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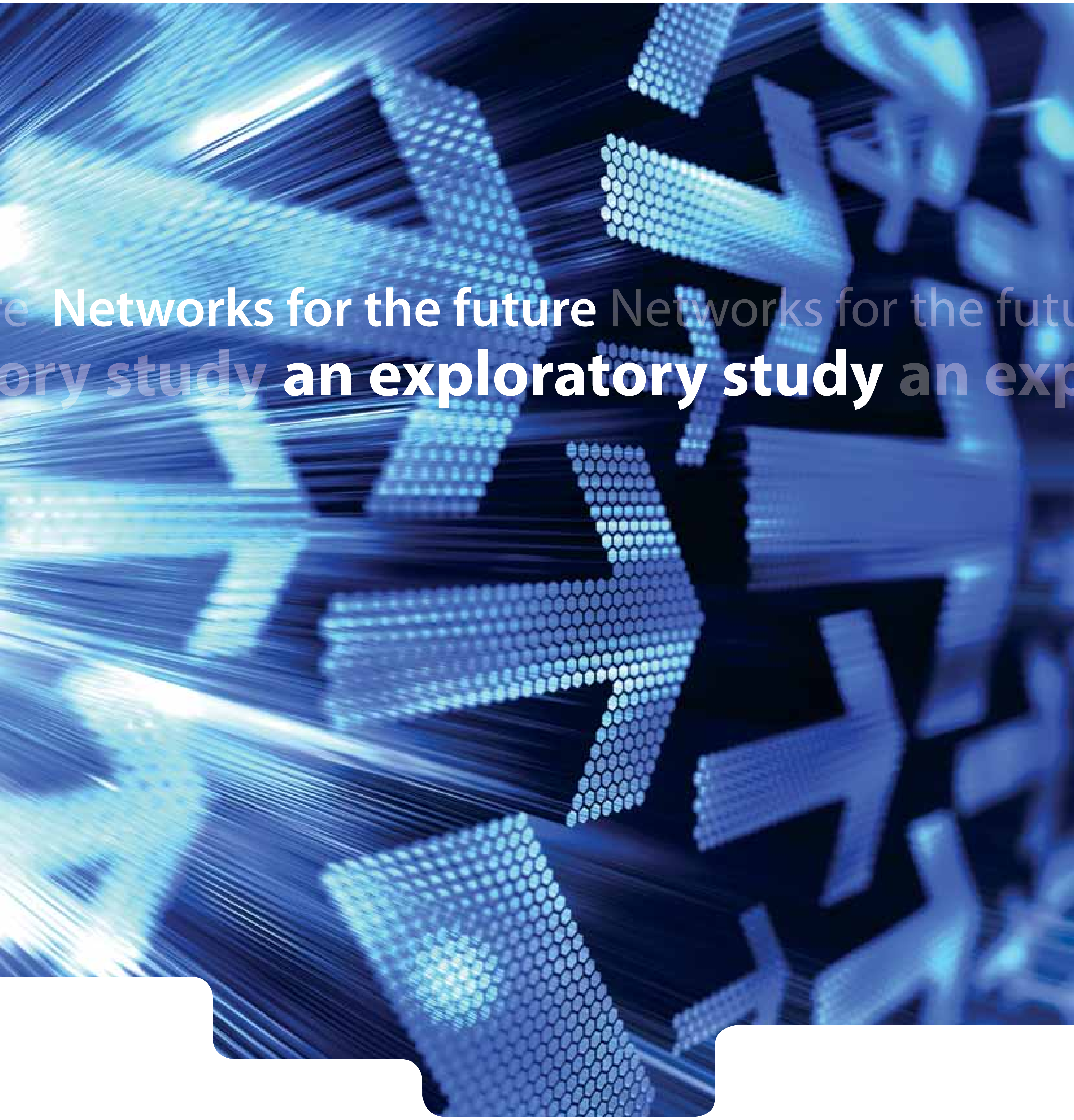
Networks for the future
an exploratory study



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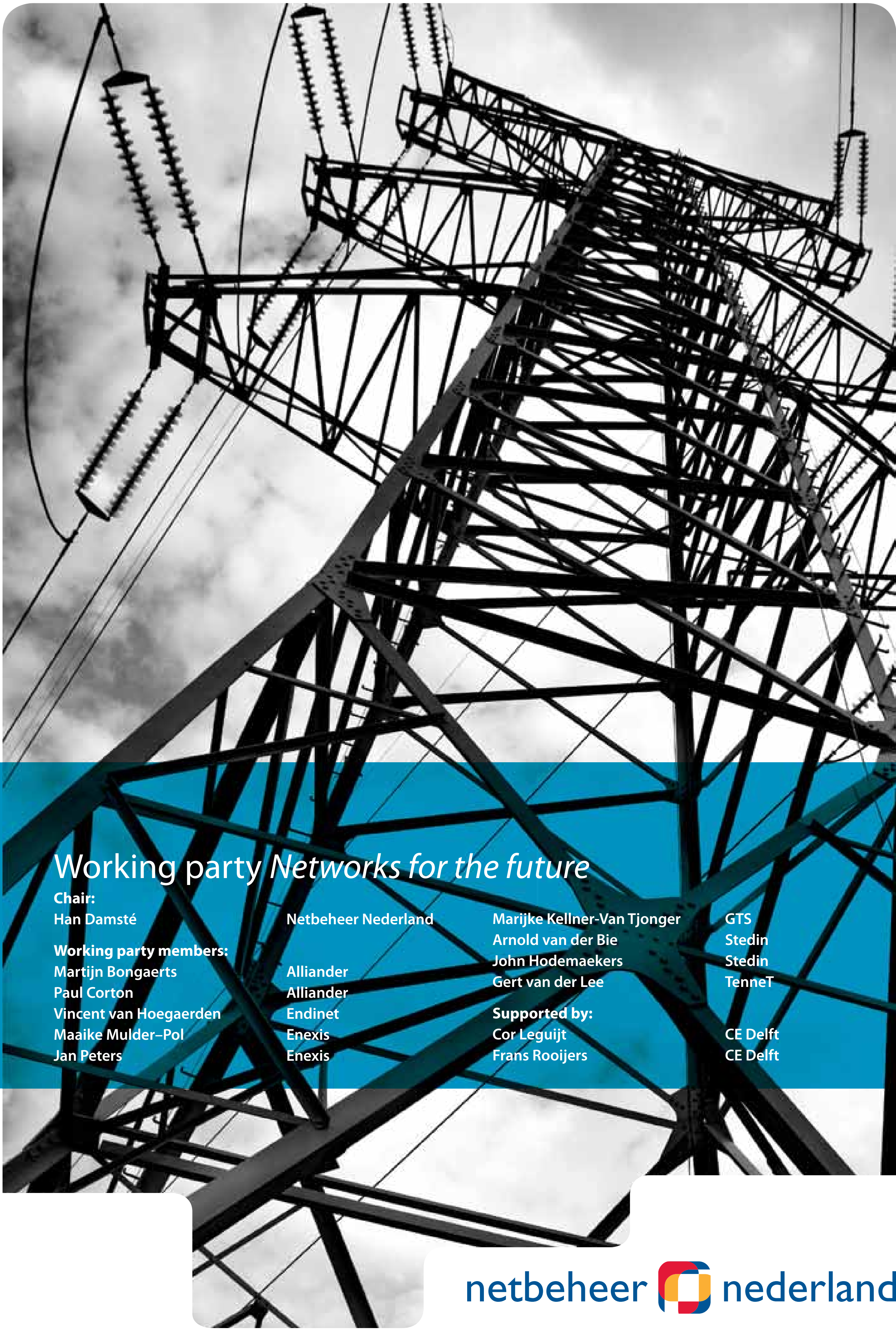

Working party *Networks for the future*

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Foreword

In this report, *Networks for the future*, Netbeheer Nederland and its members explore possible developments in the Netherlands' energy infrastructure, in particular as a result of the 'energy transition', and the role network operators have to play in that transition.

Increasing demands for sustainability have a great impact on the energy infrastructure. Network operators in the Netherlands have both the task and the ambition to contribute to the transition needed to meet those demands, a transition that in some cases will require high levels of investment in the country's energy networks. The choices network operators will have to make in carrying out these investments may have consequences for the form and speed of developments in the transition that the energy infrastructure will undergo.

We are keen to discuss with you the issues such a transition brings. *Networks for the future* is, after all, something we all have a stake in.

Jeroen de Swart
President Netbeheer Nederland

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Contents

Our starting point: the EU target of drastically reducing CO_2 emissions – based on 1990 levels, a 90% reduction by 2050

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Summary and conclusions

Global climate targets are going to have a huge impact on the energy supply as we know it today. This impact also extends to the energy infrastructure, including energy networks, which is the subject of this report. The EU aim of achieving a drastic reduction of CO_2 emissions – 90% by 2050 as compared to 1990 levels – has been taken as the point of departure for exploring the impact of climate targets on energy networks in the Netherlands.

The transition to a more sustainable energy supply will have far-reaching consequences for energy infrastructures and the role of network operators. It is certain that high levels of investment will be needed to prepare energy networks for all the changes to come. At this moment it is not possible to predict which investments will be required, how large they will need to be and where and when a start should be made. In other words, there is a considerable risk that any investment decisions made now to facilitate energy transition will, with hindsight, be inappropriate.

From the point of view of investment efficiency, delaying investment decisions would the best course to follow. This is, however, not an option. Network operators continually make investments in extensions to and maintenance of their networks that have life-spans of 40–80 years: investments made today will still be in place in 2050. Delay could mean that modifications to the energy infrastructure will be realized too late, slowing down the transition process. This well-known problem is referred to as "the network operator's dilemma".

Netbeheer Nederland is keen to take part in a dialogue with political and societal players about the role of energy infrastructure and network operators in the energy transition and which investment choices need to be made. This report, *Networks for the future*, represents the start of such a dialogue. Netbeheer Nederland presents here the most likely scenarios for energy transition and their uncertain consequences and, where possible, indicates the direction in which solutions are likely to be found.

To facilitate the dialogue, Netbeheer Nederland commissioned CE Delft to prepare a study of options for changes to the energy infrastructure (scenarios) that would enable the Nether lands to meet the target of a 90% reduction in CO_2 emissions by 2050.

Already in advance of the study, Netbeheer Nederland had two observations to make about the target:

- The 90% reduction of CO_2 emissions will not be achieved without major changes to government policies. Societal support for those changes will be required.
- Renewable sources (e.g. offshore wind, biomass), fossil fuels with capture and storage of CO_2 (coal and natural gas combined with CCS) or nuclear energy may be used to achieve the target. The use of fossil fuels is greatly dependent on the technical and economic development of CCS and on its societal acceptance.

By clearly presenting the implications of a drastic reduction in CO_2 emissions, this report may contribute to creating societal acceptance of the energy transition that such a reduction implies. Ultimately, political decisions will have to be made to translate the broad targets for 2050 into concrete actions for energy consumers, technology developers, market parties and network operators.

For energy infrastructure in the Netherlands, the study indicates a number of quite plausible consequences:

- Severe CO_2 reduction targets imply that at the local level only CO_2-neutral carriers of energy can be supplied, for example electricity (generated from sustainable or 'clean' fossil fuels), green gas and (heated) water. The increase in decentralized generation means that the capacity of local power networks in new and existing housing estates and buildings will need to be increased and made 'smarter'.

- Local distribution of natural gas will change markedly. Demand for natural gas will decline partly as a result of efficiency measures and partly because gas as a source of heating by will be replaced by other sources such as heat pumps, solar boilers, geoheat, ground-source heat pumps, waste and process heat from fossil-fuel-fired power stations combined with CCS, green gas, micro-CHP units fired with green gas, and bio-CHP at a district or central level. Jointly-owned systems are likely to play a more important role than they do now – due to their economic advantages. Natural gas may still play a role in meeting peak demand for heating; the related CO_2 emissions are relatively small.

- Centralized generation of electricity will take place especially in coastal areas, primarily because of offshore wind power, import and use of biomass, and /or the combination of conventional power stations with CCS. Increasing the capacity of the high voltage grid (transmission network) will be particularly necessary in these coastal regions.

- In the future, natural gas will play an increasingly important role as a transition fuel. Increasing the capacity of the national gas transport network is a logical consequence of this development, particularly in view of the role of the Netherlands intends to play as an international gas hub.

- At the local level, gas distribution networks will increasingly distribute green gas. Ultimately, in new building projects the distribution of gas and heat to all buildings will cease. The pace of this change will depend on the speed at which building standards for emission-free buildings with an Energy Performance Coefficient (EPC) of zero are introduced and on the outcome of the discussion as to whether gas will or will not continue to play a role in meeting peak demand for low-level heating.

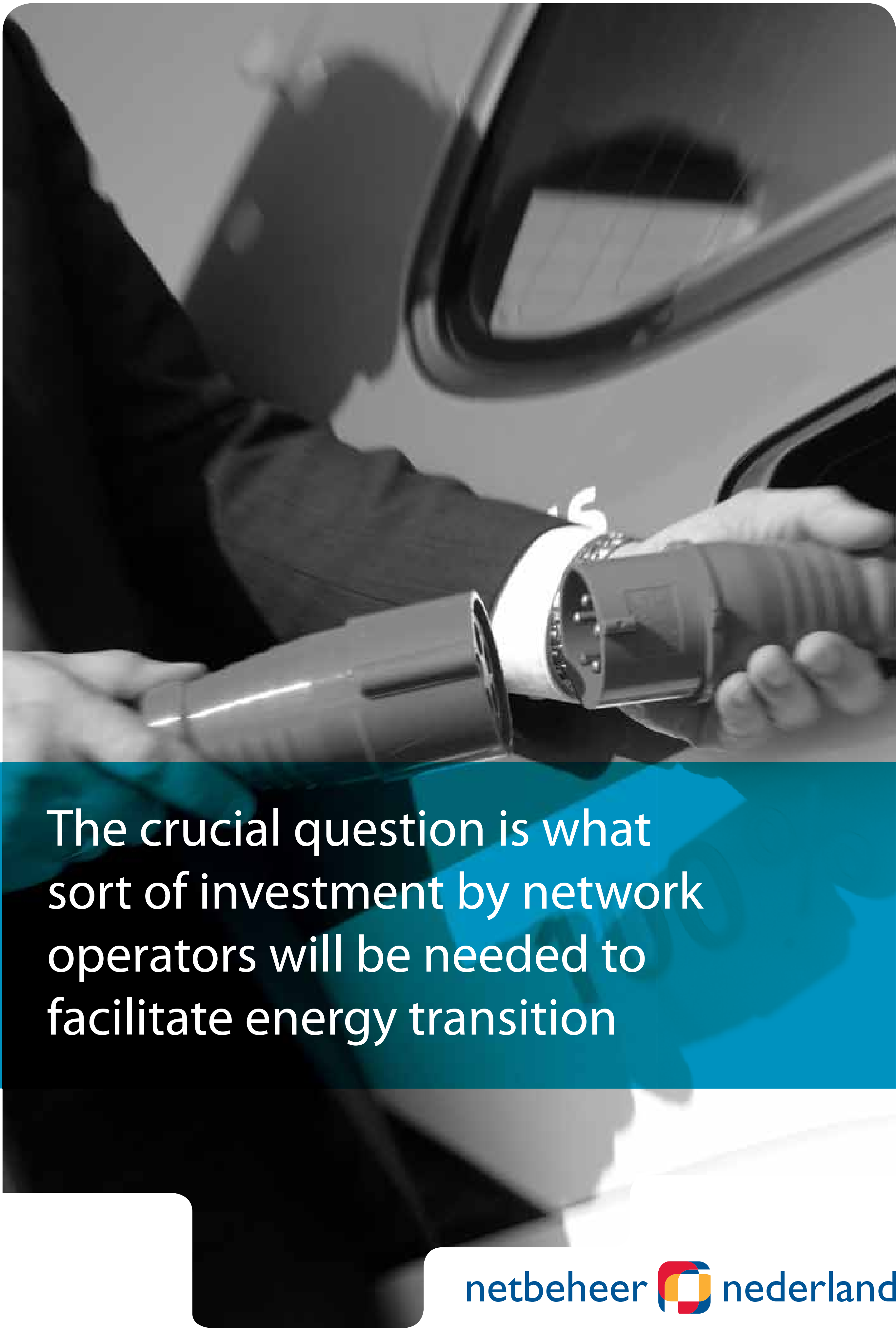
In addition to these very likely consequences of reducing CO_2 emissions to 90% of 1990 levels by 2050, there are a large number of uncertainties, many of which may exacerbate the impact of each other. The most important uncertainties are:

- The timeline for the developments of various technological innovations, for example advances in solar photovoltaic panels (solar PV), heat pumps, electric cars, micro-CHP, air conditioners, or storage systems for electricity. On the longer term, completely new innovations will be introduced that defy prediction today.
- The technical requirements that are a consequence of the technologies applied to the energy infrastructure. For example: charging electric cars; electric heat pumps – with or without extra electric heating; and injection of gas derived from biomass.
- The spatial concentration of technological developments: for growth in demand for extra capacity there is a big difference between a situation where a technology has been implemented in 10% of buildings in every (i.e. 100%) district and one for which the technology has been implemented in every (i.e. 100%) building in 10% of the districts.
- Local consequences of specific responses to local heating demands.
- The optimal manner of injecting green gas into the gas network.
- Societal acceptance of technologies such as CCS.
- The role to be played by network operators in storage, and CO_2 and heat networks.
- The degree of certainty of the 90% reduction of CO_2 emissions, because if a lower level is sufficient then some options will not have such extreme consequences, e.g. no CO_2 emissions at the consumer end.

These uncertainties give rise to questions. For network operators, the answers to these questions will play a crucial role in investment decisions to be made in the coming years:

1. How will the regulatory framework evolve to meet societal demands made on the facilitation of the energy transition, or in what way – with which institutional instruments – can optimal societal choices in the energy infrastructure be made that take sufficient account of the long term and the entire chain of demand for and production and distribution of energy?
2. Is it desirable to immediately increase the capacity of the electricity infrastructure of areas in which new building projects are underway by providing extra medium and high voltage capacity in the network structure?
3. Is it desirable to increase the capacity of the electricity infrastructure in areas where replacement investments are necessary by incorporating extra medium and high capacity in the network structure? Particularly in areas where building density is high, solutions will have to be found for these extra infrastructural features.
4. How, around 2020, can a clear picture be obtained about the level of reduction in demand for energy, the use of heat pumps and the degree to which transportation systems have electrified so that from 2020 onwards investments can be channelled to support such developments?
5. In what manner will network operators inject green gas into the gas network?
6. What effect will the use of connect-disconnect capacity have on the form of smart demand-response management to be used, and what relevant pricing mechanisms will evolve?
7. What effect will raising building standards to an EPC = 0 have on the construction of distribution networks to all buildings in new building projects?
8. Which experimental projects will be initiated for the development of innovative techniques and technologies?

Netbeheer Nederland and its member companies are eager to enter into a dialogue with politicians, society and professional participants in the energy sector about all these questions, so that investment decisions that are widely supported by society can be made for facilitating the energy transition.



The crucial question is what sort of investment by network operators will be needed to facilitate energy transition

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1 Introduction

1.1 Why this report?

In the decades ahead, our system of energy provision will undergo a sweeping transition, reflecting a society that will have virtually eliminated the emission of greenhouse gases. An important question for network operators is the form that such a transition will take, and what influence this will have on various elements of the energy infrastructure and the role of network operators. Conversely, investment decisions made by operators will have a great impact on the direction and speed of the transition.

Network operators want to engage political bodies and Dutch society in a dialogue on these important societal issues. By publishing this report, the network operators aim to facilitate that dialogue.

It is important to recognize that changing network infrastructures is a long-term process. This means that an early start needs to be made with identifying the consequences of certain developments on networks. With this report, the network operators intend to make a start with the process.

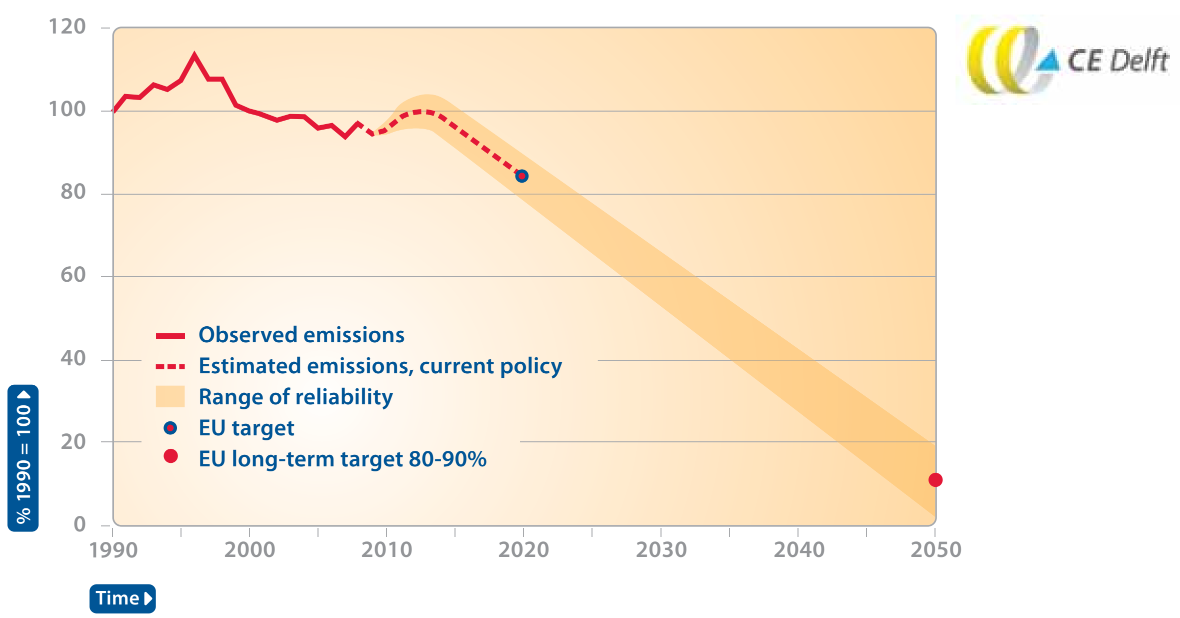
Specifically, network operators aims are threefold:

1. To develop insights into the relationship between technical developments and societal demands in relation to energy transition.
2. To reach consensus with important stakeholders about the role and position of network operators in the process.
3. To establish a basis for dialogue with stakeholders.

The audiences this report addresses include government ministries, political bodies, governmental bodies, energy companies, advisory bodies and scientific institutions, nature and environmental organizations, umbrella and branch organizations for various sectors, consumer-based organizations, and any other parties with a stake in the energy chain.

The starting point for the report is the goal of the European Union to limit global warming to a maximum of 2°C. To achieve this will require a drastic reduction in CO_2 emissions, as have been expressed in EU and national policies (20% reduction by 2020 and 80–95% by 2050)[1]. The targets for 2020 are therefore an important intermediate step on the way to achieving the more stringent 2050 goals.

Figure 1
Timeline for targets for greenhouse gas emissions (1990 level = 100)



1 *The European Council laid down in 2009 a reduction of 85–95% by 2050 (VROM, 2009). Eurelectric, the European branch organization for electricity producers, maintains a "climate-neutral" target for the electricity sector by 2050 (Eurelectric, 2009).*

In the case that lower targets are pursued, the impacts on energy networks will be less.

In addition to considering gas and electricity networks, the report also looks at heat and possible CO_2 networks. Energy demand for road transport is also taken into account since electric mobility will lead to an increase in demand for electricity. This report does not, however, cover air and maritime transport, nor does it take into account other greenhouse gases than CO_2 or the use of fuels as raw materials (feedstocks).

In a similar vein, the report considers only to a very limited degree cross-border transport of gas and electricity. Its focus is clearly energy demand and production for the internal Dutch market. Cross-border transport accounts for a high proportion of the use of the high-pressure gas network in the Netherlands. It is expected that, partly as a result of continuing internationalization of the energy market, cross-border transport will increase in the future. Since the availability of gas from North-West European gas fields is decreasing, other sources and routes will be used for the supply and transport of gas. An increase in the amount of high-pressure gas infrastructure is need to be able to meet increasing demand for gas in the Netherlands and surrounding countries.

Netbeheer Nederland commissioned CE Delft to develop several scenarios for an energy infrastructure in the Netherlands that would result in achieving the target of a 90% emissions reduction by 2050, each scenario based on different technological options. The type of impact on the energy infrastructure is to a large degree the same for each of the scenarios. The scenarios differ, however, in the size of the increases in infrastructural capacity they will require and, specifically, the level at which the increases will need to be carried out (national, regional or local networks).

The most important policy issues to be addressed in the coming years are:

- Increasing the capacity of electricity networks in new and existing buildings.
- Investments for feeding onshore and offshore wind power into the electricity grid.
- Response to demand for heat for new and existing buildings.
- The method for the injection of green gas into the gas network.
- Creating opportunities for establishing experimental projects to acquire crucial know-how.

The network operators have the tasks of facilitating the energy transition and making the investments to bring it about. To be able to combine these tasks effectively, the network operators must make far-reaching investment choices. This requires broad societal support for such measures. 2050 may seem a long way off but many of the investments needed for the energy infrastructure have a regulated pay-back time of 40 years or more. For this reason, discussions about 2050 need to begin now.

1.2 Purpose of *Networks for the future*

The central issues in this report are when and what sort of investments must network operators make to facilitate the desired energy transition, and which investments are not yet necessary. These do not relate to specific points that have already been covered in short-term investment plans but, rather, developments that are expected to occur much later. Nevertheless, these developments are already casting their shadow over the present and ultimately need to be incorporated in concrete investment plans.

The crux of the issue is that investments in network infrastructures take a long time to implement, requiring that an early start be made with determining the consequences of planned developments of networks. This includes activities such as exploratory studies, research, experimental projects, and, ultimately, rollout on a large scale.

Networks for the future is not attempting to make a case for more investments in the energy infrastructures of the Netherlands. Rather, it reflects the intention of network operators not to be overtaken by events.

For network operators, the question is how, and through which processes of institutionalization, can socially optimal choices be made to create an energy infrastructure that takes sufficient account of the long term and the entire energy chain of demand, distribution and production.

The scenario study carried out by CE Delft sketches several plausible lines of development that would enable the EU CO_2 targets to be met. For network operators, given their role of facilitating the energy transition, these are developments that are unavoidable, even though no guarantees can be given for their outcomes. Technologies that are still in an 'experimental phase' have deliberately not been included.

The intention is to update this report at least once every five years, or more often if necessary. Scenarios have been chosen that bring into view the farthest boundaries of the playing field and thus clearly demonstrate the impact that these would have on the energy infrastructure. Of course, this approach cannot deliver an exact picture of what the future will look like. In reality, all sorts of combinations of scenarios are likely to occur.

This report deals not only with electricity and gas network infrastructures in the Netherlands, but also network infrastructures for CO_2 and heat, including the roles network operators may play in them. The report looks at developments using a longer time horizon than the biennial Quality and Capacity documentation (KCDs)[2]. Choices related to the subjects dealt with in the documents are described in the KCDs.

Networks for the future provides insights into developments and describes the links between them, while also attempting to clearly identify the dilemmas to be faced. In this manner the context within which network operators make their investments and the societal choices that follow on from them become clear. It is for this reason that the report also contains estimates of the investments required for various infrastructural developments; this information can be included in the dialogue with stakeholders. The central dilemma to be found in this report is: if the network operators facilitate all technical developments and the preliminary investments required for them are made, it is possible that some of those developments will ultimately come to a halt; in hindsight, some of the investments will have been made for nothing. However, if certain technical developments are postponed until large-scale implementation is certain, it will be too late to make the adjustments to the energy infrastructure required, placing a socially undesirable obstacle in the path of the energy transition. This report does not solve this dilemma. Rather it sets out to provide insight into the dilemma, so that during the dialogue among all stakeholders the best choices can be made.

The network operators and other parties have already made a start with gaining attention for the dilemmas, as well as informing the broader public about the consequences of energy transition. In this context, relevant publications are:

- Actieplan Decentrale Infrastructuur (transitieplatforms PNG en PDE, 2009).
- Brochure 'Netbeheer in transitie' (Netbeheer Nederland, 2009).
- De ruggengraat van de energievoorziening (AER, 2009).
- De Visie van de netbeheerders op Smart Grids.
- Het gezamenlijke structurele onderzoeksprogramma 'Intelligente netten'.

2 KCDs, or Quality and Capacity documents, present the network operators' view and expectations for seven years ahead; KCDs are published every two years.

1.3 Climate policy demands substantial changes in the energy infrastructure[3]

A CO_2 reduction of 90% by 2050 will have an important impact on energy supplied and hence also the energy infrastructure. This stiff reduction in CO_2 emissions demands a transformation of the energy supply system because the greatest cause of CO_2 emissions is the combustion of fossil fuels. As a result, in addition to the concepts 'affordable' and 'reliable', a third dimension has been added to energy policies: the concept 'clean'.

Currently in the Netherlands, fossil fuels are the primary sources of energy, for example natural gas, coal and oil. To meet climate goals, the CO_2 that is emitted will have to be captured and stored. Another option is to replace fossil fuels with clean, renewable energy sources. Furthermore, a reduction in demand for energy by consumers would also make a welcome contribution towards meeting the climate goals.

For low-volume consumers, virtually only CO_2-neutral energy carriers[4] will be made available since current expectations are that it will be impossible to capture and store CO_2 produced by millions of small users. Capture and storage will be concentrated at places where large volumes of CO_2 will be emitted.

1.4 Report overview

The energy scenarios and the analyses of their consequences for the energy infrastructure of the Netherlands are described in detail in CE Delft's preliminary, supporting study (CE, 2010). In this report, *Networks for the future*, the approach taken in determining the scenarios is described in Chapter 1.
Chapter 2 describes the volume effect of the scenarios on the energy infrastructure as a whole.
Chapter 3 deals with the consequences of this for the energy infrastructure, which are, in particular, based on developments in the demand for capacity.
Chapter 4 focuses on the important transition phase towards establishing a sustainable energy chain and on initiatives that network operators themselves intend take in the coming years. Chapter 5 examines the investments in the infrastructure that will be required.
Finally, Chapter 6 discusses issues that need to be taken into account to improve the regulatory framework.
A management summary and main conclusions can be found at the beginning of the report.

3 The term energy infrastructure covers the entire energy system, from demand through to exploiting energy sources, including, among others, heat, electricity, gas, motor fuels, coal, wind power, nuclear energy and solar power.

4 CO_2-neutral energy carriers are forms of energy which in use have no net emissions of CO_2; examples are electricity and green gas, the latter being produced from biomass.

Scenarios have been chosen that bring into view the farthest boundaries of the playing field, to demonstrate the impact on the energy infrastructure

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2 Energy scenarios 2050

2.1 Changes in energy demand and technologies

Demand for energy increases with growing social affluence. This also brings with it a shift in the sorts of energy in demand: a decrease in demand for low-level heat[5] for, in particular, buildings and an increase in demand for electricity and energy to be used for mobility. It is expected that government policies will lead to reduced growth rates of energy demand. This will have other consequences than the rather mild energy efficiency policies pursued in previous decades.

It is expected that energy demand in the future will fluctuate more strongly over time than was previously the case. Although total volume demand will decline, demand for capacity from various sectors will undergo a relative increase. Demand for capacity is one of the factors that determines the adequacy of infrastructure for the transport and distribution of energy.

Factors that influence energy infrastructure include:

- Growth in societal affluence and related growth in energy consumption and demand for capacity.
- Improvements in the energy efficiency of buildings and appliances.
- Substitution of gas/motor fuels with other energy carriers such as electricity and 'heat' (e.g. electric cars, electric heat pumps, solar heat).
- Size, development and timing of peak demand (both electricity and low-level heat).
- Capture and storage of CO_2, including its societal acceptance.
- Development and use of renewable sources on a decentralized level (solar PV, solar boilers, ground-source heat, biomass, onshore wind power).
- Use of renewable sources on a centralized level (offshore wind power, biomass).
- The amount of available biomass for, among other uses, green gas.

Since 'reliability' is and will remain an important requirement for energy provision, for all scenarios that are not, or not entirely, reliable, adequate backup capacity is an important issue.

An extremely important factor behind energy transition is the amount and speed with which a reduction in CO_2 emissions must be realized and government policies that accompany these efforts. In this report, the EU target of 90% reduction in CO_2 emissions by 2050 has been used.

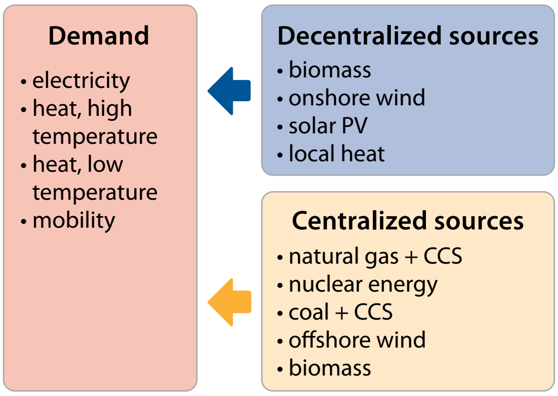
2.2 Energy scenarios

CE Delft was commissioned by Netbeheer Nederland to develop several scenarios in which the effects of the desired CO_2 reduction (90% by 2050) on the energy infrastructure in the Netherlands could be explored. The 90% emission reduction can be achieved in a number of ways and it is for this reason that different scenarios were developed. Scenarios were chosen to bring into focus the farthest boundaries of the playing field and the impact that these would have on the energy infrastructure. Conscious use of different extremes has, therefore, been made. In this manner, it was possible to determine which robust conclusions can be reached in relation to the energy infrastructure. Detailed descriptions of the scenarios can be found in CE's preliminary study (CE, 2010).

The energy scenarios combine energy demand, conversion technologies to be used, and decentralized and centralized sources of energy. Each scenario was drawn up with the aim of achieving the 90% reduction in CO_2 emissions by 2050. In this way, the scenarios give a glimpse of what could happen, what the effect of that would be on the energy infrastructure, and the developments that network operators need to take seriously into account in their network plans. The scenarios are most decidedly not a blueprint of how the energy infrastructure should develop. That is, after all, not a network operator's task.

5 *Low-level heat is heat having a temperature below 100 °C. High-level heat has temperatures above 100°C, e.g. steam.*

Figure 2
Scheme of components used in energy scenarios



All scenarios assume a reduction of demand for energy by consumers – in line with government policies. In addition, it is expected that part of demand will be met by decentralized production of heat and electricity at building and district levels, as well as in industry. This will involve CHP fuelled by green gas , solar PV and onshore wind. If CHP used in industry is also combined with capture and storage of CO_2 (CCS) then it will also be possible to use natural gas as a fuel. Finally, the scenarios differ according to the use made of a range of available energy sources.

Figure 3 is a schematic representation of three scenarios: A, B and C. These scenarios make use of the following variables:

- Energy demand (low or very low).
- Level of decentralized generation (low, medium or high).
- Centralized energy sources – wind energy + biomass (green gas or co-firing), or natural gas (with CCS) , or nuclear energy + coal (with CCS).

The naming of the scenarios used by CE Delft in its study has been taken over in this report:

- Scenario A is characterized by maximum use of renewable resources, very low demand and maximum decentralized generation.
- Scenario B is characterized by maximum use of gas (both green gas and natural gas + CCS) and medium levels of decentralized generation combined with low demand. This scenario is a more detailed version of the Flex scenario described in the Energierapport 2008 published by the Ministry of Economic Affairs (EZ, 2008).
- Scenario C is characterized by maximum use of coal + CCS and nuclear energy, low use of decentralized generation and low demand. This scenario is a more detailed version of the Power House scenario described in the Energierapport 2008 (EZ, 2008).

2.2.1 Energy demand

Energy demand comprises demand for heat, steam for industrial purposes, the number of transport kilometres and electricity. The demand for energy sources follows on from the demand for energy. Reducing demand by energy consumers is the first step to be taken in reducing CO_2 emissions. In particular, demand for both low- and high-level heat can be greatly reduced. Energy pricing and compulsory standards for appliances, vehicles and buildings also play an important role in this respect. This calls for different government policies.
Demand for electricity increases in the scenarios, in part due to partial substitution for gas and motor fuel and in part due to growth in affluence, which is accompanied by greater demand for energy. As the success of efforts to reduce demand cannot be estimated as yet, two levels of demand have been used: low energy demand, and very low energy demand.

Figure 3
Schematic representation of energy scenarios studied

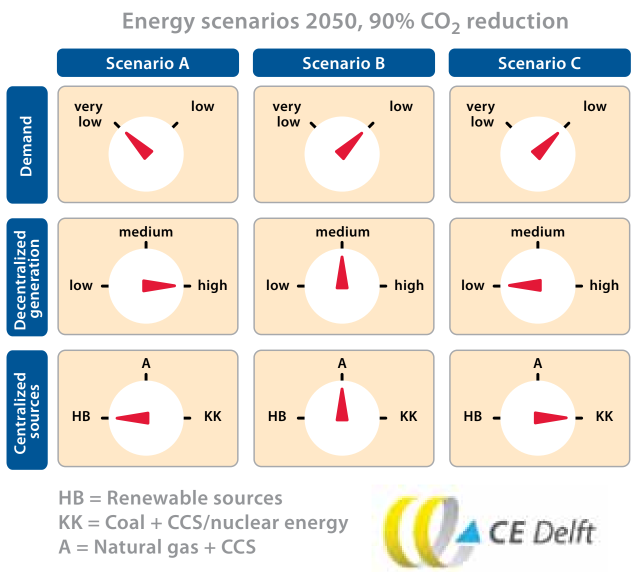


Table 1
Development of energy demand (PJ/year) by 2050

	2008	2050 low demand	2050 very low demand
Demand for electricity	432 (120 TWh)	540 (150 TWh)	450 (125 TWh)
Energy demand for mobility	170	200	175
Demand for high-level heat	500	400	300
Demand for low-level heat	600	400	300

Note 1: The demand for electricity does not include substitute demand (electric-powered transport, heat pumps) or decentralized production.
Note 2: This is not demand for primary energy. For that, conversion efficiencies are paramount.

In Table 1, energy demand is divided into four types of demand: electricity, mobility, high-level heat, and low-level heat. Note that these alone to not constitute primary demand. To calculate primary demand the effects of conversion losses (gas to heat, coal to electricity, etc.) and transport losses also need to be taken into account.

2.2.2 Decentralized production

Decentralized production of heat and electricity in to be found in all scenarios and will make a greater contribution to energy supply than is now the case. According to current insights, decentralized production will not be able to meet demand for energy entirely. Autarchy in energy, in which regions meet their own energy needs, thus making centralized networks redundant, is in a densely populated country like the Netherlands, with limited possibilities to harness solar and wind power, not possible. The mismatch in timing of demand and supply, as well as meeting demand from industry and mobility, make flexible centralized production a necessity.

On a decentralized level, use of solar power will grow as its cost price approaches the level of prices for electricity and its generation yields double (i.e. as a result of strong technical/economic improvements yields of 40 TWh/year, roughly twice the current consumption of electricity by households). Ground source heat, solar heat and geoheat in combination with waste heat will be able to meet demand for low-level heat at a decentralized level.

Three decentralized energy production options, each consisting of different combinations of solar PV, wind, green gas–CHP, and industrial CHP–CCS, have been formulated. Table 2 presents these decentralized options. Total decentralized production is expected to vary from 45 to 100 TWh/year by 2050.

2.2.3 Centralized energy sources

As already indicated, decentralized production will never be able to meet the demand for electricity entirely, let alone meet total demand for energy. In 2050 centralize energy production will, therefore, still be necessary to a large degree. As consequence, import of fuels will be needed – natural gas, too – because by 2050 'conventional' reserves in the Netherlands will be virtually depleted[6].

Table 2
Components of scenarios with decentralized energy production; absolute annual production (TWh/ year and GWe) by 2050

Scenario component	**Low**		**Intermediate**		**High**	
TWh/year	*GWeTWh/year*		*GWeTWh/year*		*GWe*	
Wind	5	2	10	5	15	7
Solar PV	5	5	15	17	40	44
Green gas–CHP	5	1	10	2	15	3
Industrial CHP–CCS	30	6	30	6	30	6
Total	**45**	**14**	**65**	**30**	**100**	**60**

6 *Note, however, that according to Energie Beheer Nederland (EBN) it is likely that large amounts of 'unconventional' natural gas could still be extracted.*

Wind energy
Wind energy is one of the important sustainable sources of energy for the Netherlands. Both offshore and onshore wind energy have been given a prominent role in the national programme 'Clean and efficient'. In the case of offshore wind energy, there is a societal desire for network operators to install a single 'power socket at sea', making separate connections for each wind park to the power grid onshore unnecessary. Issues that need to be dealt with include the distribution of costs, organizational structure and spatial planning. For a marked increase in offshore wind energy (> 10 GW), provisions will have to be made for storage, to allow electricity generated during peak periods to be put to use later on. This might take the form of storage basins alongside the wind parks, as used, for example, in Norway (NorNed cable).
A large amount of experience has been gained with onshore wind energy over the past decades as a result of the installation of large numbers of wind turbines, particularly in windy, sparsely populated areas. The existing infrastructure in those areas is in many cases not sufficient to deal with the large volumes of electricity generated and its capacity will therefore need to be increased. This will lead to regional differences in investments needed by network operators. Furthermore, the legislative framework is not geared to optimizing investments in this sort of infrastructure.

Only offshore wind power can be considered as a significant centralized source of energy in the Netherlands. Three technological options have been worked out that could meet demand and still allow CO_2 emissions to be reduced by 90%. In working these options out, choices also had to be made about energy carriers and energy sources for mobility and low- and high-level heat:

- Mobility – electricity, biofuels, hydrogen.
- High-level heat – natural gas + CCS.
- Low-level heat – residual heat, green gas.

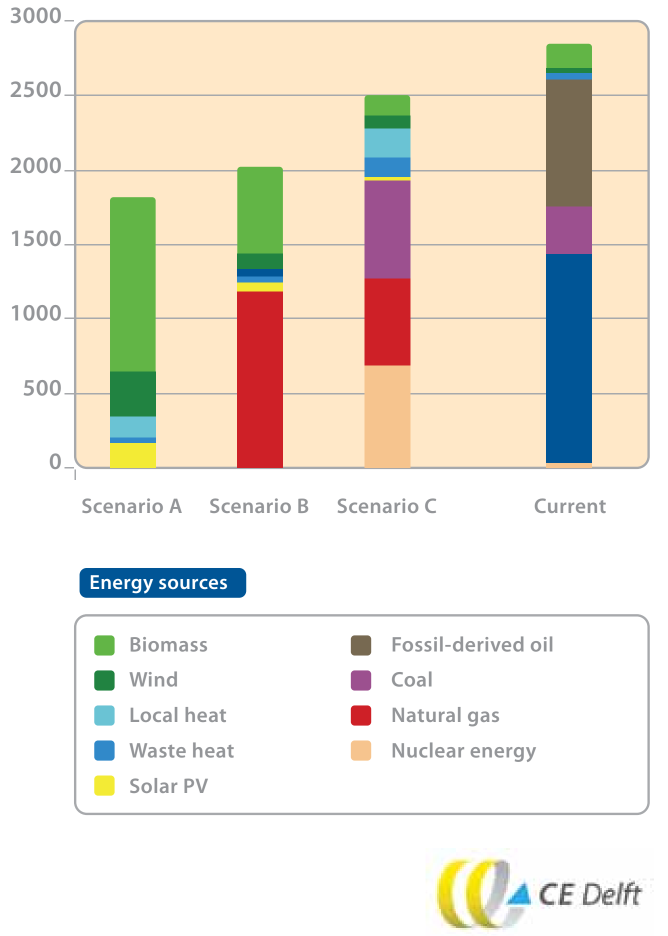
The contribution from various energy sources in comparison with those currently used is shown in Figure 4. All these sources are, as required by the 90% CO_2 reduction target, free of emissions; some make use of CO_2 capture and storage.

2.2.4 Matching demand and supply

Some energy sources (e.g. wind and sun) vary in their production capacity, which has to match fluctuating demand. This is especially the case for electricity, but this also applies to low-level heat since growing use is made of local heat sources (e.g. solar-thermal energy). A number of factors have an important influence on the matching of demand and supply:

- Gas capacity (centralized – gas-fired power station + CCS; decentralized – green-gas CHP) offers excellent flexibility (regulation) for matching demand and supply of electricity. In large measure, use can be made of the existing gas infrastructure.

Figure 4
Contribution of various energy sources (PJ/ year) under the energy scenarios studied; compared with the current situation



Micro-CHP will only play a very limited role in creating that same flexibility for solar PV, because the total capacity is too limited (even if 70% of dwellings have micro-CHP, as under Scenario B) and there is often no sunlight at moments when there is no demand for heat. Storage of heat would provide a solution to this problem but it results in rapid decline of the added value of micro-CHP.

- Local storage of electricity will become important, but it is costly and is therefore not considered feasible on any large scale at the moment; storage in batteries of electric cars does offer technical possibilities in the future for local storage of electricity. In particular under Scenario A, extensive local storage of electricity has been allowed for, to accommodate large volumes of power from solar PV. Optimization in relation to expanding network infrastructure and smart load-supply management systems will take place when such storage facilities are finally implemented.
- Demand-response and load-control systems will grow in importance in an effort to optimize investments in energy infrastructure, grid capacity and production facilities.
- Improved forecasting of production from wind and solar sources will improve the match between demand and supply of electricity.

2.3 Conclusions related to the energy scenarios

To meet the EU target of 90% reduction in CO_2 emissions by 2050, drastic changes will need to be made in the energy infrastructure of the Netherlands. To be able to get a clearer idea of these changes, Netbeheer Nederland commissioned CE Delft to develop – based on current publications and insights into technical possibilities – several scenarios that would enable the reduction target to be met. These scenarios incorporate relatively extreme choices in relation to:

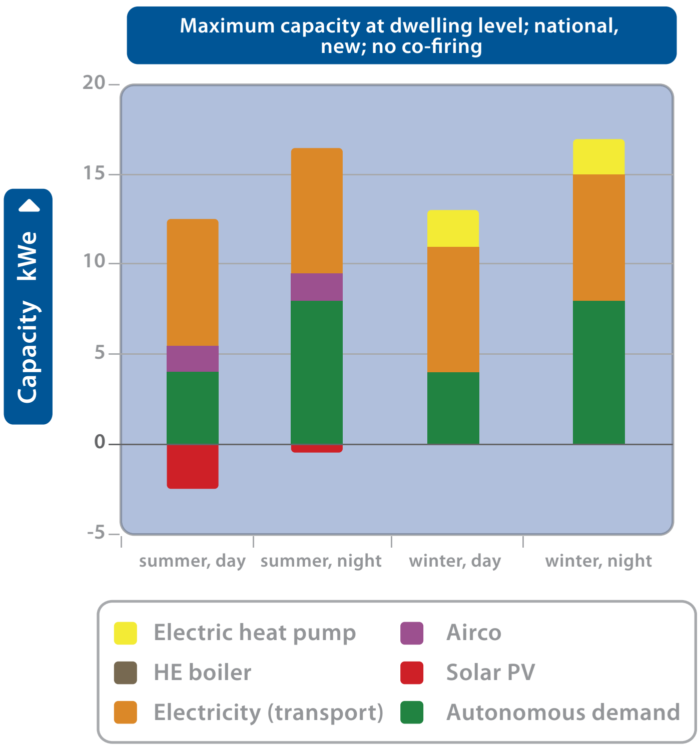
- Potential savings.
- Decentralized generation.
- Large-scale CO_2-neutral generation.

The capacity of the energy infrastructure must be sufficient to not only meet typical energy demand but also to meet demand at peak moments (e.g. the coldest day of winter) and provide backup for variable energy sources, such as wind power and solar PV. This issue dealt with in Chapter 3.

Maximum consumption at dwelling level

The bar diagram shows changes in consumption capacity at the dwelling level for a detached dwelling if it has a charge point for an electric car and uses a heat pump in winter.

At the neighbourhood level, the effects average out due to a large spread in the moment when charge points are used for recharging electric cars. The effect of solar PV at the dwelling level is smaller, but since the input of each dwelling more or less coincides with that of all the others, on a neighbourhood level the cumulative effect needs to be taken into account if solar PV (15 m^2 per dwelling) is widely implemented.



The exploration of scenarios described in Chapter 3 provides a number of robust conclusions about the situation in 2050. 'Robust' in this context refers to conclusions that apply for all the scenarios and thus result from the substantial reduction in CO_2 emissions itself; the conclusions are less dependent on how the reduction will be realized. Energy saving is the first essential step in the transition to establishing a sustainable energy supply. Government policy is an important factor in achieving this. Further, a number of conclusions can be drawn for each energy carrier:

1. Electricity:

- Electricity will become an important energy carrier due to substitution for other carriers and growing societal affluence.
- Demand for electricity will increase strongly at the local level (electric heat pumps, electric mobility) as a result of substitution for other energy carriers.
- Fluctuations in renewable sources (e.g. wind power, solar power) mean that flexible capacity (in particular gas) will remain necessary.
- Decentralized production (especially by solar PV) is included in all scenarios and will reduce demand for power produced in centralized facilities. Demand for backup capacity will, however, remain.
- Decentralized production will be subject to large peaks, which will often not coincide with demand for electricity.

2. Gas:

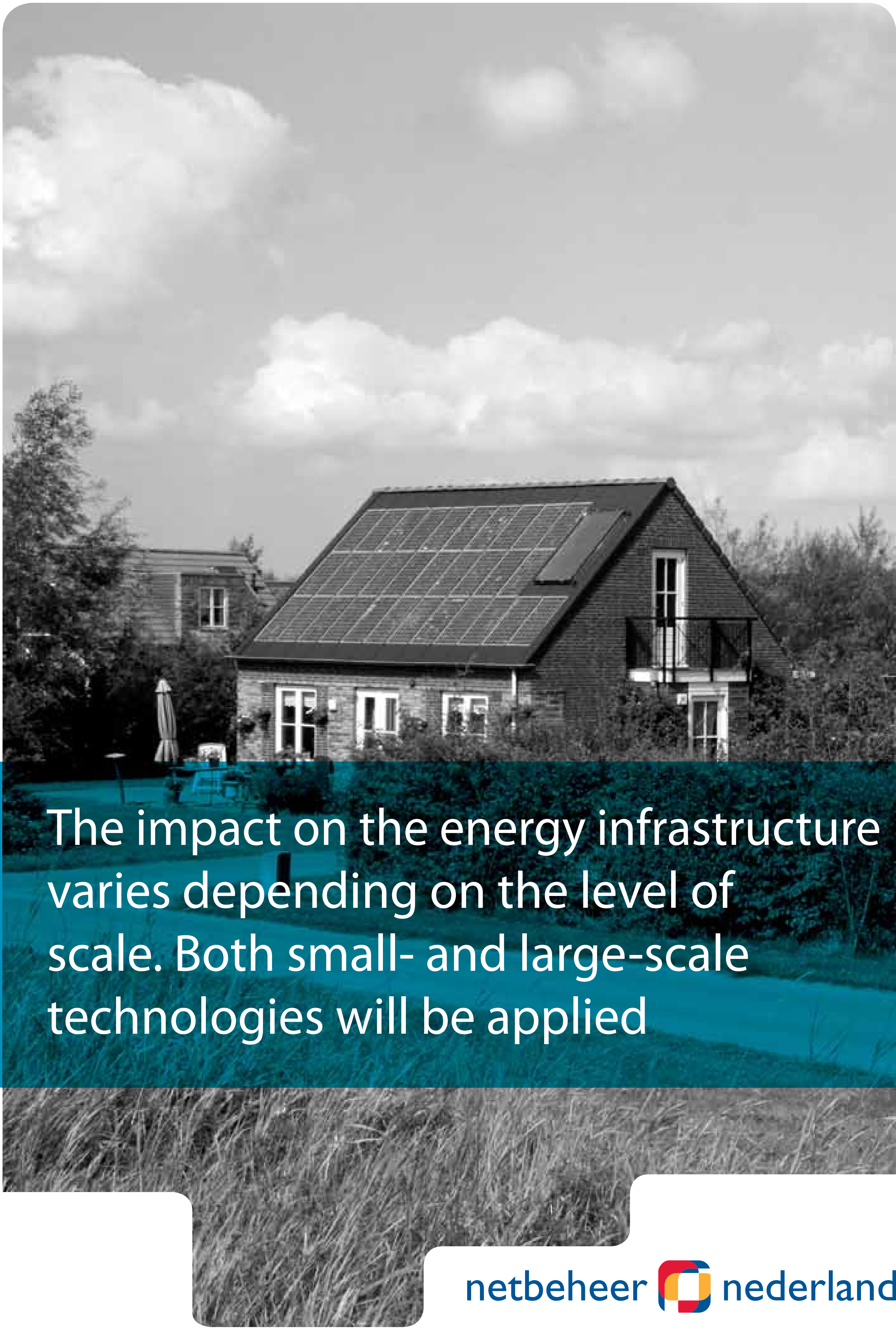
- Local distribution of natural gas will change markedly. Natural gas will in large measure be replaced by alternatives because of the CO_2 emitted upon combustion and the lack of technical facilities for capture and storage of CO_2 at the household level. Natural gas can still play a role in meeting peak energy demands. The CO_2 emissions involved are relatively limited.
- Green gas will therefore take over the role of natural gas in parts of the built environment (the proportion of green gas varies greatly among scenarios and is greatest under Scenario B).
- To meet peak demand for heat in the built environment, the transport capacity for gas will be maintained, despite the expected decline in demand for low-level heating in built-up areas.
- Regionally cultivated biomass has been included in all scenarios albeit for a variety of applications (electricity, heat, green gas). There is too little domestically grown biomass available for the transition from natural gas use to a sustainable gas supply. Choices will have to be made if domestically grown biomass is to be used. It is logical that biomass will be used for applications that yield the highest return on investment.
- A large role for biomass in the production of green gas (with large-scale import of 'biogas' or pellets for the national production of gas and electricity or biofuels) is dependent on the question of whether the Netherlands can access sufficient quantities of sustainably produced biomass on global markets for its domestic energy supply.
- Cross-border transport of natural gas to other countries will increase during the transition period, becoming important in the final phases of Scenarios B and C.

3. Heat:

- Decentralized production and delivery of sustainable heat from a variety of sources (ground source heat, geoheat, solar heating) is included in all scenarios.

4. Motor fuels:

- Use of natural gas for the production of motor fuels will be replaced by biofuels, electricity and hydrogen. The contribution of each of these sources varies per scenario. The proportion of motor fuels used for mobility will decrease in favour of electricity and hydrogen.



The impact on the energy infrastructure varies depending on the level of scale. Both small- and large-scale technologies will be applied

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3 Consequences for the energy infrastructure 2050

3.1 Introduction

The analyses of the scenarios presented in the previous chapter deal with the distribution of total volume of demand, which is the most important factor in determining CO_2 emissions. Networks, however, are not configured by volume but, rather, according to capacity. Integration of fluctuating local energy sources such as wind and sun will certainly have an effect on the volumes of fossil-derived energy carriers used, and only to a much lesser degree on the capacity of networks. After all, on a windless, dark winter's day lighting will still be needed and buildings will still need to be heated.

The energy scenarios developed are not goals in themselves. They can, however, help to draw up sound scenarios for energy supply in the future and relevant energy infrastructures to accompany it, as well as making uncertainties in future requirements for those infrastructures visible. The impact on the infrastructure differs with the level of scale. Small and large scale technologies and techniques will be implemented. In this respect it is useful to distinguish between their implementation in local, regional and national networks. Cross-border transport capacity for both gas and electricity is also an aspect that needs to be taken into account with national networks.

Although the scenarios are all different, there are a number of conclusions that apply to them all. Furthermore, the transition phase is important for the development of the network infrastructure; transition is dealt with in Chapter 4.

3.2 Local networks in 2050

In 2050, virtually the only energy carriers that will be delivered through local networks will be those that are 'emission-free' (electricity, water (hot, cold), green gas).

Local electricity networks will have to be made suitable for both delivery and production of energy, as well as 'smart' matching of demand and supply. Furthermore, the capacity of these networks will have to be expanded to provide the increased transmission capacity needed as a result of both delivery and local production. If there are 'smart' approaches for matching demand and supply, the extent of any expansion needed could be limited. Smart solutions would, however, require major changes in the infrastructure and issues of acceptance at the consumer level may arise. In part this relates to investments in energy storage (e.g. batteries and boilers) and in part to the way energy is consumed, since the use of demand-response (connect-disconnect) capacity will be controlled by network operators, based on their access to relevant information. To motivate consumers to change consumption behaviour, it is to be expected that pricing incentives will need to be introduced. Increases in the capacity of existing electricity grids will be carried out primarily during planned network replacement and maintenance activities, while capacity increases for new networks could implemented during the construction stage. In both cases the increase in capacity will mean that fewer buildings will be connected to the medium-voltage transmission network, or that extra transformers and substations will be integrated into the grid. Altogether, this would require high levels of investment and, particularly in existing[7], densely built areas, would be difficult to carry out.

At the local level, local choices – as is also now the case – will have to be made as to how demand for heat will be met. In 2050, natural gas will not be distributed to all buildings because of the resulting local emission of CO_2. Green gas could replace natural gas in this case. Other technological options include heat pumps that make use of ground-source heat or outside air and installing large and small heat networks. Moments when demand for large amounts of low-level heat occurs, such as cold winter mornings (temperatures down to – 17 °C), have a great influence on energy infrastructural choices. For this reason, the gas network is currently configured to be able to deliver 5 million m^3 of gas per hour, to heat all buildings in the Netherlands under such extreme conditions.
If gas-fired central heating units are replaced by extra insulation in combination with electric heat pumps then big problems may occur at a local level if those heat pumps use electricity as a backup heat source, making it necessary to upgrade the capacity of the electricity network even more than already described. There will also need to be greater capacity available at power stations to meet demand.

7 *'Existing buildings' refers to buildings, neighbourhoods and districts that currently exist. The term 'new buildings' refers to buildings that are to be or have been recently built and includes new and redeveloped areas.*

Gas will continue to play an important role in many installations (e.g. supplementary boilers in jointly-owned heating networks, green gas in micro-CHP units) in all scenarios, although the volumes expended will often be quite small. Choices will be made at the local level, under the influence of national regulations, as to the best way to meet demand for heat. Factors that influence local choices include:

- Rates and expectations about rates.
- Investments necessary.
- Competition from other uses of biomass.
- Government policies on energy saving in existing buildings and the manner in which components such as joint initiatives and green gas are valued in those policies.
- The scoring of components such as joint initiatives and green gas under EPC standards for new buildings; current government policy aims to lower EPC standards to zero by 2020.
- The choice of using natural gas to meet peak demand for heat, including limited emissions of CO_2 associated with it.

Finally, in areas ear-marked for new residential development, variations are possible for the distribution of green gas (e.g. for cooking) using gas networks of much smaller capacity than those currently in use. This also depends on local choices.

3.3 Regional networks in 2050

The capacity of regional networks will be increased by 2050 to allow electricity from wind parks and CHP installations to be fed in and to match the upgraded capacity of local networks. Capacity increases in local networks always result in commensurate capacity increases in 'upstream', higher voltage networks. In particular under Scenarios A and C, an extremely extensive upgrading of the medium-voltage network will be required: in Scenario C due to the markedly top-down nature of its electricity infrastructure, in combination with low levels of decentralized generation and lower reductions in energy demand; and in Scenario A particularly because of the large amount of decentralized production. In these cases, opportunities will arise for optimization between upgraded network capacity , local storage and load management.

Current regional gas networks can play an important role in security of supply of energy at any moment under a variety of conditions. Although use of regional gas networks may decline, demand for capacity will continue to exist, which is determinant for ensuring that the infrastructure remains intact. The gas networks are suitable for the inflow and transport of green gas. Current capacity of the gas networks is sufficient to meet future demand for green gas and natural gas, except for Scenario B, under which not only industry but also the electricity sector make enormous use of natural gas with CCS. For the application of this technology in Scenario B, CO_2 networks have been planned on a regional scale that link up with large industrial complexes.
In cities and built-up areas, heat transport systems will bring residual heat from centralized heat installations to local distribution networks. In cases where it is technically and economically feasible, network operators could play a role in the transport of heat and CO_2.

Injection of green gas

In the Netherlands, manure is the most obvious source for the production of green gas from domestic biomass. This raises questions about the best way to inject green gas into the gas networks. KEMA recently investigated optimal ways of fermenting and upgrading green gas (KEMA, 2010). The study shows that decentralized fermentation combined with centralize upgrading requires the lowest level of investment. For an investment of € 1 billion, raw gas piping (including injection into the regional gas network) can be laid to a central unit for upgrading the raw biogas to green gas.
The unit cost of this green gas would vary from € 0.80 to € 2 per m^3. Assuming co-fermentation with maize, the maximum total production of green gas is estimated to be 4 billion m^3. If green gas is produced without co-fermentation, yields drop to 0.8 billion m^3 and the investment required of the network operators would be only € 600 million.

Table 3
Generation capacity of electricity needed under the three scenarios in 2050

Generation Capacity (MWe)	Scenario A decentralized = high demand = very low	Scenario B decentralized = medium demand = low	Scenario C decentralized = low demand = low
Centralized	22,000	24,000	34,000
- storage	5,000	-	-
Decentralized	60,000	30,000	14,000
- storage	20,000	5,000	-

3.4 National networks in 2050

Centralized generation capacity for electricity varies greatly among the three scenarios, but for both the scenario with greatest use of renewable resources (Scenario A) and the scenario using coal and nuclear energy (Scenario C) a strong expansion of production capacity – and with it distribution networks – will be necessary. Table 3 shows the generation capacity for each scenario. In Scenario A, the need for more centralized capacity is the result of the shorter production periods for wind power than for conventional power stations (and thus more network capacity is required for each TWh). In Scenario C, the marked expansion is due to a strong increase in demand for electricity. To address issues of 'reliability'/'security of supply', under Scenarios A and C greater flexibility in the capacity of the gas network is needed. In cases where there are great amounts of wind (Scenario A), storage systems may offer the possibility of matching supply and demand, although such systems are costly and, in view of the amounts that may need to be stored, perhaps not a realistic solution. Decentralized production capacity varies from 14 GW under Scenario C to 60 GW under Scenario A.

In 2050 power stations will be concentrated around four sea harbours in the Netherlands: Eemshaven, IJmond, Rijnmond and Sloegebied. These locations offer well established lines of supply for generation fuels (coal, biomass) and are convenient for discharge of cooling water. Links between the national transmission network and offshore wind parks and/or the four sea harbours will need to be upgraded, increasing the capacity of the main transport infrastructure. Under Scenario B, extra measures will be required for the gas infrastructure because the demand for gas (natural plus green gas) will increase in volume as compared to current demand: from current demand of 1,400 PJ/year (44 billion m^3) to 1,650 PJ/year (50 billion m^3) under Scenario B (green gas plus natural gas with CCS). The capacity of the gas infrastructure is insufficient for the latter volume, particularly since the production time will decrease.

The capacity required for the high-pressure gas network to meet domestic demand will decrease under Scenarios A and C but increase under Scenario B. However, under all scenarios demand for transport capacity of gas will increase during the transition period, requiring an expansion in capacity of the high pressure gas network.

3.5 Grid losses in electricity networks

Changes in the energy infrastructure resulting from the energy transition will affect losses in electricity networks. Further losses will occur in storage systems.

Better use of network capacity has the side-effect of increasing grid losses. For a given network and voltage, grid losses increase by a power of 2 for an increase in the amount of electricity transported. In relative terms, the greatest losses occur in the medium-voltage network. Although grid losses are important in terms of cost and proportion of total energy consumption, their influence on the entire energy system remains limited. Optimization of the total energy system is the primary concern; grid losses are just one of the factors affecting this.

3.6 CO_2 capture and storage

It is not possible to predict whether a strict CO_2 emissions policy will lead to an enormous increase in the use of more renewable sources or a greater use of 'clean' fossil technologies. An important factor in this is the success of CO_2 capture and storage. If it is a technical and economic success, as well as being acceptable in societal terms, then centralized use of fossil fuels will continue to play a great role for much longer than would otherwise be the case – provided it is combined with CO_2 capture.

Fossil fuels will be used on a limited number of sites; the CO_2 emitted will be captured. If this is technologically and economically feasible, network operators could/will have to play a role in the transport and storage of the CO_2. On the basis of current insights, technologies (nuclear fission) and availability of nuclear fuel, opinion is divided as to whether nuclear energy can play an important role in providing electricity. Under Scenario C, nuclear installations are expected to deliver 10,000 MW of power.

3.7 Sensitivity analysis

This report's point of departure is a drastic reduction of CO_2 emissions: by 2050 a reduction of 90% as compared to 1990 levels. The question arises as to the sensitivity of the analyses for a CO_2 policy that is less strict. From the point of view of the network operators, a less drastic reduction in CO_2 emissions translates into less drastic consequences for the energy infrastructure. Use of natural gas without CO_2 capture is then still possible, so that distribution of natural gas at the residential level remains possible.

There will also be less substitution[8] of gas by electricity and 'heat'. Consequently volume and capacity demand for electricity will not grow as rapidly, resulting in less investment needed for expanding the network infrastructure. The volume and capacity of CO_2 to be captured and transported will also decrease, thus requiring fewer infrastructural measures.

3.8 Conclusions

Table 4 presents an overview of the effects of a stringent reduction of CO_2 emissions on the demand for capacity and the energy infrastructure.

A parallel point of discussion is the optimal inflow of green gas derived from biomass produced in the Netherlands. A KEMA study (KEMA, 2010) indicates that decentralized fermentation in combination with centralized upgrading to green gas will require the lowest level of investment. The green gas would be injected at centralized points into the regional gas networks.

Table 4
Effect of scenarios on demand for network capacity in 2050

++(+) strong to very strong increase
\+ increase
= no change
\- decrease
-- no demand

		Scenario A Renewable sources Decentralized = High Demand = Very low	Scenario B Natural gas CCS Decentralized = Medium Demand = Low	Scenario C Nuclear energy + Coal CCS Decentralized = Low Demand = Low
Electricity	High voltage	+++	+	++
	Medium voltage	+++	++	+++
	Low voltage	+++	+	++
Gas	High pressure	+	+	+
	Medium pressure (8 bar)	=	=	=
	Low pressure (100 mbar)	-	=	--
Heat	Regional	+	=	+
	Local	++	+	++
CO_2	Mt/year	=	++	++

Note 1: As stated earlier, it may be assumed that demand for electricity transit will increase under Scenarios A and C; under Scenario B this will be the case for gas transit.
Note 2: On page 23 it is stated that the structure of local networks will depend on whether natural gas will continue to be used to meet peak demand for heat. If the use of natural gas for this purpose does continue, then gas infrastructure will continue to be needed. Due to a lower demand for heat – the result of higher EPCs – the gas infrastructure will require a lower transport capacity than is currently the case. For existing buildings, the decision to make green gas available or not will be dependent on local decisions.
Note 3: Demand for capacity in the high-pressure gas network will increase under all scenarios, due to cross-border transport of gas to other countries in the transition period, and as a consequence of domestic developments under Scenario B. In the case of Scenario A, it is not logical for the Netherlands to develop as described in this scenario, i.e. to use less gas when neighbouring countries are using more gas.

8 *Substitution is not only a consequence of CO_2 emissions policy. It also depends on factors such as costs/prices related to technologies and fuels.*

Regional high-pressure gas networks can be expected to have to deal with an increase in natural gas consumption in the near future

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4 Transition period

4.1 Introduction

Energy transition will take place in different ways depending on the area in question. It makes a difference for the sorts of energy sources used and the speed with which transition takes place whether an area is rural or urban in nature. That will also be the case depending on the energy carrier used. The energy infrastructure will gradually grow towards the situation described for 2050.

This chapter describes the developments and the driving forces behind them for each type of infrastructure. Government policies will be necessary to effectively ensure CO_2 reductions through pricing mechanisms and setting standards, and thus bring the transition about. Meeting the target of 90% reduction of CO_2 emissions by 2050 will not be easy! The market will not make the transition of its own accord.

Energy saving by consumers to the extent assumed in the scenarios is another thing that will not happen of its own accord. In addition, all scenarios are dependent on certain technological developments (e.g. CCS and solar PV) and the development of sufficient societal support for, among other things, the consequences for spatial planning. Energy infrastructure may be an important facilitating factor in energy transition, but it is not likely to be the most difficult issue to be dealt with.

4.2 Electricity infrastructure

The capacity of electricity networks is likely to be insufficient fairly early on in the transition process. This will be due to new types of demand for energy, such as electric mobility and electric heat pumps, and the effect of new, variable energy sources, such as wind power and solar PV. These technologies will not be applied on a large scale for the coming decade although their impact may be considerable on a local scale. Fortunately there is excess capacity in current electricity networks, although the exact amount differs from region to region. Up until now, the gradual increase in demand for electricity has been met from this excess capacity, which was created when the networks were built. This capacity is, however, quickly disappearing.

The need for increasing the capacity of both local and national networks in the near future – in ways described in the previous chapter – should be taken seriously into account. For new networks, upgrading capacity can be carried out when they are being constructed. For existing networks, this could be done when scheduled replacement investments are being implemented.
Another issue with the electricity infrastructure is the integration of onshore and offshore wind power. The infrastructures related to both are highly dependent on political decision-making, for example regarding subsidies and the issuing of licences.
The degree to which the electricity infrastructure will need to be upgraded, and the investment schedules associated with that, is described in CE's preliminary study (CE, 2010).

At the local level, a lot of energy will have to be put into making networks 'smarter' so that an optimal match between supply and demand can be achieved, including options for local storage of electricity. Smart networks, smart meters, storage and management of demand are the 'tools' that have been chosen to create societal advantages, but their use does depend on societal support. Sufficient price incentives for consumers will also be required to manage demand over a wide scale.

4.3 Gas infrastructure

Ultimately, distribution of natural gas will decrease to locations where it is not possible to capture and store CO_2 emitted upon combustion. That does not mean that no gas at all will be distributed to those areas, but rather that natural gas will be replaced there by green gas. At €1 per m^3 (excluding taxes), green gas will be more expensive than natural gas is at this moment (CE, 2010).
Distribution of natural gas could remain desirable as a relatively cheap means of meeting peak demand for heat. The speed with which natural gas will be replaced by green gas is for this reason dependent on government policy. Furthermore, under an increasingly more stringent CO_2 emissions policy, competitive demand for biomass from other applications will grow.

Standards for building-related energy consumption in new buildings in the built environment are being gradually tightened (EPC). Current policy is to ultimately lower the EPC rating to zero by 2020 and ensure that all new buildings are climate-neutral. (An EPC of zero does not automatically mean that gas distribution will cease, however: although natural gas cannot be supplied in substantial volumes, it would remain a possible carrier for meeting peak energy demand.) To achieve this, appliances such as electric heat pumps, solar boilers and jointly-owned emission-neutral options such as geoheat[9] will meet demand for heat in buildings of the future – in combination with measures to reduce demand.
In relation to the transition to this situation, it is important to note that for the current EPC of 0.8 it is cheaper to continue to distribute gas and use HE-boilers than establish 'all-electric' dwellings (KEMA, 2010).
In other words, the speed with which these developments are implemented is directly linked to the speed with which a stricter EPC standard is implemented.
Further, specific local choices will continue to play a role, just as they do now in the development of residential building projects. Demand for heat for existing buildings will decline further, in part autonomously and in part as a result of specific government policies.

While currently the policy instruments used especially aim at stimulating less demand, or making it a more attractive option, for the future the idea of introducing compulsory standards for the energy efficiency of existing buildings is being mentioned more and more.
This should lead to lower volume demand for gas, although to be sure of delivery, particularly during cold spells, existing network capacity remains essential.
In many areas, gas will continue to provide heat during such periods.
Under the influence of stricter general CO_2 emissions policies, local choices will have to be made for existing buildings. Distribution of natural gas will be replaced by the distribution of green gas. Heating alternatives include electric heat pumps, green-gas-fired central heating boilers, solar boilers, and large- and small-scale heat networks.

In relation to regional high-pressure gas networks (> 8 bar), there will be an increase in the use of natural gas for generating electricity and producing heat for industry. Important investments in the national gas network are therefore necessary, particularly for transmission purposes.

Green gas

In addition to changes in electricity networks, changes will also take place in gas networks. In the Netherlands, approximately 30 PJ/year of green gas can be produced from manure and delivered for injection into the medium-pressure network. Network operators are playing an active role in realizing this development. Further demand for a greater proportion of green gas is expected to evolve. This gas will have to be produced close to one of the four designated supply harbours from imported sustainable biomass or, alternatively, it may be imported directly as green gas from Eastern Europe. There is, however, a great deal of competition between a variety of applications for biomass, such that complete replacement of natural gas by green gas is not expected to be economically feasible. Competitive options are, for example, co-firing in power stations, production of biofuels and use as raw materials for the chemicals sector.

9 *This will depend on how such jointly-owned facilities are rated under the EPC system.*

New energy infrastructures

Energy transition will result in, among other things, an expansion of the existing infrastructure for the distribution of heat, as well giving rise to completely new infrastructures. An example of the latter is networks for the transport and storage of CO_2; while expansion of waste-heat networks and connection to a variety of waste-heat sources are examples of the former. Increased access to small heat (and cold) networks, which will be supplied by sources such as geothermal heat, ground-source heat and solar heat, demand expansion of heat distribution networks. In rural areas, biogas networks (for gas of a lower quality than natural gas) could be constructed to transport gas from fermentation plants to large-volume users of gas.

An interesting question is whether current network operators should play a role (and if so, which one?; as regulators, or not?; and when?) in the operation of CO_2 networks, large and small heat (and cold) networks, and also biogas networks.

4.4 Heat and CO_2 infrastructures

Heat (hot water), coming from town heat systems or sustainable heat sources in suburban districts, will grow in importance as an energy carrier. In sparsely inhabited areas, high investment costs will prevent the construction of large-scale heat networks. In those areas, there will be an increase in the number of small, jointly-owned heat installations.

Gradually a CO_2 infrastructure will evolve, based on positive experiences with experimental projects for the storage of CO_2 in exhausted gas fields. With this infrastructure in place, CO_2 emitted from industrial sources will be collected and stored at a central location.

4.5 Network operators' initiatives

The following initiatives related to energy transition can be undertaken by network operators:

1. The network operators wish to play a proactive, facilitating role in the transition towards creating a sustainable energy supply. To establish that sustainable energy supply it is essential that stakeholders collaborate. Network operators wish to take the initiative to bring parties together and establish a consensus. To this end, collaborative agreements such as, for example, Smart City initiatives could be developed.

2. Network operators will actively participate in experimental projects for smart grids. In recent years, many technical developments have been introduced and refined. Nevertheless, the challenge with smart grids lies in combining input from a variety of areas: society, economy, technology, and legislation and regulation. With smart grids, the relationships between consumers, producers and networks are different from the usual situation. More active participation by consumers and other users is necessary. In experimental projects the following aspects can be subjected to realistic testing:

- **Institutional structures:** which new roles can the various players take (consumers, producers, network operators, market parities) and what will the institutional framework be? Experience can be gained with the sensitivity of consumers to incentives (e.g. price) intended to encourage active participation in energy transition.
- **Market model:** what are the characteristics of the market and what are the new rules for players?
- **Applications for clients:** how can consumer applications (use, production) be implemented with improved efficiency and environmental friendliness; how compatible are the applications with each other and the networks; and what businesses cases exist for these applications?
- **Networks:** what are the opportunities and limitations presented by various technological concepts? How do their components work in practice, how compatible are the components with each other and which business cases exist for them – sensors and communication and control equipment included?

The network operators will use 'experimental' projects to get a clearer idea of developments, both with and without smart grids. Some of these experimental projects will involve techniques that are important at the small-scale consumer level, including possibilities – and their acceptability – for active matching of demand and supply and for local storage:

- Micro-CHP.
- Solar panels.
- Heat pumps.
- Electric mobility.
- Green gas intake.

Parts of the experimental projects desired can currently be found spread throughout the Netherlands; municipalities are quite ambitious in this respect. Further steps to draw these activities together and place them on a higher plane will be needed before all criteria for these types of projects can be met. This should be provided by the national innovation programme 'Intelligent Netten' (smart grids), to which the network operators have already contributed a great deal of input. The programme comprises four experimental projects involving approximately 1,000 households. These projects must be operational in the period 2013–2015 so that each of the four seasons will be included in the experiments twice. A lot of effort will have to be made between 2010 and 2013 to form the consortia needed to complete the preparations that the projects require for their successful completion.

3. Currently, the technical issues related to the injection of green gas into the natural gas networks (in combination with the legislative and regulatory framework described in Chapter 5) are receiving a great deal of attention. Several intakes are being placed in the gas network for this reason.

Studies on ways of using biogas more efficiently will also be carried out in the near future. Ideas for this include the collection of biogas, after which it would be injected into natural gas networks at centralized points. This could take several forms; decentralized to centralized. Through gas pipelines or the collection of manure and biomass for centralized fermentation.

The network operators wish to play a proactive role in these developments and, working together with other stakeholders, create a socially optimal situation that reflects a healthy balance between aspects such as financing, security and customer choice.

4. In addition to their facilitating role, the network operators can contribute directly to reducing CO_2 emissions. Total network losses place the network operators collectively among the top five largest energy consumers in the Netherlands. Efforts are already being made to reduce these losses or to make them sustainable. These efforts could be extended further to include:

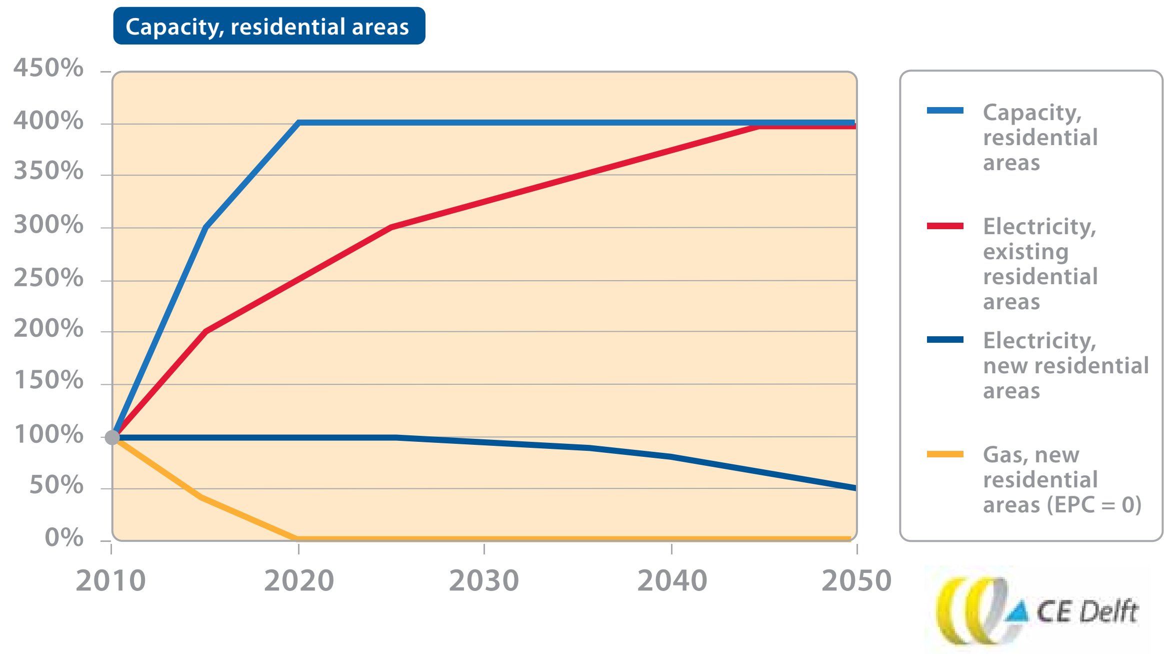
- Greening of network (electricity) losses with own green-generated electricity. A network operator is, under the current legal framework, allowed to compensate for network losses using self-generated electricity – instead of buying in electricity. In this manner wind parks, for example, could be used to make up network losses with green electricity. In view of the cumulative size of network losses, such a step would bring about a substantial increase in the use of sustainable electricity in the Netherlands.
- Besides self-generation, greening of losses could also be achieved by buying in green electricity from suppliers.
- Locating and repairing of leaks in gas pipelines can be more actively pursued. This would limit methane (CH_4) emissions; methane is a potent greenhouse gas.

4.6 Conclusions

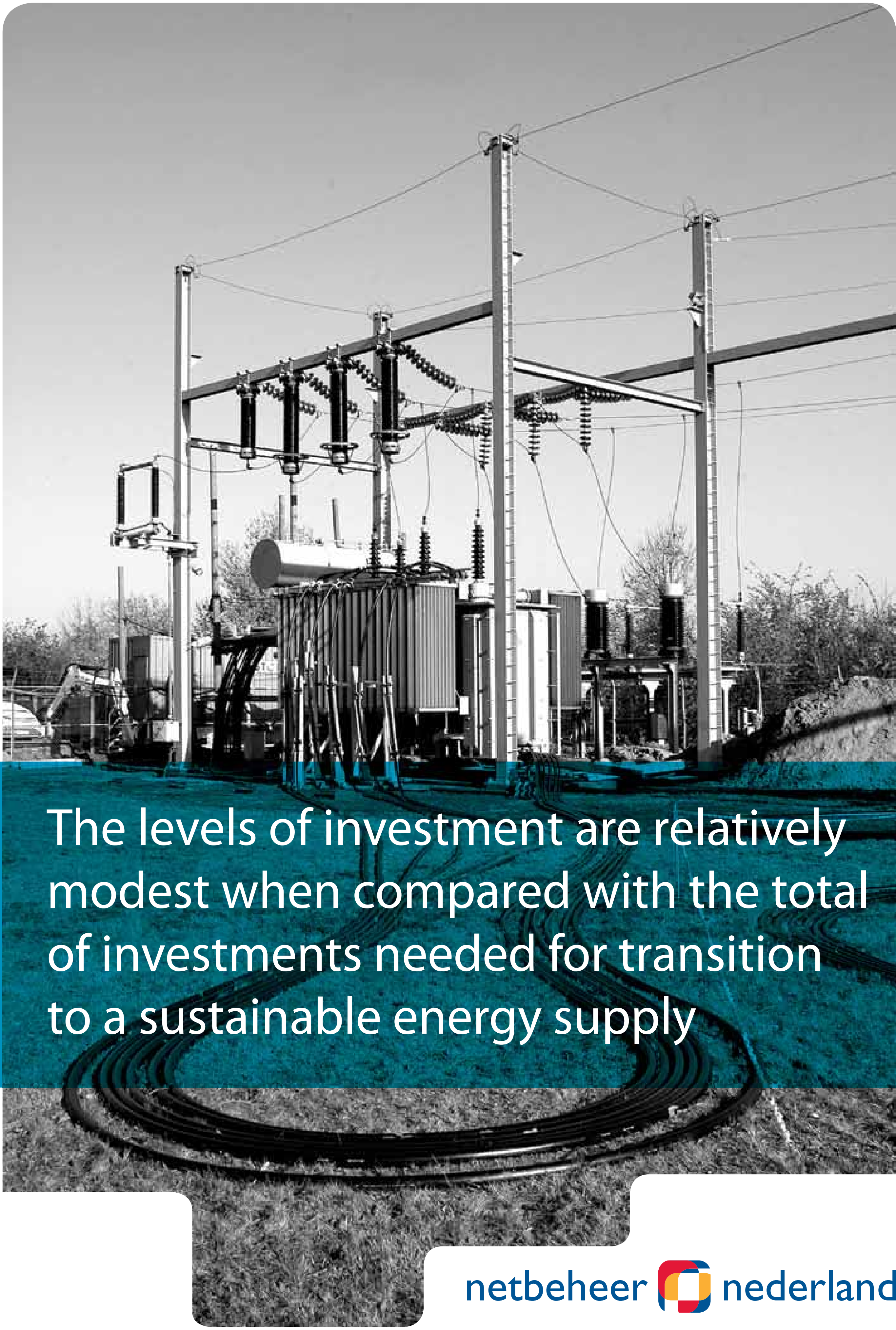
Figure 5 shows development of demand for capacity in the electricity and gas networks of residential areas; current demand has been set to 100%. In the future, demand will increase for electricity and decrease for gas. Decreasing demand does not mean, however, that existing networks will be closed down. The increase in demand for electricity shown is especially due to the use of electric heat pumps, solar PV and electric cars. Calculations for heat pumps exclude the use of electricity for supplementary heating since this would necessitate provision of greater network capacity. Other solutions will be needed to satisfy peak demand for heat. Alternatives include heat storage and the use of gas, which, of course, requires a gas infrastructure to be in place. The decline in demand for gas in new housing estates will, therefore, not be as steep as shown in Figure 5.

In the near future, network operators will launch initiatives that will smooth the process of energy transition. An important aspect in this will be experimental projects set up to provide more and clearer ideas about the effects of various innovative developments on the energy infrastructure. In addition, new electricity networks will be constructed with greater capacity and the capacity of existing networks will be upgraded as part of replacement investments. Increase in capacity will require the development of new design criteria for the network infrastructure.

Figure 5
Development of demand for capacity in local gas and electricity networks (existing and new residential areas[10])



10 *The term new residential area is used for new areas and for redevelopment areas; the building standard for these from 2020 onwards will be EPC = 0.*



The levels of investment are relatively modest when compared with the total of investments needed for transition to a sustainable energy supply

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5 Investments

5.1 Introduction

Expanding the capacity of the energy infrastructure requires extra investment. Related to this is the question which investment decisions need to be taken. These concern investments that the network operators have to make on behalf of society. One of the main aims of *Networks for the future* is to make a start with the societal dialogue about the investments to be made. Investments are mentioned in this study with the express aim of giving societal stakeholders an insight into the size of the extra investments to be made by the network operators in comparison with the normal investments they make every year.

On the one hand, in the bottom-up analysis performed by CE (CE, 2010) realistic worst-case figures were calculated for the increase in demand for capacity. Here, 'realistic worst-case' means developments that are realistically possible and may, therefore, not be disregarded and from which realistic–pessimistic choices were selected to forecast demand for network capacity. The bottom-up analyses gave good results for residential areas but were less useful for other land use types, such as business parks and industrial areas, for which customized analyses are necessary. A study was also carried out for electricity[11] based on the projections of volume demand under Scenarios A, B, and C. Results of both analyses are reported as ranges in Table 6.

The figures exclude the effects of smart grids, which will effectively lower costs. The extent of the cost reductions is not yet clear; determining this would be one of the aims of experimental projects.

Investments will also be made in both small- and large-scale heat networks, in CO_2 networks and in storage. The degree to which these investments are implemented is in part dependent upon exact developments (see the scenarios). However, in the case of heat networks, these are also greatly dependent upon local choices that will be made. For this reason, no investment estimates have been drawn up for them.

Part of the ranges for the investment estimates is the result of the use of electric heat pumps. In this context, analyses were done for 'with' and 'without' electric supplementary heating. Use of substantial electric supplementary heating for heat pumps brings with it the need for higher network investments but lower investment costs for heat pumps, because these will then require smaller capacity.

Timelines for investment choices are affected by the following considerations:

- Increasing capacity of electricity networks in new building projects already during the construction phase; investments keep pace with area development.
- Increasing capacity of electricity networks in built-up areas during replacement investments for existing networks.
- Depending on discussions about using gas to meet peak demand for heat, decisions will need to be made whether or not to continue expanding gas infrastructure – perhaps in a limited form.
- Investments for feeding onshore wind power into the electricity network follow on from applications for the connection of wind turbines to the net. In this, regional differences need to be taken into account. Furthermore, the fact that the current regulatory framework is not, in relation to connecting wind power to networks, aimed at minimizing the infrastructural investments required also plays a role.
- Investments for connecting offshore wind power to the net – providing a power socket at sea – are to a great extent determined by the Dutch government.
- Investments required to increase the capacity of the high-pressure gas network and the high-voltage electricity grid are accounted for in the long-term plans of Gasunie and TenneT, respectively.

5.2 Investment in networks of the future

Together, network operators invest an average of around € 800 million annually (see Table 5), although it should be noted that the amounts can vary considerably from one year to the next.

11 *Source: D-Cision, 2010: this was included in its entirety as an appendix in CE Delft's preliminary study (CE, 2010). Figures (rounded off, but no ranges) from the appendix have been included in Table 6.*

Table 5
Current average annual investments (in millions of euros) in gas and electricity networks by the network operators collectively[12]; average over period 2005–2008

	Gas	Electricity	Total
Regional network operators	96	297	393
TSO[13] (Gasunie/TenneT)	250	170	420
Total	**346**	**467**	**813**

The following factors have an important influence on estimates of the extra investments needed for the changes that will accompany the energy transition:

- Prices of capital equipment; with 2050 in mind, equipment will need to be carefully budgeted.
- Estimates of transport needs.
- The timeline for transition developments.
- Capacity still available in existing networks.

The ranges that apply to extra investments in network infrastructures to facilitate energy transition are shown in Table 6; these have been taken from CE Delft's study (CE, 2010). Total extra investments range from € 20 billion – the lower limit for Scenario B – to € 71 billion, the upper limit for Scenario A. All amounts include investments up until 2050.

Table 6
Summary of the extra investment (billions of euros) in energy infrastructure related to facilitation of energy transition in the period up to 2050

	Scenario A	Scenario B	Scenario C
Feeding in offshore wind power	9 - 15	3 - 5	3 - 5
Feeding in onshore wind power	2	1	0
Increasing capacity of HV network and HV/LV transformers	11 - 12	6 - 12	12
Increasing capacity of MV network and MV/LV transformers	5 - 19	5 - 8	5 - 14
Increasing capacity of LV cables	0 - 15	0 - 5	0 - 8
Increasing capacity of LV connector cables	0 - 3	0 - 1	0 - 1
Increasing capacity of gas transmission network	ca. 4	ca. 4	ca. 4
Construction raw gas infrastructure, green gas intake	ca. 1	ca. 1	ca. 1
Investments in experimental projects	p.m.	p.m.	p.m.
Investments in heat infrastructure, CO_2 infrastructure, and storage	p.m.	p.m.	p.m.
Total	**32 -71**	**20 - 37**	**25 - 45**

ca. = approx.
p.m. = amount to be determined

12 Sources: working group for this report and annual reports of Gasunie and TenneT. Figures for regional network operators have been taken from regulatory annual accounts and refer to net investments, excluding contributions paid by clients and investments in gas connections.
13 TSO = Transmission System Operator.

Smart grids, because they match the timing of demand and network capacity, can result in lower levels of investment being required for increasing infrastructural capacity. The implementation of smart grids and demand-response management of capacity will require quite some societal debate about the role of network operators (facilitator or manager) and the use of more ICT applications in the energy supply chain.

Estimates of the extra investments are based on current insights regarding the technical demands that energy transition is likely place on energy infrastructures – demands that network operators have to take into account if they are to facilitate energy transition. The infrastructure should not hinder developments in the transition to realizing a sustainable energy chain. The amounts given in Table 6 show that the investments required will be substantial in relation to the total annual investments in energy infrastructure normally made by network operators.

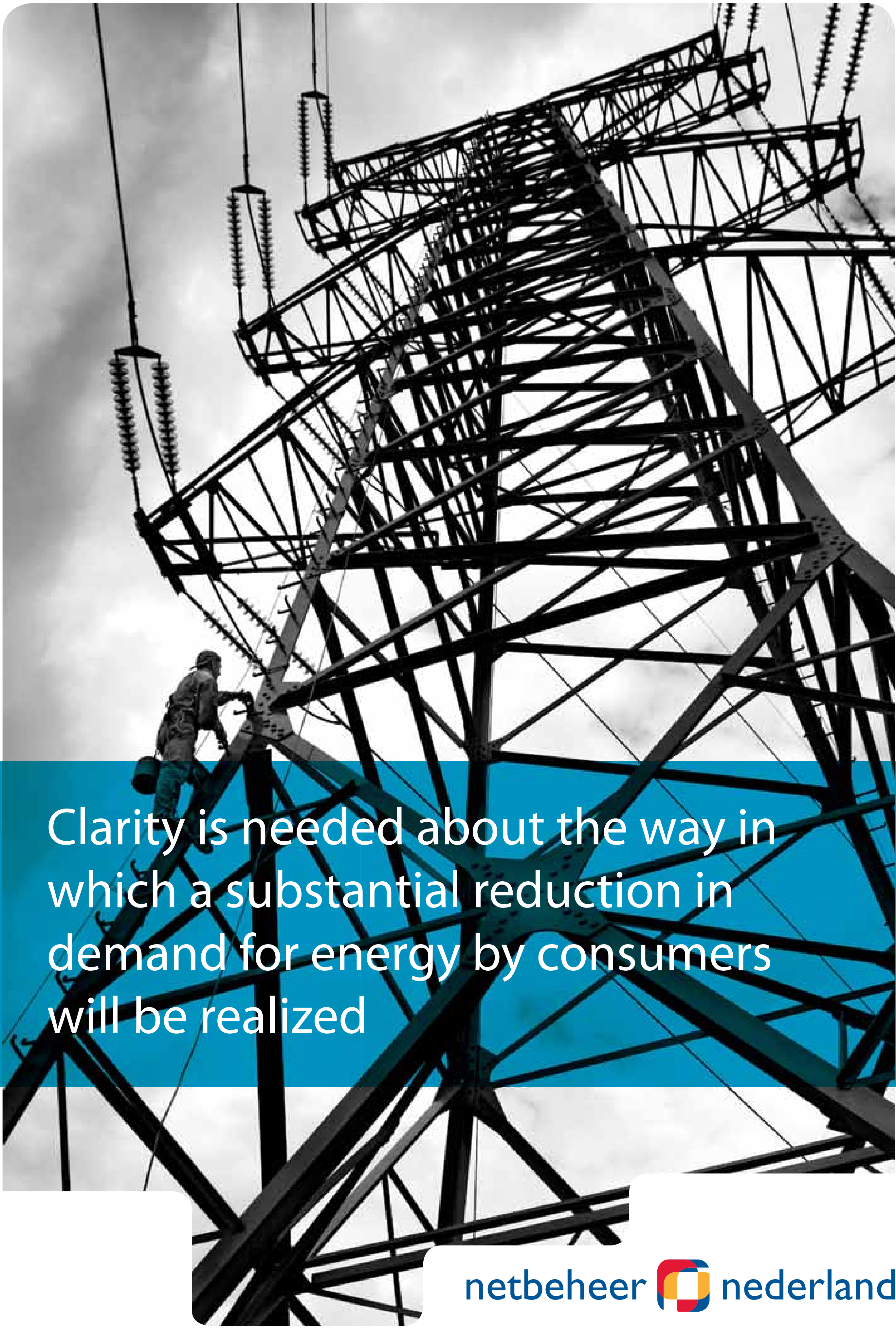
The investments are characterized by many uncertainties, both in terms of the timeline, which is related to the speed at which the energy transition proceeds, and in terms of future price developments.

This is another reason for network operators and society to engage in a dialogue about society's requirements and the choices to be made in relation to energy transition, as well as what is expected of network operators.
Around 2020 the extent of the reduction in demand for energy, the amount and concentration of decentralized electricity production, the use of electric heat pumps, and the degree of electrification of transport should become clear so that investments from 2020 onwards can focus on Scenario A, B or C.

Although the amounts are substantial, they are relatively small against the investments to be made for the entire energy transition. Proper insulation of all existing dwellings in the Netherlands alone will require an investment of € 70 billion. Total investments for wind turbines, solar PV, storage, power stations, etc., are expected to cost billions and billions of euros. Investments in infrastructure are, therefore, substantial and important, yet they do not constitute the largest component of the investment required. Other studies (e.g. ECF, 2010) confirm this.

It is striking that extra investments in energy infrastructures continue to be necessary even though demand for electricity will have fallen by 2050. The main reasons for this are:

1. Substitution of motor fuels by electricity; this will create a higher demand for capacity in the electricity infrastructure; note that the supply chain for motor fuels falls outside the scope of this report.
2. Increases in production, in particular electricity from renewable sources of a variable character (e.g. wind, sun); backup capacity in the form of gas-fired furnaces and/or storage remains, therefore, necessary. For this reason, the degree of utilization of the infrastructure will fall. Moreover, connecting onshore and offshore wind parks will require new networks (currently non-existent) and therefore extra levels of investment.
3. Substitution of natural gas by electricity in the built environment. Distribution of natural gas is per unit of energy far cheaper than for electricity.
4. Extra demand for capacity in transmission networks, for the transit of gas and electricity.



Clarity is needed about the way in which a substantial reduction in demand for energy by consumers will be realized

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6 Regulatory framework for successful transition

The changes in the energy infrastructure of the Netherlands as have been outlined in this report will also require the Dutch government to make regulatory changes. Choices will have to be made at a political level as to the role of network operators in the transition to a CO_2-neutral energy supply. Specific aspects that will have to be dealt with are:

- In what way and with which institutional instruments can progress be made towards making socially optimal choices for the future energy supply that take sufficiently into account the long term and the entire energy chain.
- The key role to be played by gas as a transition fuel: applicable in both decentralized and centralized situations to provide a secure supply of energy (upon the introduction of sustainable but variable forms of energy such as wind and solar power).
- Clarity about the role to be played by the network operator TenneT with respect to offshore wind power (power socket at sea) and with respect to possible large-scale storage facilities. The issue of offshore wind power already had to be addressed in 2010; storage facilities perhaps in 2020.
- The idea that regulation of connection costs for onshore wind power will, from a societal point of view, not deliver optimal outcomes.
- Choices about the role (and its nature) of network operators in the transport and storage of CO_2.
  If CO_2 storage is to play a significant role from 2020 onwards, then the role of the network operators must be clearly established by 2015.
- Gas networks will have to be made suitable for intake of green gas at the medium-pressure level.
- The role and tasks of network operators in regulating the transport and production of raw green gas need to be clarified.
- The fact that regulatory developments for gas networks do not take into account the possibility of premature dismantling – which under some scenarios can occur in some areas.
- Clarity about delivery of heat and the role to be played by network operators. The current regulatory framework (Heat Act) does not appear to be compatible with a major role for network operators in the delivery of heat.
- Clarity about the way in which a substantial reduction in demand for energy by consumers will develop – it won't take place on its own. Standards for energy efficiency and price incentives will be necessary. Smart meters and a good billing system could play an important role in achieving this. In the very near future, clarity will be needed about the requirements to be met by smart meters and the billing system to be used because development of these facilities costs a great deal of time, followed by many years to actually implement them.
- Clarity about the investment climate that network operators will face, so that they can actively support and increase the pace of the energy transition.
  A balance will need to be found between aiming for efficiency and aiming for effectiveness. That will require focus on apportioning investment risks between network operators (and their shareholders) and society.

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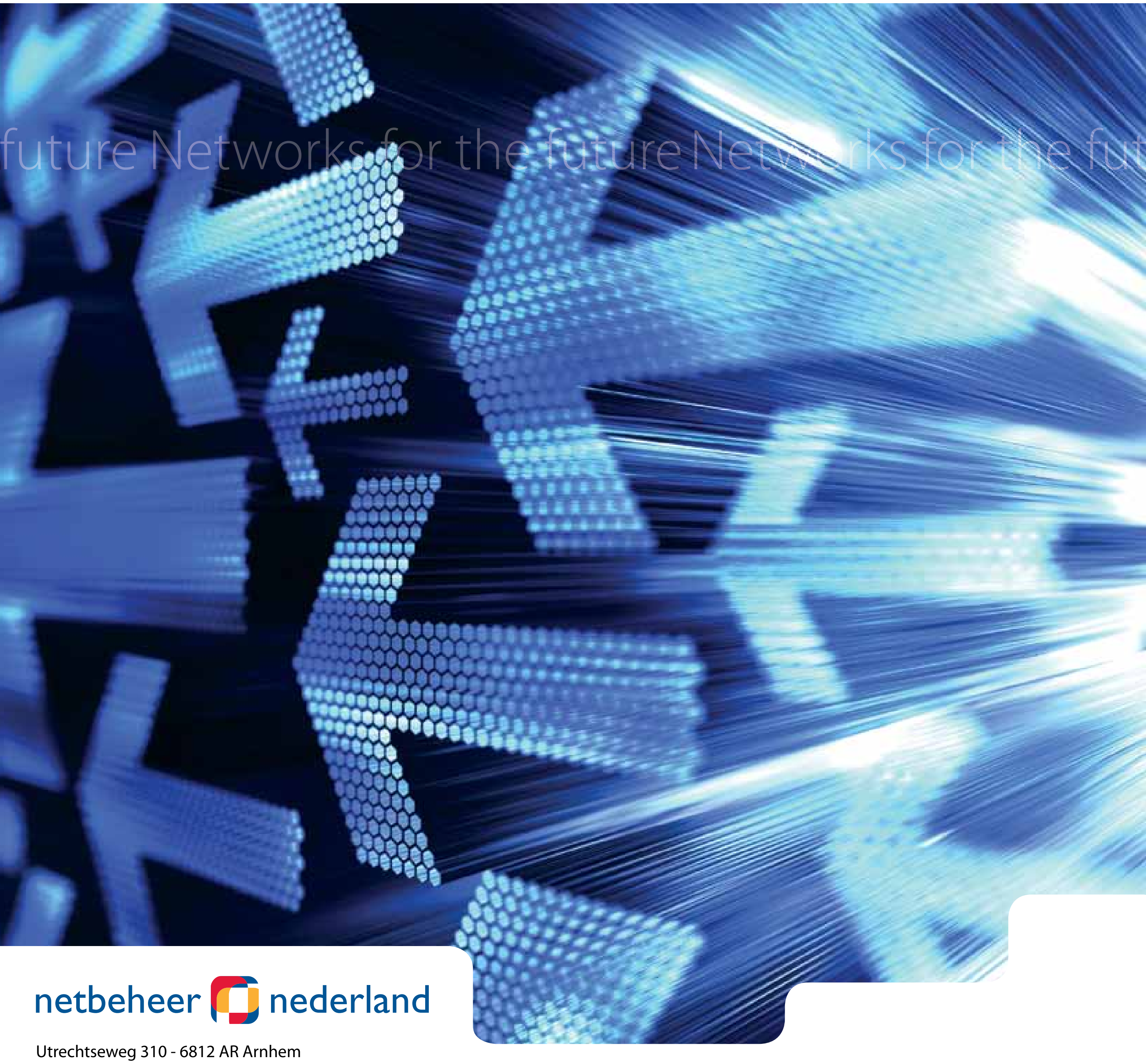

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