Optimal maintenance is crucial in energy systems because of the major and indeed increasing proportion of the infrastructure in overall energy costs (and risks in relation to certainty of supply). Extraction, conversion and storage of energy in poorly accessible settings (such as offshore wind and solar, offshore hydrogen, geothermal energy sources) also result in high inspection and maintenance costs. In the event of the gas network being used for hydrogen, the quality requirements are much stricter. AI offers new opportunities for making inspections and maintenance of the energy system more effective.

In the case of predictive maintenance, inspection and monitoring data are used (if necessary, in combination with external data like weather conditions) to predict the remaining lifespan and failure behaviour on the basis of the current condition of the object in question, perhaps caused by wear and tear or damage. This information can then be used for deciding (autonomously or not) on what follow-up action, if any, to take (further inspections, scheduling maintenance, acute action, etc.). Embedded AI solutions are also important in this regard for local analyses and alarms.

For an accurate picture of the current condition, a link with and interpretation of monitoring data is needed (large quantities of data through distributed fibre optics, optic technologies, parallel interpretation of different types of sensor). It is essential in this context that new anomaly detection methods are developed that are able to recognize more specifically and more sensitively any anomalies from normal operations and to link them to a possible cause. This information can then be accessed using augmented and virtual reality for rapid real-time decisions.

Predictive models about the degradation of composite materials and components (such as generators and compressors) can be improved by analysing historic monitoring data, maintenance and failure data, in combination with physical models and stability studies from the laboratory.

Better predictions about failure behaviour lead in turn to improved maintenance scheduling. Optimal maintenance planning is very important in cases where maintenance costs are very high as a result of difficulty of accessibility (offshore, downhole, deep sea) or where costly maintenance shutdowns are required.

Maintenance and remote monitoring entails such aspects as image recognition, automated operations, and robotics for drones.

Finally, there are challenges and opportunities for having installation and disassembly work carried out by robots or with the help of augmented reality (1.1) and for taking this and automated maintenance into account during the design stage of installations.

2.5 Energy-efficient AI

Although AI can make a major contribution towards achieving carbon-free energy systems, AI technologies themselves consume large and fast-increasing amounts of energy: unless any action is taken, algorithms are expected to account for around 10 per cent of global energy consumption by 2025. The development of energy-efficient AI, both in the form of algorithms and in the form of hardware, is therefore a priority.

Energy-aware algorithms and more efficient hardware innovations are needed not just in data centres, for example, but also in decentralised locations, in the form of embedded and local AI solutions. Local solutions avoid the energy costs of communicating with data centres, while at the same time making AI solutions more robust and more private. For more details, see a separate description of the Lower Energy Acceleration Program (2021).

3 AI INNOVATION CHALLENGES FOR THE ENERGY TRANSITION

In this chapter, we present an overview of the AI challenges for the energy system, organised according to the relevant AI sectors and aimed at AI researchers and developers.

3.1 Machine learning

Techniques for recognising and learning from patterns in data have great potential for benefitting a large number of areas. However, success depends on improvements to a range of aspects. For example:

- How can physics and/or domain knowledge be used in combination with data-driven models?
- How can we detect and qualify anomalous behaviour efficiently – both sudden anomalies and gradual drifts towards suboptimal operational regimes?
- How can we integrate different predictive models efficiently?
- How can we factor uncertainties into predictions efficiently?
- How can we train and update models efficiently (for time series in particular)?
- How can we make models sufficiently decentralised, energy-efficient and robust for embedded solutions?
- How can we use AI technologies to accelerate complex simulations and analyses without making concessions to quality?

3.2 Planning, optimisation algorithms and search algorithms

Algorithms can be useful for operational and strategic decisions alike. Examples of challenges in this context are:

- How can we include all relevant uncertainties in the decision-making process?
- How can we optimise decision-making in relation to possible future developments (no regret)?
- How should we approach complex decision-making criteria (multiple objectives, considerations)?
- Which model is suitable for factors that are difficult to quantify, such as social acceptance?
- How can we produce results quickly if the system and the optimisation problem are very extensive and complex?
- How can we deal with a changing situation while carrying out earlier decisions?
- How can we give very high reliability guarantees (99.9999%) for the operational decisions?
- How can we carry out algorithms with minimal energy consumption?

3.3 Autonomous (agent) systems

Decentralised control means that decisions are taken locally. This may be a suitable approach if part of the relevant complexity is also local. Intelligent, autonomous agents then work together in a multi-agent system. Examples of the challenges are:

- How can we take swift and autonomous decisions in a complex environment?
- How can intelligent agents coordinate their decisions quickly and efficiently, taking the interests of the human actors that they represent into account? What market and negotiating mechanisms produce the best outcomes for the whole system?
- How can we structure/coordinate distributed decision-making (bottom-up)?
- How can autonomous decisions be audited/checked?
- How can we give very high reliability guarantees (99.9999%) for a system consisting (partly) of autonomous actors?
- What is a suitable design for robots that control and perhaps repair autonomous infrastructures? (See also 3.4 Computer vision).

3.4 Computer vision

Recent years have seen a great deal of progress in the field of image recognition. Objects can now not only be located in motionless images, but also followed in video, with specific details being recognised. In the context of the energy system, there are questions in particular related to automatic inspections and maintenance:

- How can the status of material, assets, and infrastructure be determined using video or other images?
- How can a possible error diagnosis be made on the basis of such images?
- How can predictions of wind and solar yield be improved on the basis of images or LIDAR information?

3.5 Interaction between AI, among AI systems and people

Many of the opportunities for AI are found in supporting processes and people who ultimately decide and in which people are needed for supplying relevant information. Its success will depend largely on the interface between the AI systems and the users. Here are a few challenges that need to be met for realising the potential of AI:

- How can people and AI systems interact productively and understand each other's behaviour in their contexts?
- How can a large number of linked AI systems and human users create a stable and scalable system?
- How can we create AI systems that earn human confidence and which meet the preconditions of sound administration, such as transparency, explicability, fairness and accountability?
- How do we explain the considerations relating to decision-making to stakeholders/decision-makers (explainable AI)? How can we visualise this effectively?

- In doing so, how can we take account of multiple stakeholders?
- How do we optimise the interaction between people and algorithms during decision-making processes so that the eventual result is as desirable as possible, both real-time and strategically?
- How do we ensure we have a system that is sufficiently robust against cyber attacks?
- How can computer vision applications be processed locally and robustly, and in a privacy-aware manner?

3.6 Data

Data is essential for accurate, effective, and reliable AI. Each potential application of AI in the sustainable energy system depends on the availability of data. Privacy and energy data are closely interrelated. Data raises various challenges and questions.

- What data is needed for machine learning, simulations and decision support?
- How can these datasets (and algorithms and models) be made available for the relevant stakeholders in a manner compatible with the GDPR, taking into account privacy and security, and be non-discriminatory, understandable, accessible, and up-to-date?
- How do we ensure reliable and trusted data for the purpose of taking optimum and accepted decisions?
- How do we prevent bias in the data gathered (for example, data from a market could primarily represent a choice for a traditional and inexpensive energy source, or data could come primarily from a particular geographical location, with all the consequences that that would entail, etc.)?
- How do we interpret data efficiently, robustly, and transparently and how do we make it available for the purpose of decision-making?
- How can historic and unstructured information be used?
- What additional data/information is needed in order to arrive at an optimum decision (value of information)?
- How can data be enriched, improved, checked, added to? How do we 'preserve' measurement data for longer by continuing to compare it with incoming data?
- How do we present the information so that it is useful for the user?
- What standards are needed for consent, using data, exchanging data, and the transparency of algorithms?

The NL AIC Data Sharing working group makes processes, methodologies and software available for responsible data sharing, with interoperability and data sovereignty as the basic principles. The above questions will be answered in close cooperation with this working group.[2]

2. https://nlaic.com/en/building-blocks/data-sharing/

4 THE NETHERLANDS AS A LABORATORY FOR THE ENERGY TRANSITION

We are proposing that the Netherlands will become a lab for the energy transition – first of all, it already has a reasonably effective knowledge and innovation system. We propose that is strengthened in order to develop new AI and other technologies for the energy transition. Unlike many other countries, the Netherlands has separated the businesses of the generation of energy and that of distribution. Moreover, the country is also a suitable location for (more) testing grounds and as the forerunner in the actual transition to a more decentralised energy system, with a much larger proportion of renewable energy.

4.1 Facilitating innovation

A great deal of domain knowledge is needed for AI applications in the energy sector – applications take multiple forms and quickly broaden their scope. The work of the Top Sector Energy has yielded rich ecosystems and solutions, which can now be upgraded with AI.

Developments in the decentralisation and digitisation of the energy system are moving fast. The fragmented and uncoordinated manner in which companies and institutions operate makes them unable to respond sufficiently quickly to these developments. More concerted development is needed to create or improve the building blocks for a flourishing energy infrastructure with AI.

4.1.1 The Netherlands as a testing ground

Much progress can be realised in the short term through the construction of a (virtual) testing ground for AI research and innovation for the benefit of the energy transition. In this digital infrastructure, researchers and businesses acquire an overview of the available tools and data and the opportunity to use it or to try out ideas. This is also the place where people can meet and share the tools they themselves have developed and agree on standards.

We can test solutions in the testing ground using everyday users, something that is essential for developing solutions in practice. Their complexity means that they cannot be developed solely in technical laboratories. Examples include investigating what AI innovation challenges mean for energy-consuming households, energy-producing local collectives, or users of electric cars.

The testing ground can be initiated by NL AIC – the AI hubs bring existing data, knowledge, and tools and include local companies from the region in question. The testing ground facilitates agreements on how to use the results, code and data.

4.1.2 Success factors in strengthening the testing ground

The preconditions (data sharing, governance, availability of talent) must be met and clear agreements should be made about how results are to be shared in order for the testing ground to continue to flourish and grow. This includes agreements relating to data and knowledge:

- Publishing, for the benefit of international research and education, scientific articles, white papers, open-source code, data samples, data generation, national and international standards.
- Judiciously sharing data (see 3.6), for the benefit of the economy in the Netherlands, with every affiliated party: concluding reports from subsidised projects, all data real-time, also codes for detailing standards, for example, good metadata. This also includes a digital twin of the energy system, or parts of it. Rules should apply here regarding use, and what you may share with whom and when, taking account of what is needed to make it of use to the party sharing the data.
- Bringing AI researchers and energy experts together.

4.2 The Netherlands as a laboratory

There are certain areas where the Netherlands is in the lead, such as regarding the charging infrastructure, energy management systems in non-residential buildings, and system integration, and where AI applications also have international potential. The excellent condition of the electricity and digital infrastructure, the size of the country, its position by the sea, its well-educated population, and its high levels of prosperity make it the ideal location for using one of the first large-scale decentralised and intelligent networks in practice. This entails numerous challenges, no matter how well organised the sharing of data in the testing ground is. Examples that come to mind are extra rules but also technology relating to the real-time sharing of data, and privacy issues.

When it comes to supporting decision-making, too, the Netherlands offers a unique and interesting context: it is common practice to involve all stakeholders at an early stage of any far-reaching processes. This presents extra opportunities and challenges in using AI to support such processes. At the same time, being at the head of the field of AI technology will offer highly advantageous economic perspectives in due course – this relates to the timely adjustment of industry and the economy to the new situation as well as to the creation of new AI export products and services. In addition to the testing ground, therefore, we would like to make it easier to put AI innovation into practice in the Netherlands.

5 WHAT NEXT?

AI plays a key role in many areas of the energy transition and can help accelerate the process. This acceleration offers substantial opportunities to the Netherlands to help steer the process by developing essential components that meet the tough quality requirements and which function well together. However, being in the vanguard brings risks – risks that individual companies currently dare not and cannot take.

The plan by the NL AIC Energy and Sustainability working group is to start with a number of essential steps en route to the bigger goals:

a. Making an overview of existing data, models, and tools; in collaboration with the Data Sharing working group.
b. Bringing stakeholders together and identifying current initiatives.
c. Developing the details of the testing ground.
d. Fleshing out a number of specific programmes at the Dutch Research Council and the Netherlands Enterprise Agency, based on the opportunities set out in this document, existing results and current initiatives
e. Fleshing out and supporting project proposals for EU programmes, ELSA and ICAI labs, and chain projects that form part of current large-scale initiatives in the field of energy, aimed at the AI components; see the two examples in Appendix A.

An important task for the NL AIC, and for this working group in particular, is the integration of the AI component in current and new developments. As well as the prompt exchange of knowledge and experience and the coordination of activities, an important goal is to make it possible to integrate the various AI contributions.

In the near future, we will also be supporting new initiatives that are in line with this vision, including the organisation of matchmaking and an intensive collaborative partnership with the Human Capital working group for the purpose of helping energy professionals, policy employees, and administrators acquire more AI-related knowledge and skills.

Get involved

The above approach will enable the Netherlands to reap the economic and social rewards from AI and to be at the front of the field, internationally. Would you like to assist the energy transition in Netherlands with the help of AI? If so, please contact the NL AIC Energy and Sustainability working group.

Please note:

The vision set out here does not apply to other AI and sustainability themes. They are being developed in collaboration with interested members of the NL AIC and other relevant working groups. Examples includes Technical Industry, Agriculture and Food, Built Environment, Mobility, and Transport and Logistics.

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APPENDIX 1 TWO CONCRETE PLANS TOWARDS THE IMPLEMENTATION OF THE VISION

In this chapter, we describe two examples of projects that can start now, and which will a) produce something in the short term (quick win) and b) form a first step towards bringing together AI developments in the energy domain.

Development of sustainable energy provision in the built environment

The problem

A large proportion of the energy transition in the built environment takes up a lot of space (including underground). This places an additional burden on the electricity network in the case of an all-electric solution, for example, or the creation of a heat network, or the excavation of a geothermal well. In order to enable effective decision-making and execution in relation to the energy transition, it is important to have a clear picture of the current state of the environment, the possible options, and their impact. For example, there is the question of how a heat network can be integrated in existing infrastructure in the ground (sewerage systems, drinking water, etc.), and what the most favourable location is for a geothermal well and what its effect on the electricity network would be.

The development of renewable energy, such as heat networks, requires carefully balanced investment and other decisions. The recently published report *Geothermie* in de *Gebouwde Omgeving* ('geothermal energy in the built environment') refers to uncertainty around sufficiently prompt distribution and geology, the long and unpredictable process for obtaining permits, inadequate grant instruments, public support, and the lengthy nature of the development process as problem areas. Moreover, the development process regarding the use of geothermal energy and heat networks is currently not centrally coordinated. AI can play a significant part in lessening the uncertainty relating to the physical situation and distribution, by making clear the effects on society and the environment, and in other areas too.

An important aspect is that the failure costs of the implementation may be considerable - if it appears during the implementation stage that the plan has to be modified because something has been overlooked, the additional costs for a single project could easily escalate into the millions.

What AI can be expected to achieve:

The energy transition requires complex investment decisions – the construction of a heat network, for example, is fraught with uncertainties and risks and is part of a complex chain that includes property owners such as housing corporations, homeowners, the heating company, the developer of the source, and local authorities. There are also other aspects – both above and below ground – to consider and coordinate, such as greenery, water (including drinking water), housing renovation, infrastructure, etc.

The process of taking these decisions and coordinating action takes time and often has to take place in a particular sequence. Moreover, the interests that have to be considered are in many cases not especially transparent. AI can make a significant contribution towards improving decision-making processes and making them more efficient by unlocking and improving:

- existing data (data combination, interpretation, visualisation, and quantification of uncertainties) forecasts (including of uncertainties), thereby creating a clearer picture of the current situation, including space in the subsurface;
- development scenarios (integrated representation of decision-making information with the help of digital twin), supplementary to existing instruments such as the initial analysis;
- a clear picture of possible improvements (for example, analysis of problem areas, integrated system optimisation, value of information analysis).

Relationship to fundamental questions

How can we generate the required information (interpretations, forecasts) and make it easily accessible in support of the decision-making process for the local energy transition for the built environment? It is important here that the outcomes and how they are represented are clear to all stakeholders.

The following elements are required to achieve this:

- A national infrastructure for standardised, reliable, and transparent data and analysis tools, including agreements on linking and sharing the available data (in relation to geology, use of space both above and underground, costs), data quality control, data enrichment, and a description of uncertainties in the data;
- Releasing information for decision-makers/ stakeholders by means of a data model (and then a digital twin of above and underground);
    - Transparent and insightful presentation of forecasts (current situation, completion and management costs, heat production, demand for heat, social effects, etc.);
    - Analysis of problem areas: understanding of problem areas (such as lack of public support, integrating heat network in subsurface, uncertain geology, issuing of permits) and identifying possible solutions (such as acquisition of additional data);
    - Interaction with other functions (integration, inconvenience, etc.); Impact on other current and future functions (water pipelines, electricity network, foundation risks, traffic, etc.)
    - User-specific interfaces based on decision-making process.
- Open-source software architecture that offers scope for integrating reliable, auditable and explainable models for forecasts and scenarios (including descriptions of uncertainties) relating to heat production, storage performance, demand for heat, cost movements, impact on other functions, etc.) and system designs on multiple geographical scales (from street to region);
- Procedures for model updates, such as an update of heat demand models, with up-to-date data;
- A method for balancing demand for heat and heat production during various time scales (hour, day, week, seasonal fluctuations and during the various stages of development);
- Charting the decision-making process and the balancing of interests for the development of heat networks with geothermal energy sources (decision criteria, need for information on the part of decision-makers and stakeholders);
- Decision-making support, including:
    - Value of information: impact of additional information on decision-making process
    - Integrated and robust optimisation of system design (including uncertainty/ no regret)

Quick wins

A local digital twin for a specific case study (connecting subsurface, the heat network and demand for heat) that demonstrates the feasibility of physically integrating heat networks in the subsurface; where can this be done easily, and where might there be possibilities of creating space (and at what cost). The aim is an integration, interpretation and visualisation (combining relevant information for decision-makers) of relevant subsurface-related information for more carefully balanced considerations at local authority/regional/provincial levels.

Congestion and dynamic energy management

The problem

More and more locations in the electricity networks are experiencing congestion as a result of a rapid increase in the number of land-based wind farms, solar parks, data centres, and changes in use caused by local generation and electric transport. This means that new producers and customers cannot yet be connected until the networks have been expanded. Such expansions often involve major investments and take a long time to realise.

The design of networks is based on a particular load and takes account of an N-1, which means there is an alternative plan if essential parts should fail. Various solutions to the problem of congestion are now being tried for use until the network has been expanded, including connecting at times when it is possible, or dealing with overloads through the use of the congestion trading system (GOPACS).

What AI can be expected to achieve

Whether a section of the grid is deemed to be at full capacity is determined by a contractual promise of availability in combination with load profiles, which are determined historically. By using more datasets in combination with real-time readings and by developing predictive algorithms for this purpose, it is expected that greater use and generation will be possible throughout the grid than has so far been the case. As a result, some of the congestion can be relieved, or at least optimised with minimal control of peaks.

Relationship to fundamental questions

The use of the electricity system is changing from predictable load profiles to a dynamic system with different consumption patterns (through the electrification of heat and industry, and through electric vehicles) and other generation methods, such as the sun and wind. Meanwhile, the system has to remain in balance on a second-by-second basis. This means that the dynamics of use have to be supported by the dynamics of the network. The only thing is that this cannot be done in real-time: it has to be more than real-time. The system has to be ready for demand in five minutes' time, in an hour, in a day, and in ten years' time.

This dynamic system is no longer just the assets, but a combination of generation, use, status and predicted status of components, regulations, market connections and behaviour. The electricity network is already integrating low-voltage, medium-voltage, high-voltage, and interconnections throughout Europe. At every layer, action is being carried out on the basis of the status and predicted status. The assets, energy flows, capacity and frequencies, generation and use will be measured in their new form and the complex combination can adapt to the demand according to algorithms, demand at that moment, the next hour, the next day and the next year.

The basic components currently being developed are limited to the network of a network operator – capacity and frequency readings, and readings of the status of a cable leading to data streams. Through machine learning, the data streams detect the type of consumption and the type of generation. This makes it predictable and leads to alternative plans.

The step change that is needed is, first, to regard the network of the whole of Europe as a combined entity and, second, to enable the new integrated energy system in this European setting (that is, the assets, consumption, generation, rules, customer demand, market forces) to work.

The following elements are required to achieve this:

- Standards for the data flows for application of the 61850 standard.
- Reference software architecture that offers scope for multiple suppliers.
- Reference hardware architecture that offers scope for the development of sensors, alternative systems.
- An increasing number of open-source algorithms, for predictions, detection, adjustments to the system.
- A method for dealing with possible futures (hour, day, year, ten years).
- A method for a system of systems : algorithms/ agents that work together and check and compete with each other. In the network domain, for example: an algorithm that organises alternatives, with the monitoring of results by a second algorithm that it uses to order a third algorithm – to improve the prediction regarding solar energy in a particular part of the country, for example. Another example is that of interaction with the market (energy suppliers, aggregators) or interaction with other energy carriers (heat, hydrogen).
- Methods for AI software to work locally and distributed on embedded platforms, so that robustness and data privacy can be guaranteed.
- Methods for making operations secure from cyber attacks.
- A method for exchanges between grid levels and grid operators horizontally (for example DSO-DSO) and vertically (DSO-TSO) and interconnection.
- A picture of the consequences of customer demand on infrastructure and a method for producing forecasts from that.

<u>Quick wins</u>

In the next one to two years, we are aiming to develop predictive algorithms for a specific grid (from a small, possibly private grid to a bigger region) by using historic readings, current readings, weather forecasts, and big data. The purpose is to look at whether a number of congestion areas can be released (conditionally) as a result or whether modifications can be applied to networks.

APPENDIX 2 ANALYSIS OF DOMAIN CHALLENGES BASED ON LONG-TERM MISSION-DRIVEN INNOVATION PROGRAMMES 1-5, 13

Below is a summary of the most important challenges, based on the published reports of long-term mission-driven innovation programmes 1-5 and 13 in 2019 and 2020. The far right-hand column contains brief descriptions of the challenges where we believe AI will make a significant difference.

Mission	Long-term mission-driven innovation programme	Generic challenges	AI challenges/tasks
Carbon-free electricity system	**1.** **Renewable at sea (Long-Term Mission-Driven Innovation Programme 1: Renewable electricity at sea, 2019)**	**1. Cost reduction and optimisation (scaling up safely and affordably)** • Zero breakdown and robotisation • Optimal wind farm design • Next Gen WTG • Balance of plant optimisation • Floating solar **2. Integration in the energy system (including storage and conversion)** • Future offshore energy infrastructure • Offshore wind on demand • Off-grid offshore wind farms **3. Integration in the local environment (ecology and multi-use)** • Net positive contribution to ecology • Multi-use of offshore wind farms • Zero-emission circular offshore wind farm How does supply match demand, contribution to stability of energy system, role of transport infrastructure, storage, markets, flexibility of supply, offshore conversion.	• Zero breakdown and robotisation of installation and maintenance. Predictive maintenance. Autonomous robots in extreme conditions; • Balance of plant optimisation (= mature AI industry); • Integration in the energy system (including storage and conversion). Future offshore energy infrastructure. • Predicting and responding to bird migration patterns; • Monitoring, predicting and responding to impact on local environment; • Coordination with chain on multiple use of space, including with shipping and fishing industries (preventing high costs caused by late intervention); • Automated cybersecurity throughout the energy chain; • Reuse (assessment) of current gas and other infrastructure; • Investigation into sun and wind climate, and into wave and current movements, including their mutual effects.
	2. **Renewable on land (Long-Term Mission-Driven Innovation Programme 2: Generation of renewable electricity on land and in the built environment, 2019)**	This concerns the use of renewable sources, particularly the wind and sun, on land. Distinction between the built environment and the non-built one. Reducing costs of generation. Making new applications available, optimally integrated in their local environment. Accelerating implementation, while not losing societal enthusiasm. Achieving and safeguarding integrated sustainability. DP 1a. Enablers and broadly applicable innovations in the field of technology. DP 2a. Solar power systems in the built environment. DP 2b. Solar power systems in the non-built environment. DP 2c. Wind farms in the non-built environment.	DP 1a • The development of control and monitoring systems of wind and solar installations. • Forecasting technology: combining flows of satellite data, weather data, weather models, climate change, resource assessment (wind and sun), real-time network and consumption information in order, among other things, to coordinate energy production and demand as effectively and efficiently as possible; • Design and visualisation: Development of design tools and the use of visualisation software. DP 2a • Design of solar systems, with regard to their lifespan; • Reducing the costs of producing and assembling the building element, including the solar power function; • Optimising the transport and installation costs of the system, the operational and maintenance costs, and the costs of disassembly and recycling the system (and its components); • Optimising the benefits of a solar power system in the built environment; • Solutions for increasing self-consumption (smart energy management) and for separating supply and demand, through storage or conversion, for example. DP 2b. • What are optimum system designs? • What are optimum strategies for maintenance and management of the solar power system? • How can the costs of installation be reduced through the use of robots, for example? • Optimising the design according to yield and location. This concerns radiation, the albedo effect, cooling, contamination aspects, and the effect of waves movements on the yield. DP 2c. • Designing wind systems: for quieter turbines and more aerodynamic add-ons to blades, new blade designs are needed; • Improving procedures for carrying out maintenance and the introduction of technology like robotics for remote maintenance and autonomous maintenance; • Cybersecurity and safety of the energy system.

Carbon-free built environment	**3. Acceleration of energy renovations (Long-Term Mission-Driven Innovation Programme 3: Acceleration of energy renovations in the built environment, 2020)**	Achieving the three main concepts for heat and cooling during renovation: (1) electrification, (2) heat networks, (3) sustainable gas and combinations of same; Applicability in existing situation (compact, silent, installation and user convenience, use of space, etc.); Availability at lower integrated cost price at system level (towards 30-50 per cent for individual solutions, 15 per cent for collective systems) compared to current cost levels; Ensuring the availability of innovative solutions keeps pace with the expected increase in speed of natural gas-free energy renovations (attractiveness, construction methods, ease of installation, industrialisation, etc.); Using sustainable sources (such as solar heat, thermal energy from water, geothermal energy, and forms of bioenergy for collective heat), including the necessary system connections and back-up facilities for winter peaks. Sub-themes: 3.1 – Development of integrated renovation concepts. 3.2 – Industrialisation and digitisation of the renovation process. 3.3 – Building owners and users key factors of energy renovations.	• Development of assessment models that show which solution is appropriate to a specific situation, including decision-making support tools for configuring renovation concepts; • Validation and improvement of renovation concepts by using data; • Development of custom-made propositions and sales channels; • Increase public support for new solutions. In addition: • Preventing (or limiting) failure costs when drawing up plans and during projects; • Clarity of current energy position of the home; • An understanding of the space and condition of the shallow subsurface for the infrastructure for new heat solutions; • Understanding of practical costs of renovation.
	4. Sustainable heating and cooling (Long-Term Mission-Driven Innovation Programme 4: Sustainable heat and cooling in the built environment (including horticulture), 2020)	Achieving the three main concepts for heat and cooling during renovation: (1) electrification, (2) heat networks, (3) sustainable gas and combinations of same; Applicability in existing situation (compact, silent, installation and user convenience, use of space, etc.); Availability at lower integrated cost price at system level (towards 30-50 per cent for individual solutions, 15 per cent for collective systems) compared to current cost levels; Ensuring the availability of innovative solutions keeps pace with the expected increase in speed of natural gas-free energy renovations (attractiveness, construction methods, ease of installation, industrialisation, etc.); Using sustainable sources (such as solar heat, thermal energy from water, geothermal energy, and forms of bioenergy for collective heat), including the necessary system connections and back-up facilities for winter peaks. Secondary programmes: 4.1: Heat pumps. 4.2: Delivery, ventilation, and tap water systems. 4.3: Small-scale heat storage. 4.4: Sustainable heat networks. 4.5: Large-scale thermal energy storage. 4.6: Geothermal energy. 4.7: Low-temperature heat sources.	Monitoring and optimisation of existing heat networks and collective thermal energy storage (in terms of both technical performance and user costs) • Decision-making support for the renovation of individual buildings (insulation, electrification, heat storage, ventilation, etc.); • Optimisation of regulations for building-related and space-dependent smart heat facilities/storage/ventilation, perhaps in combination with electricity consumption and generation; • Decision-making support for the design of collective heat networks, in particular with sustainable heat sources like geothermal energy, biomass, and low-temperature sources in combination with the seasonal storage of heat; • Optimisation of operations/regulations of collective heat (and cooling) networks and large-scale heat/cooling storage; • Predicting demand for heat, heat loss through storage and heat networks, and heat production through geothermal energy and the sun, in the short term (days) and in respect of seasonal influences; • Improving the design of heat pumps and of thermal energy storage; • Understanding and managing the subsurface and the environmental impact on soil and water caused by heat storage, geothermal energy, or thermal energy from water; • Understanding and managing the effect on health in relation to indoor air quality; • Introducing total cost of ownership in energy-related regulations; • Detecting and diagnosing errors (pumps, valves) and leaks in heat network; • Types of partnership and revenue models for different parties in a collective system?

Carbon-free built environment	**5.** **The energy system in balance (Long-Term Mission-Driven Innovation Programme 5: Electrification of the energy system in the built environment, 2020)**	The emphasis in long-term mission-driven innovation programme 5 is on the supply of electricity in the built environment. Slowly but surely, the electricity system is facing increasing pressure as a result of the energy transition. System innovations are needed to facilitate the distributed generation of electricity, to smooth out peaks and troughs, to bring supply and demand in balance more effectively, to approach electricity more smartly, and to connect with other energy carriers and infrastructures via conversion. Without system innovations, the energy transition will come up against barriers, such as the physical and financial limits of grid expansion, limits to the certainty of supply and the affordability of the electricity system. Work is underway on increasing the flexibility, including the use of storage, that will be needed by 2030 to cope with the consequences of the decline in the use of gas and with the larger fluctuations in the supply and demand of energy.	
	5.1. **Electrification at building level**	Smart energy services and flexibilisation of buildings; unlocking flexibility	Smart energy services require: • Adaptable and flexible systems; • Availability of information and safety (including for building clusters of larger property owners, such as local authorities, housing corporations, school umbrella organisations, etc.); • Interaction and acceptance among users. Transactive energy. Flexible and adaptable building energy management systems. AI should provide the information on which this is based and should form part of DSSs for decision-making (see the long-term mission-driven innovation programme 13)
	5.2. **Electrification at area level**	Transition paths for deploying flexibility; integrating renewable generation and electromobility in the energy system; local energy systems.	• Digital twinning and simulation studies for supporting the process; • Scenario formation and sensitivity analyses; • Development of coordination and control of local energy systems; • Acceptance among users of energy cooperatives.
	5.3. **Market mechanisms for flexibility in the built environment**	Support systems for the deployment of flexibility for different objectives.	Development of (new) market mechanisms and coordination systems for flexibility in the built environment (AI challenges similar to those under 5.1) • Adaptable and flexible systems; • Availability of information and security. • Interaction and acceptance among users.
	5.4. **Electric infrastructure in the built environment.**	Construction and maintenance of the electricity infrastructure including monitoring and control; also attention for DC networks in this context.	Predictions and pattern recognition are important for monitoring and control • Key area for AI application

A robust and socially accepted energy system (Long-Term Mission-Driven Innovation Programme 13: A robust and socially accepted energy system, 2019)	**13.1.** **Knowledge for integrated decision-making**	The development of knowledge for the purpose of taking sound decisions, underpinned by high-quality knowledge and information	The basis for information and innovative tools: Establishing the basis for information: What technical, economic and social data is needed to shape the future energy system and the transition path? • Sharing data securely; • Data enrichment (missing data, transfer learning); • Standardisation of syntax, semantics, and data enrichment; • Digital twins (digital subsurface, infrastructure); • Multi-modelling, linking related sets of models, integration of economic, technical and behavioural knowledge; • Explainability; • Integrated analysis at multiple scales; • Supports collaboration among people from different fields. Integrated system studies and sector linking. • Better choices for clarifying uncertainties, preconditions and dilemmas. Certainty of supply: flexibility, transport, conversion and storage • Investment and system allocation issues in a complex and uncertain environment involving numerous stakeholders with differing and sometimes conflicting interests. Ways of unlocking this knowledge that are understandable for the decision-makers (who do not always possess a technical background).
	13.2. **Inclusive energy transition**	Development of knowledge and methods for just decisions that enjoy support and which can be properly integrated in the local environment.	• Coordination and balanced use of spatial planning above and below ground. • Participation in relation to energy transition: Regional energy strategies – implemented as a digital twin. • Collaboration and decisions – reliable basic data. • Energy justice – what are the effects of measures such as having flexible energy tariffs.
	13.3. **Integrated energy infrastructure**	Effective and integrated design of cost-efficient multi-commodity energy infrastructure for changing supply and demand and the necessary flexibilisation.	New knowledge and tools that contribute towards the integrated consideration that the energy transition entails (uncertainty of policies, cost movements, changes in demand, versatility). • Multi-scale modelling and sector linking; • Quantifying, modifying and optimising the role of flexibility; • Uncertainty in timetable and adaptive design (no regret, robust investments).
	13.4. **Flexible energy markets**	Economic aspects of the energy transition, such as revenue models and market mechanisms for low societal costs and the right incentives for stakeholders.	Energy markets: market mechanisms and regulation, revenue models.
	13.5. **Storage and conversion**	Integrating large-scale storage and conversion for the integrated energy system.	Identifying the potentially necessary energy storage capacity in the Netherlands
	13.6. **Operational management and digitisation**	Operational management of energy system with a focus on regulatory mechanisms and digitisation.	Investigation into the need and options for and approach towards management in the future hybrid decentralised energy systems. Mechanisms for the operational regulation of the energy system (market mechanisms, algorithms, interactions)) • Profiling and forecasting of flexibility; • Development of mechanisms and algorithms for direct control of the energy system; • Setting up and assessing system mechanisms; • Security and privacy in the energy system; • Digital architectures and standards for monitoring and control of the energy system; • Framework for digital infrastructure; • Development of facilities for gathering and sharing operational energy data; • Development of the control room of the future.

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