TOWARDS A FUTURE-PROOF ENERGY SYSTEM

FLEXIBILITY AND VALUE

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INTRODUCTION

Energy production is changing worldwide. While demand for energy in Europe and the US is flattening, growing economies such as China, India, Russia and Brazil are experiencing the most energy-intensive phase of their development. Global energy demand is expected to increase by at least 30% by 2035. This growth is encouraging all countries to reduce their dependency on imported fossil fuels. The negative climatic and environmental effects of greenhouse gas (GHG) emissions are likewise driving this trend, with the EU targeting an 80% reduction in GHGs by 2050.

Natural gas and oil have played a dominant role in the Dutch economy since the middle of the 20th century, leading to the creation of an extensive refining industry and a range of energy-intensive industrial sectors. These sources accounted for 20% of the Dutch Treasury's revenue in 2010.

THE TRANSITION FROM FOSSIL FUELS TO SUSTAINABLE ENERGY

The Netherlands' starting-position for a transition to sustainable energy production differs significantly from that of other countries. The country is economically dependent on its own gas production and the transportation of oil and oil products, and is vulnerable to changes in the reliability and affordability of the existing system. By comparison with other EU states, the proportion of the energy mix attributable to sustainable sources in the Netherlands is relatively small at 5%. The transition to future-proof energy production will extensively transform the Dutch energy system as it stands today.

PURPOSE OF THIS STUDY AND KEY DEFINITIONS

This study examines the possible consequences of upscaling sustainable energy sources and integrating them into a system that is currently based on fossil fuels. It focuses on the years between now and 2030. '**Flexibility**' is herein defined as *the ability of market participants to quickly react to changing circumstances so as to preclude excessive or inadequate electricity levels*. '**Balancing**' is herein defined as *the combination of all measures and processes which ensure that energy input and energy uptake are always equal, thereby making for a stable system*.

The results of this study are intended to be used as the basis for a dialogue within Dutch society on the conditions under which the energy transition will offer new opportunities to strengthen the economic position of our country. Such a dialogue should take into account: (i) ways of improving how energy markets function, (ii) an open innovation policy on the part of government and business that recognizes that the transition of our energy system will require the maximum leeway for experimentation, and (iii) the social value of small-scale initiatives as the incubators of decentralized energy production.

APPROACH AND STRUCTURE

This study is based on a range of different sources and methodologies. Particular use is made of three scenarios: (i) commitments valid till 2023 as laid down in the Energy Agreement for Sustainable Growth, (ii) analysis of trends in the period up till 2030 as developed by Urgenda (the Dutch organization for sustainability and innovation), and (iii) the exploratory scenarios developed for Netbeheer Nederland (Netherlands Network Management) by the consultancy CE Delft. Part 2 outlines how today's energy system operates. Part 3 presents important trends in Dutch and European energy production expected to occur between now and 2030. Part 4 provides an overview of measures to increase the flexibility of the energy system. Part 5 discusses the characteristics of an efficient energy market and compares these with the current situation, and Part 6 offers key conclusions and recommendations.

2. HOW THE ENERGY SYSTEM IN THE NETHERLANDS WORKS TODAY

THE IMPORTANCE OF AN EFFICIENT ENERGY SYSTEM

Reliability, affordability and sustainability have always been the pillars of our energy system, and the Netherlands has a very reliable system, with targeted energy markets. Two factors are very important for a reliable electricity system: (i) demand for, and supply of, electricity are always in balance, and (ii) sufficient capacity exists to transport the electricity to where it is needed.

BALANCE RESPONSIBLE PARTIES (BRPS) AND KEY CLIENTS

Unlike in most other European countries, the system of Balance Responsibility plays a central role in balancing supply and demand in the Netherlands. It is enshrined in law. BRPs indicate the previous day what volume of electricity they will supply or purchase per quarter the following day. Major producers, major consumers and suppliers have responsibility in law to provide programs for the production, transportation and consumption of electricity and also to abide by these programs. All parties have a responsibility to conclude contracts for the sale and purchase of electricity, or to trade this on the stock exchange. This system significantly underpins the robustness and reliability of our electricity system, for it allows production and purchase levels to be predicted one day in advance. Small consumers do not have Balance Responsibility. In their case, this rests with their supplier. Suppliers receive a statement showing what their small consumers have used in accordance with an established profile.

ENERGY MARKETS: FROM LONG-TERM TO IMBALANCE MARKET

Producers sell electricity, and consumers buy it. Electricity is a special product in that it cannot be stored in large quantities; it therefore has to be produced at the moment it is needed. For this reason, various markets have arisen for the purposes of trading electricity at different points in time, as the value of electricity can change over time. Having different markets fosters flexibility.

Real-time activities and concomitant markets and prices are essential ingredients of a competitive and efficient market. It is theoretically possible to sell all electricity in real time, but the reliability of such a system would depend on the existence of sufficient transportation capacity to deliver it. The current markets, which operate on a longer time-scale, ensure that sufficient transportation capacity exists.

- The **imbalance market** (operated by TenneT) is the market of the moment. If the parties cannot stick to their programs, the differential is made up by this market. If there are shortages or surpluses in the system, TenneT can request suppliers to produce more or less electricity, or purchasers to take more or less, so as to bring the system back into balance. Only BRPs can participate in this market; small consumers cannot.
- On the **intra-day market**, which is operated by APX, electricity is traded between the close of the day-ahead market (every day at 12:00 noon) and five minutes before the moment it is supplied. Only BRPs can participate in this market; small consumers cannot.
- On the **day-ahead (or spot) market**, likewise operated by APX, electricity is traded the day before it is used, creating a market balance between supply and demand. Bids must be submitted by 12:00 noon each day, and parties can bid in hours or other blocks of time. Prices are determined in accordance with the bids. Only BRPs can participate in this market; small consumers cannot
- On the **long-term markets** – which are operated by Endex, brokers, or the BRPs themselves – long-term agreements are made before the moment of trading. This can occur directly between producers and suppliers, or else via third parties (brokers and Endex). Long-term agreements are attractive because they offer BRPs security, investors clarity regarding projected returns, and purchasers certainty regarding prices in the long term. Small consumers who do not operate programs enter into long-term contracts with their suppliers.

NATIONAL AND LOCAL MARKETS; MARKETS FOR TRANSPORT CAPACITY

The trading of electricity can have a national or a local dimension. This is because there are limits to the available transport capacity, and the price of electricity is determined by the availability of means to transport it. Every country in Europe has a national electricity market with prices for that country. If there is sufficient import and export capacity, the prices in neighboring countries should be the same, creating an international market with roughly similar prices. If there is insufficient capacity to transport electricity across borders, however, price differences between countries can develop. Whether a market is national or international depends, therefore, on the utilization of international connections. Local markets can also develop within a single country in the event of congestion within the transportation system. At the moment, prices within the Netherlands are uniform, with TenneT intervening to keep them at the same level nationwide.

Besides the markets for electricity as a product, there are also markets for the transportation of electricity. These markets involve those who supply transportation capacity (TenneT, regional suppliers) and those who require it. The markets are regulated, with the relevant procedures and tariffs laid down by law. Congestion is also a factor, and the role this will play in the future is currently unclear. Various studies into the subject offer a range of possible future scenarios. It is possible that (local) transportation shortages will increase.

With the Energy Law of 1998, the Netherlands introduced a robust system of markets that has made for a reliable electricity system. This system was developed in the past, when supply always followed demand. The situation has since changed, due to flexible production systems and the increasing possibilities offered by information and communications technology (ICT). The current market system can be improved so as to better support these new functionalities.

3. DEVELOPMENTS IN THE DUTCH ENERGY SYSTEM

The proportion of sustainable energy in the Dutch energy mix will continually increase in the coming 15 years, although the rate of this change is uncertain. What is clear, however, is that the first consequences will be apparent with the energy system. The output of energy from solar and wind sources is dependent on weather conditions; not all conventional energy production plants are able to make up potential shortfalls, and unless adjustments are made, the Netherlands may experience problems with the balance of its electricity system and the quality of its voltage before 2030. To prevent this, it will be necessary to make the energy system capable of receiving energy efficiently from sustainable, flexible sources.

TWO GENERAL TRENDS

A robust trend in all scenarios is the growth of the proportion of energy from renewable sources such as sun, wind, hydropower, biomass and geothermal. Although natural oil and gas as well as coal will play a dominant role in the energy mix in the coming decades, the energy technology portfolio will change substantially. Almost all scenarios envisage strong growth in wind energy (onshore as well as offshore), solar panels and biomass, besides more gradual growth in options such as solar heat, hydropower, electricity generated from waste, thermal storage, wood stoves and electric thermal pumps. A significant proportion of this energy will be generated by fluctuating energy sources such as sun and wind. This will significantly influence our energy system. A second trend, at least in Europe, is the rapid growth of the proportion of local and regional initiatives in the area of energy saving and the production of renewable energy. Involved are groups of citizens and companies who translate their environmental concerns into joint energy projects. Municipalities and corporations, hospitals, schools, universities etc. approach renewable energy with diverse motives. And these initiatives are on the increase.

EXPERIENCES IN GERMANY

The energy supply systems of Germany and the Netherlands are closely interlinked, and we can learn from both. Experiences with the ‘Energy Revolution’ and the ‘Nuclear Exit’ show that the advent of local renewable energy production can have consequences for the entire system. Germany has great hopes for the renewable energy industry, envisaging not just reduction in GHGs, increased security of supply and greater sustainability, but also job creation. Renewable energy is encouraged by a feed-in system that obliges the nearest network operator to purchase the electricity for a fixed tariff, which protects German producers from the risk of fluctuating electricity prices. The fact that renewable energy is largely owned by German citizens themselves is therefore an important driver of growth. Besides this, the nuclear disaster in Fukushima in 2011 triggered a powerful reaction in Germany and encouraged Chancellor Merkel to accelerate Germany’s phase-out of nuclear power. Coal-fired power stations, which produce relatively cheap electricity, have been used to make up the energy production shortfall.

SCENARIOS FOR THE NETHERLANDS

A great deal has been written about the future of energy production in the Netherlands. From 2006 to 2012 alone, at least 20 different scenarios for the coming decades were outlined. In a different study from this one, we have compared these studies with each other. They varied so much in application, approach and assumptions that they offer highly contrasting expectations of how the energy system will develop. This makes it very difficult to identify a robust path for the transition to renewable power in the Netherlands. The range of different scenarios shows that our country lacked a stable and consistent energy policy until recently. This situation was transformed by the Energy Accord for Sustainable Growth, which draws on the input of some 40 key stakeholders and maps a transition path up till 2020-23.

THE ENERGY ACCORD FOR SUSTAINABLE GROWTH (2020-23)

The most important elements of this agreement are: (i) average reduction in energy consumption of 1.5% p.a., (ii) energy savings of 100 PJ by 2020, (iii) an increase of the proportion of renewable energy production from the current 4% to 14% by 2020, with a further increase to 16% by 2030, and (iv) the creation of at least 15,000 full-time jobs, most of them in the coming few years. If these goals are achieved, a good 30% of Dutch energy production will be attributable to renewable sources by 2020 – stable production from coal supported by biomass, and fluctuating production from solar and wind. The 2014 National Energy Survey estimates that by 2030 some 49-53% of energy produced in the Netherlands will come from renewable sources.

FUTURE SCENARIOS FOR DUTCH ENERGY PRODUCTION IN 2030

Besides the Energy Agreement, two other publications provide future scenarios for Dutch energy production in 2030. The first was published in 2014 by Urgenda. This well-documented analysis is entitled *100% Sustainable Energy for the Netherlands by 2030: You can do it if you really want to!* and is based on data from the International Atomic Agency and a group of Dutch experts. The second is by CE Delft and DNV-GL, and presents five different future scenarios, comparing these with a business-as-usual scenario. This study offers insights into possible transition paths and the accompanying financial, economic and technical boundary conditions. Both studies indicate that energy provision in the Netherlands will change rapidly in the coming decades and emphasize profound energy savings, the growth of renewable energy supplies from solar, wind and biomass, and shifts between central and decentral energy production.

SUSTAINABLE, RELIABLE AND AFFORDABLE?

The Netherlands has established a reliable energy system in recent decades. At the moment there is more than enough production capacity to cover changing energy requirements. Dutch policy aims at an energy system that is sustainable, reliable and affordable. These three ambitions are not necessarily mutually supportive and can actually run counter to one another. The major dilemmas are: sustainability versus affordability; sustainability versus reliability; reliability versus affordability; unequal distribution of decision-making power, costs and bids; and how to act in conditions of uncertainty. With the proportional increase of variable, renewable energy sources, all parties must take measures that will ensure the continuance of a reliable and stable electricity system. And time is growing short: by 2020, some 20-25% of energy produced in the Netherlands will come from renewable sources, and this figure will rise to approximately 50% by 2030. The Netherlands will have to chart a considerably steeper growth path in this area than its neighbors. In the coming decades, an energy system will be developed whose starting-point is flexibility, and in which electricity, gas and thermal energy will be integrated in such a way as to balance the fluctuations of demand and supply. In developing this system, not only are sustainability and reliability boundary conditions: affordability will also be a key factor.

4. SOURCES OF FLEXIBILITY

In this report, the term 'flexibility' is used to cover all the options available to participants for reacting to possible surpluses or shortages of electricity by means of production, storage or reduction. This section describes the various sources of flexibility and their application to the energy markets. It shows how not every source of flexibility is suitable for every type of flexibility requirement, which may be measured in seconds and minutes, hours and days, or weeks and months.

FLEXIBILITY OF SUPPLY

Each form of electricity production has its own characteristics. These are determined by the energy source, the steps necessary to convert the respective source to electricity, and the scale or potential power of the installation. The speed with which production can be increased or reduced and the potential power are key differentiators. A nuclear plant, for instance, has a ramp up/down time of more than eight hours and a rated power of 100 to 1,000 MW. For a combined heat and power plant, these figures are less than 15 minutes and between 1 and 10 MW, while for a solar panel, the question of ramp up/down time is not applicable and the rated power is less than 1 MW. To prevent potential capacity shortages, special capacity remuneration mechanisms exist in different countries. The price is maximized at the moment a shortage occurs. At the same time, a number of producers receive compensation from collective resources so as to be able to produce at the same moment. So far, the European Commission is of the opinion that capacity remuneration mechanisms should be avoided as much as possible. Their introduction should not, in the Commission's view, allow inefficient electricity production plants to be artificially kept in operation or unnecessary new capacity to be created.

FLEXIBILITY OF DEMAND

Flexibility of demand involves consumers of electricity adapting their needs within certain limits regarding the quantity or the timing of supply. If there is little available in the system, they can reduce their consumption, and vice-versa. This involves a shift in the timing of the requirement for energy, not a lowering of consumption levels. Various technologies influence demand for electricity, such as cooling systems, air conditioning, thermal pumps, and the charging of electric cars. The development of intelligent steering should make it increasingly easy for consumers to move the time when electricity is used. Demand management can play an important role in stabilizing the energy system when a significant proportion of it is based on variable production. It can also help smooth out peaks in demand.

TECHNICAL SOLUTIONS

Demand management helps increase the flexibility of the system, using congestion management, peak shaving and regulation of supply and demand. Decisions about adjustments can be made centrally or locally, and ideally by consumers themselves. In normal circumstances, decisions about adjustments can be made on the basis of various sorts of information. These include (i) whether one-way or two-way communication exists between the consumer and the 'system', (ii) security of response on the part of the consumer, and (iii) direct or indirect signals (indicating, e.g. settings v. price). When two-way communication occurs, it is possible to abstract data without communicating potentially sensitive information. Available demand managements systems include PowerMatcher™ (from Flexiblepower Alliance), TRIANA (from TU Twente), DEMS (from Siemens) and Open ADR (from OpenADR Alliance).

MANAGING DEMAND IN THE CASE OF LARGE-SCALE CONSUMERS

The possibilities and advantages of demand management vary from user to user. **Small business users** are more prepared to make the necessary investments than are consumers, and they constitute the most obvious target group for demand management. The great advantage of **consumers** is their numbers, and they can have a considerable influence on the system if they all employ demand management. The (biggest) **large-scale users** often have specific demand that is governed by contracts. Many are not (yet) using the available possibilities to shift demand.

CURRENT SITUATION

At present there is little to stimulate small consumers to adapt their demand. Shifting energy in time delivers no financial advantage if the energy is used at another moment for the same price. Demand management by small consumers in the Netherlands is currently to be encountered in experiments and pilots that are very technology-focused, although commercial examples do exist in America and France.

OPPORTUNITIES AND HURDLES

Demand management is an important option for ensuring the flexibility of the system. New opportunities for this appear to lie in offices and commercial buildings with large-scale cooling, although these are not 'large-scale users' as such. The feasibility of introducing demand management to the energy markets is dependent on a variety of factors. It is essentially comparable with production management, and this offers opportunities for optimizing the system. A significant obstacle at present is the lack of possibilities for dynamic pricing and charging, as well as the uncertainty regarding potential cost savings on the part of consumers.

FLEXIBILITY THROUGH ENERGY PRODUCTION

The storage of energy is an ideal source of flexibility, allowing the production and utilization of energy to be separated in time. Production of renewable energy is currently mainly for the medium- and low-voltage networks, but the advent of large-scale windmill parks means that the high-voltage network will also be served by renewable energy. Storage can be applied at all these levels. In the case of **small consumers**, storage allows them to separate the moment of purchase from the moment of utilization. They can load energy in the hours when the price is low and discharge it when it is high. Consumers represent numerically the largest party within the energy system and are not yet exposed to volatile prices such as exist on the APX or the imbalance markets. Their sole choice is between a constant tariff and a day/night tariff, and their own production is netted. The value of owning an energy storage system is currently low for individual consumers and also for **small business users**, partly because of the investment costs involved. Another category of end-consumer is the **prosumer**, for whom storage offers the possibility of separating the moment of their own production and utilization. The netting regulations make storage financially uninteresting for prosumers too. Grouped together in local energy initiatives, however, they can aggregate their production and consumption and reach a scale that might be interesting for trading and network applications.
In the case of **network operators**, storage can support distribution by protecting against resonances and interruptions, and offering an alternative to conventional production centers that 'deliver' electricity reactively. **Large-scale central storage** is interesting for two reasons. The first is because is because of the advantages of scale, which facilitate adaptions to other storage technologies. The second offers the possibility to locate storage within the built environment, in less expensive and more remote locations.
The various possibilities for storage should out course be connected to technologies that are actually capable of realizing these adaptions. Three things are important here: energy density, response time, and storage time. Energy can be stored by electrical, mechanical, thermal, chemical or electro-chemical means. It is to be noted that electrochemical means – batteries – allow for quickly loading and discharging energy over long periods, and are therefore potentially suitable for power and volume applications.

CURRENT VALUE AND COSTS OF STORAGE

In terms of its affordability, the value of storage must be set against its cost. For the electricity markets, the value of storage is in direct relation to the volatility of prices in these markets. To date, storage has been in almost all cases too expensive to justify implementation. It is therefore worth examining which combinations of applications might increase the value of storage.

SYSTEM VALUE VS VALUE FOR THE OWNER

Because trading in storage creates the most value for the owner, its potential value to the system is often overlooked. Although a positive business case might be made for large-scale storage, technical, policy and market factors often present obstacles. On top of this comes the uncertainty of the energy market, which is in a state of transition and therefore makes long-term investments risky.

FLEXIBILITY THROUGH INTERCONNECTION AND SYSTEM INTEGRATION

The countries of north-west Europe have an interconnected energy transport network. This makes possible the creation of a European gas and electricity network, which would involve an enlargement of the market. The greater size would inhibit price volatility but would increase transport costs. However, energy policies in Europe are national in character and are not aligned with one another. A coherent European energy policy is a precondition for managing cross-border aspects of the market. The energy system does not consist of the electricity network alone. The Netherlands also has an extensive infrastructure for gas, and also for thermal at local level. Combining these systems would increase the size of the overall system and also increase utilization of the existing infrastructure.

ONE PERSON'S FLEXIBILITY IS NOT ANOTHER'S

There is not one single sort of flexibility: different solutions exist for different wishes and requirements. The choice of solution is determined by the technical specifications of the source and the value that can be derived by introducing the respective solution to the market.

5. MARKET DESIGN AND REGULATION

The integration of sustainably generated energy and corresponding policies will call for changes to the current system, and flexibility will be required both of users and of suppliers in the future. The starting-point is competition in supply, which supports good price formulation, transparency and liquidity. The second is the identification of any inefficiencies, and the third is intervention by government to protect the public interest.

ECONOMIC REQUIREMENTS FOR FREE COMPETITION

If energy markets are well equipped to do their job, then producers and end-consumers take decisions that are in the best interests of society. Production also develops in a positive direction. Five policies are important for efficient markets: (i) prices give the right signal, (ii) there are enough markets, (iii) the markets are accessible to all, (iv) the markets are liquid, and (v) the markets are transparent, so that everyone can analyze the circumstances and form an opinion.

Fluctuating prices characterize the current day-ahead market, the intra-day market and the imbalance market. Large-scale users can operate in these markets, but small consumers, who have to enter into contracts with fixed prices, cannot. This compromises the flexibility of the Dutch markets. The concept of aggregation of these smaller participants is barely developed in the Netherlands, unlike in other countries. The day-ahead market, the intra-day market and the imbalance market are suited to trading in flexibility, and could be improved by the application of ICT. Local markets could also be drawn on. Further study is needed to ascertain whether the day-ahead market, intra-day market and imbalance market can be improved so as to make it easier to trade large amounts of electricity from fluctuating sources. At the moment, all BRPs have access to the short-term markets (APX, intra-day and imbalance). Small consumers do not have access, because they have no Balance Responsibility. Sustainable electricity from fluctuating sources can be better integrated into the system if all parties involved are able to act flexibly, which includes consumers using smart meters. Inclusion of small consumers in the day-ahead market, the intra-day market and the imbalance market would also increase the liquidity of these markets. It is also difficult to obtain transparent data about the Dutch electricity system (e.g. to ascertain the number of users in particular groups, capacity levels and transport costs). This situation could be remedied by the creation of a website in which past and present prices and volumes on the various exchanges are made accessible to all.

MARKET INEFFICIENCIES

Two forms of inefficiency characterize electricity markets: (natural) monopoly and external effects. Competition within the infrastructure for electricity is barely practicable. It is efficient if there is a single infrastructure that all parties use. In the Netherlands, electricity networks belong to the government, and are regulated accordingly. This situation was appropriate in the past, when passive users were not able to influence their consumption of electricity. The situation has changed now, however, and small consumers should be able to exert an influence on the cost of the network. An important external effect (environmental cost) is the emission of GHGs, whose cost is not factored into electricity prices. The application of a CO_2 levy would make sustainable electricity cheaper and polluting energy more expensive. Even if the markets are efficiently organized and regulations exist to correct external effects, the outcomes might be undesirable from a societal point of view. Ensuring that the markets operate in such a fashion that flexibility can easily be traded is the best way of ensuring security of supply. Allowing consumers to choose between volatile prices, which are on average lower, or fixed prices, which are on average higher, will ensure affordability and obviate the need for government intervention.

6. VALUATING FLEXIBILITY: OPPORTUNITIES AND PREREQUISITES

Unlike many other studies, the starting-point for this study is not the depiction of some wished-for future state but rather the portrayal of the current status of energy production and energy markets in the Netherlands. This final section recapitulates on the main points in the foregoing ones, outlining on the one hand the context for the energy transition in the Netherlands and on the other the greatest challenges that lie along the transition path. The essential challenge is to meet the electricity system's growing need for flexibility in a timely and effective manner.

THE ENERGY SYSTEM IN TRANSITION

The energy system is changing worldwide and the effects are visible in Europe and the Netherlands. Two general trends are recognizable here: (i) the proportion of energy from renewable sources will increase, although fossil fuels will continue to have a leading role in the energy mix in the coming decades, and (ii) especially in Europe, there is a rapid increase in the numbers of local initiatives for saving energy and producing energy from renewable sources, both for individual use and for supplying the net. The proportion of fluctuating energy sources (solar and wind) will rapidly increase in the decades to come, making the electricity supply ever more dependent on the weather.

BALANCING SUPPLY AND DEMAND

Unlike most countries in Europe, the Netherlands has a system of BRPs for balancing supply and demand. This has created a very high level of reliability, and the Netherlands can even take large electricity surpluses from Germany. An efficient energy production system is characterized by maximum reliability and minimal failures, with supply and demand always kept in balance, even when either of these fluctuates. If they are not kept in balance, problems in the electricity system can occur, for the current system has few possibilities for storing electricity.

WHEN DOES RELIABILITY COME UNDER PRESSURE?

The speed at which fluctuating energy sources will grow in the coming decades is not known, but the 2014 National Energy Survey estimates that by 2030 some 49-53% of energy produced in the Netherlands will come from renewable sources. Whether these fluctuating energy sources will create problems for maintaining the balance of the electricity system and the quality of the voltage is not known, however. It is thus unclear when, and to what extent, the Netherlands must take measure to be able to continue to ensure a reliable electricity supply; scenario studies suggest a period of 10 to 15 years.

SOURCES OF FLEXIBILITY

It is unlikely that the system of Balance Responsibility in its current form will be able to maintain the balance between supply and demand with a growing proportion of electricity generated from fluctuating sources. This is for two reasons. Firstly, the basis for the current system is that the supply of electricity is adjusted whenever the expected energy demand requires this. Electricity production from fluctuating resources is difficult to regulate, however. Secondly, the current system is designed for trading between large, specialist players, and is not accessible to the growing proportion of small consumers who are producing energy locally. Small consumers might in future play a greater role, but only with the help of aggregators. Flexibility is a key concept for the electricity production of the future, and requires that all parties involved are in a position to swiftly react to balance supply with demand. This study describes various technologies that can enable this degree of flexibility. These range from continuously controllable energy production through dynamization of energy demand and strengthening of the connections between power plants and energy networks to the introduction of effective storage capabilities. Not all these sources of flexibility have the same characteristics and application possibilities, and a reliable system has to take a range of different factors into account – costs, energy-producing capacity, physical scale and temporal dynamics.

NEW REQUIREMENTS FOR ENERGY MARKETS

The upscaling of renewable energy sources also imposes new requirements on the energy markets. An efficiently functioning market is essential to stimulate appropriate behavior on the part of market participants in the form of price signals. A precondition for this is that all participants should have access to these markets under the same conditions. This applies to all suppliers, great and small, and all purchasers, great and small. At the moment, however, small consumers have in practice no access. ICT could be deployed to help change this situation.

VALUE OF FLEXIBILITY; TYPES AND DIMENSIONS OF FLEXIBILITY

The transition to a future-proof energy system is not just a technological one: it involves changes in economics and behavior too. The energy market must be shaped in such a way that all market participants can sell or buy at the moment when this is necessary and profitable. One person's flexibility is not another's, and so the specific characteristics of each energy source must be suitable to the various energy markets.

RECOMMENDATIONS

To support the transition to a future-proof energy system, a follow-up study should address the following issues:

1. **Adaptations in the design of the energy market**, which should migrate from one based on *centralized, stable supply* to one based on *flexibility with value*. This requires the admission of new market participants, market transparency, and fluctuating prices.
2. **Dynamic modelling of flexibility in the energy system.** To protect the affordability of our energy production, more insight is required into the way the various sources of flexibility influence price.
3. **Portfolio analysis of flexibility sources.** A key conclusion of this study is that a combination of flexibility sources is required in order to facilitate flexibility at various levels in the system. These sources require further investigation.
4. **Economic opportunities: Value model for players.** Flexibility can acquire an economic value in an energy market in which electricity prices are variable and external costs are discounted in the price. Further study is necessary to explore the contribution that aggregators might make here.
5. **Learning by doing: Practical experiments and living labs.** Uncertainty is inherent in any transition process, and parties who are prepared to experiment with the development of the necessary flexibility in the energy system should be given ample opportunity to do so.

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