De Markerwaard

A strategy study of the energy transition, 2020-2030

Authors: Hans van de Vorst
Joke Driessen
Chaco van der Sijp
Wiebe Heitman
Ico van den Born

Summary

This report addresses the importance of security of supply during the energy transition. Our society will have to make many decisions in the coming years for the energy transition and the achievement of climate objectives. At the regional level, they involve investments and coordination with network operators. With a variety of strategic energy transition options, the right choices will not be trivial. This study shows that a region must establish the security of supply of each option first, before deciding how to reduce CO_2 emissions and transition costs.

This study illustrates how SecuoS can assist a region in making optimal choices from three points of view:

1. reduction of the CO_2 emissions
2. security of supply within set limits
3. limitation of the transition costs

While evaluating all possible demand variations, this study emphasises that security of supply considers the available production capacity, not the total installed capacity.

SecuoS performed this study for an imaginary region "De Markerwaard". The population of De Markerwaard is 400 000, distributed over four cities. Its energy network covers the electricity, built environment, industry, agriculture, and mobility sectors. The energy network is representative for the systems in other regions of The Netherlands. For the next ten years, De Markerwaard has concrete plans to develop additional solar and wind energy, geothermal energy, reinforcement of the 50 kV distribution net, increased hydrogen use, and heat pump applications.

The region is seeking reassurance that their ambitious plans will meet all requirements regarding the CO_2 emission, security of supply, and transition cost. SecuoS has studied the supply and demand of all energy carriers in all sectors of De Markerwaard with an ARTIS model. ARTIS is an application for calculating the available capacity of continuous production systems. The study covers the period 2020-2030. It takes variable weather conditions into account, using weather data for Schiphol airport of the past 20 years. The study exposes the bottlenecks in the original plans of De Markerwaard clearly and proposes specific improvements to tackle them.

This study is addressing the following questions:

Are the plans of the region sufficient?	No. There will be shortfalls in the supply of electric power and heat.
What are the bottlenecks?	From 2021 onwards, there are increasing shortfalls because the gas-fired power station can no longer adequately meet peak demand. The shortage occurs initially only in winter and from 2025 onwards also in summer. During 2023-2025, the capacity of the 50 kV distribution grid is insufficient. From 2025 onwards, the agriculture sector has a 13 MW shortage of heat, during unplanned downtime of the geothermal project.
How can they be addressed?	Contracts need to cover additional electric power import, mounting to 150 MW in 2030. De Markerwaard must double the capacity of the 50 kV distribution grid two years earlier than initially planned. The geothermal project in the agriculture sector requires heat storage corresponding to 7 days at full production.

The three key insights are:

1. Every region must take the security of supply as a strict boundary condition when evaluating CO_2 emissions and energy transition costs. A region must establish the security of supply of each option first, before assessing how to reduce CO_2 emissions and transition costs. Not the other way around.
2. The transition plans of De Markerwaard do not come cheap. The bottom line shows that the expected cost of energy, excluding all subsidies, taxes, duties, costs of CO_2 certificates, trading margins and costs at the demand side, increase from 6.6 €cent/kWh in 2020 to 9.3 €cent/kWh in 2030. The cost calculations are based on the current price levels and can be adjusted once new information on price trends becomes available.
3. An ARTIS model for a larger area, or a country, can offer a transparent platform for the long-term planning of the integrated energy system and balancing of the surpluses and shortfalls between the regions.

This study has four chapters:

Chapter 1 describes the background, scope and objectives, the approach and the modelling tool used.

Chapter 2 describes the network configuration of the ARTIS model of De Markerwaard, including the five sectors: electricity, built environment, industry, agriculture and mobility.

Chapter 3 provides a brief overview of the assumptions concerning the weather influences, the sources of losses, storage sizes and the CO_2 emission factors.

Chapter 4 provides the results with the expected security of supply, reduction of CO_2 emissions, and costs of the energy transition of De Markerwaard.

Table of Contents

1 Introduction

This chapter provides the objectives, execution, and monitoring of the CO_2 reductions in the Netherlands. It discusses the scope of the regional energy strategy and the scope of this study. The main objective of this study is to gain insight into all aspects of the system integration and future security of supply of the investment strategy of De Markerwaard. De Markerwaard wants to calculate the production availability of decentralised electricity generation and sustainable heat generation so that it can better manage their regional energy strategy. The approach of this study is based on using the ARTIS modelling platform.

1.1 Background

This section provides the objectives, execution, and monitoring of the CO_2 reductions in The Netherlands.

1.1.1 Country objectives

One of the objectives of the Dutch National Climate Agreement [1, 2] is to reduce the national greenhouse gas emissions in 2030 by 49% relative to 1990. This objective had already been set in the Coalition Agreement [3]. In terms of CO_2 emission equivalents, this corresponds to a reduction by 48.7 megatons per year in 2030.

In 2018, a reduction by 15%, in CO_2 equivalents, had already been achieved [4], driven by a 52% reduction of the CH_4, N_2O and F-gasses emissions. However, in 2018, the CO_2 emissions had only been reduced by 1%. Therefore, the focus till 2030 will be on the energy system, which represents the largest source of CO_2 emissions.

1.1.2 Regional execution

For the built environment and mobility sectors, the national task will be implemented by 30 regions, as assigned by the National Program for the Regional Energy Strategy, see [5, 6]. The ambitious program comprises a large scale energy transition towards sustainable electricity, the heat transition in the built environment, and the necessary storage and transmission infrastructure.

Each region has to prepare an investment plan and confirm its feasibility with the network operators, see [7]. For compatibility reasons, all plans must adhere to the national analysis, monitoring, and calculation method set by he Dutch Environmental Assessment Agency. By June 2020, the National Programme will bundle all regional plans to form a draft national strategy. In March 2021, the National Programme will finalise its strategy 1.0, so that the implementation can start.

Under the firm condition that the security of supply must be preserved at all times, a series of complex considerations will need to be made.

With a multitude of strategic options for the energy transition, the best choices are not at all obvious.

1.1.3 De Markerwaard

Calculation models are constantly evolving and require testing on realistic situations and scenarios. However, the regions will continue - to collect further information in the coming years. To circumvent the sensitivity of the use of premature data, SecuoS has assumed an imaginary region.

This region is called "De Markerwaard" and it has a scale and complexity that is representative for real regions. It serves as a

With the imaginary region of "De Markerwaard" as example, this study illustrates how SecuoS can assist a region to make the best choices, from the perspectives of reduction of CO_2 emissions, preservation of security of supply within set boundaries, and limitation of transition costs.

sandbox for evaluating different strategies and as a testing ground for the development of calculation models.

At a later stage, when a region has determined a revised set of validated assumptions and input data, the calculation model can be easily updated.

1.1.4 Considerations

Energy transition plans usually aim to ensure the effectiveness of the reduction of CO_2 emissions and the reduction of costs. What often remains underexposed is the effect on the precondition of security of supply. This boundary condition is paramount.

SecuoS has developed the ARTIS platform to enable a region to make the complex trade-off between emissions, security of supply and costs. The platform evaluates the supply and demand of energy for all sectors and carriers, taking into account seasonal effects and the continuously changing weather influences.

The concept of security of supply includes all possible variations of demand and available production capacity, and is not limited to the total installed capacity only.

The study of De Markerwaard is a good demonstration of how to use the ARTIS platform for other regions. The transparent platform makes it possible to compare and aggregate studies. The platform is exceptionally suitable for an integrated study of a cluster of regions.

1.1.5 Monitoring and trends

The Climate and Energy Outlook will report annually on the expected CO_2 emissions in 2030. Depending on technical and political developments, the reference scenario will be updated annually and, if necessary, the national and regional tasks will be adjusted.

The calculation model for De Markerwaard can be used to respond to the anticipated trends for the period 2020-2030. The most salient ones are the further reduction of the levelised cost of energy (LCoE) of solar energy and the further improvement of the reliability of novel scaled up technologies such as electrolysis and geothermal energy.

1.1.6 SecuoS

SecuoS is independent and a world leader in security of supply. We have a deep understanding of large-scale and complex energy projects. Our global team is well networked and has skin in the game.

1.2 Scope

This section discusses the scope of the regional energy strategy and the scope of this study.

1.2.1 Regional Energy Transition

The objective of a regional strategy is a careful geographical integration of renewable energy production, sources of residual heat, and supporting infrastructure. In a region, the local government cooperates with society stakeholders, network operators, industrial partners, and citizens directly, to develop regionally supported options. The options include the production of sustainable electricity, the heat transition in the built environment, and the supporting storage and transmission infrastructure. The regional strategy may cover the objectives of other sectors. The regional steering group is responsible for including the overall sector objectives in the strategic planning, see Figure 1.1.

As part of their planning process, all regions must prepare estimates of their future demand for electricity, natural gas, and heat. They need to agree on these estimates with the network operators. The network operators will confirm which proposed grid and network connections can be realised, taking into account the future security of supply. The regions are required to submit an extensive data set, which includes expectations of their future peak demand, to support this process. System integration is not part of the regional scope.

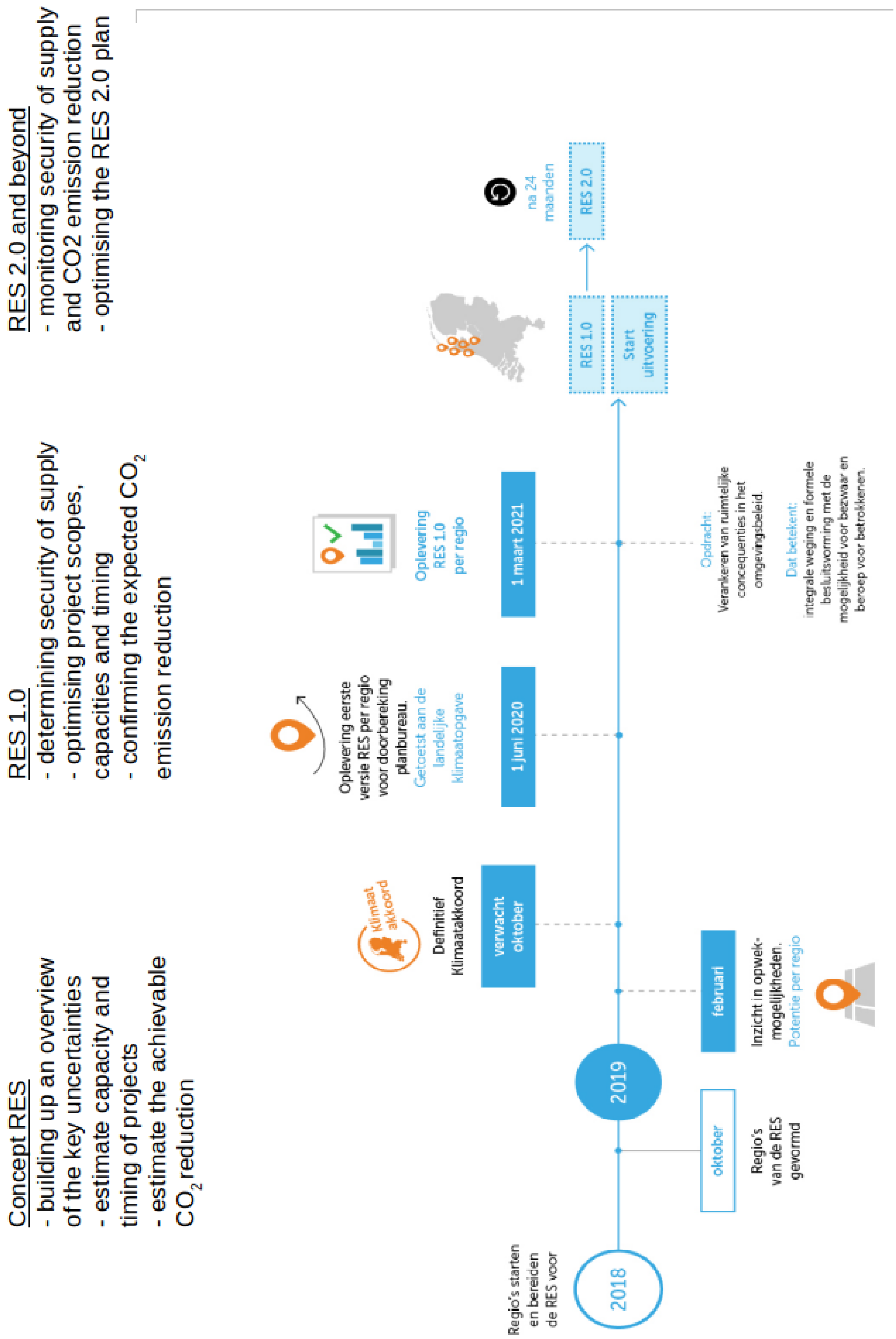

Figure 1.1: road map of the National Program for the Regional Energy Strategy (RES)

1.2.2 This study

The regional strategies cover the built environment and electricity sectors only. This study also covers the industry, mobiity and agriculture sectors. The scope of this study comprises:

- De Markerwaard
- all sectors: electricity, built environment, industry, agriculture, and mobility
- all energy carriers: electricity, natural gas and biogas, fossil fuels, heat, and hydrogen
- all links of the value chain: production, conversion, storage, transport and consumption
- the conversion and transport losses
- the (seasonal) storage facilities
- maintenance and inspection events
- all existing and planned energy and infrastructure projects with a capacity of al least 1 MW

This study showcases critical aspects of the system integration of De Markerwaard into the national grid, and how De Markerwaard contributes to the CO_2 emissions reduction in The Netherlands.

This study uses stochastic models for several random processes, each of which can impact the security of supply negatively or positively:

- Operations: capacity profiles and fluctuations, reliability, unexpected downtime
- Nature: the impact of the weather, seasonal effects
- Technical integrity and maintenance: inspections, preventive actions, repairs, safety

This study does not consider:

- facilities that are not critical to the security of supply
- facilities for production, storage, transport and consumption that have a capacity of less than 1 MW
- correlations in space and time of wind speed, temperature, and demand
- CO_2 capture and storage
- the possible phasing out of biomass after 2030
- energy markets and prices
- demand management

1.3 Objectives

The main objective of this study is to gain insights into all aspects of the system integration and future security of supply of the investment strategy of De Markerwaard. These insights contribute to an objective consideration of all risks involved and support the joint decision-making process, thereby speeding up the energy transition.

The model computes on an hourly basis the amount of electricity import that the De Markerwaard requires, as a function of the growing demand and the progress of regional renewable production. The development plans, maintenance and inspection plans, seasonal effects, random influences of the weather, and unplanned downtime are all taken into account. The model incorporates all random factors that are critical for production to create a complete picture of the expected losses.

The study breaks down the losses for the initial plan and each incremental improvement step. It identifies possible improvements in the long-term plans and makes recommendations for restoring the balance between renewable capacity, long-term contracts, and security of supply.

The study reports the expected losses, relative to demand, in size and duration, as functions of time and as averages over the transition period 2020-2030.

For the draft strategy, the study raks the critical systems according to their contribution to the losses. The study identifies possible improvements and makes recommendations for reducing the dependence on conventional power generation while maintaining the security of supply.

1.4 Expected variations and measures

De Markerwaard wants to calculate the production availability of decentralised electricity generation and sustainable heat generation in order to manage its regional energy strategy better.

The target reduction of 49% is an expected value. The future realisations, however, will vary, depending on random factors (e.g. weather, demand, project delays). De Markerwaard wants to know what variations they can expect and which measures they can considere in their regional energy strategy to counteract these variations.

1.5 Process

This section discusses the study approach and the input data.

1.5.1 Approach

The study approach is:

- explanation of the starting point in 2020
- step-by-step structure of the draft strategy, over the period 2020-2030
- calculated for the draft strategy, see Figure 1.2:
    - security of supply when integrated into the national high-voltage network
    - the expected reduction of CO_2 emissions, over the period 2020-2030
    - an estimate of the implementation costs for the draft strategy

When evaluating CO_2-emissions and energy transition costs, the security of supply of all options must be established first. Not the other way around.

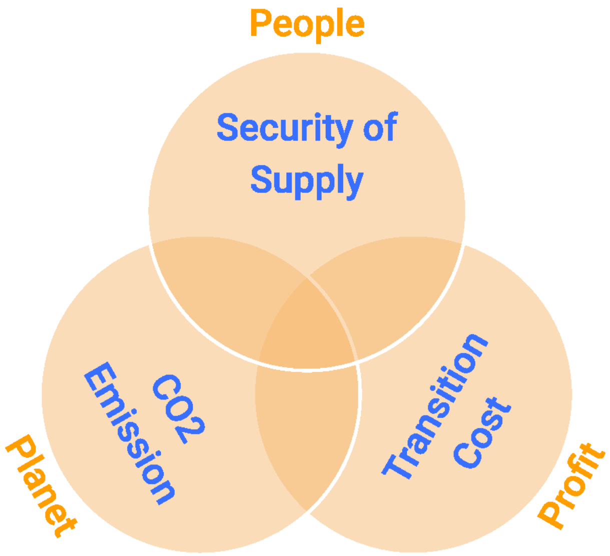

Figure 1.2: security of energy supply is a firm boundary condition when searching for sustainable and affordable solutions

1.5.2 Input data

This study was kept simple by only including the largest uncertainties that the real regions may experience. There was no collaboration with any of the 30 real regions.

The capacity data and demand profiles reflect the net capacity, that is after storage and transport losses and after potential demand management. The probability distributions of the weather influences originate from the KNMI.

Although not the case in this study, a security of supply study usually starts with the development plans, process diagrams, capacity data and the expected development of the demand that is supplied by the client. The data on maintenance and inspection plans and failure probabilities are preferably derived from the actual plans and historical data of the client. This data is supplemented by information from technical databases, such as compiled by OREDA, see [14] and IEEE. All assumptions, possibly with a variety of scenarios, should be established in consultation with the study team.

1.6 ARTIS

SecuoS has developed ARTIS to provide managers and project developers with insight into the development of possible green energy projects where the aspects of system integration and security of supply are paramount. The model includes all possible influences on demand, local production and distribution, including the weather influences and other random factors, and calculates the expected strategic need for centrally generated power. Having a transparent model contributes to the objective assessment of all risks, the joint decision making and therefore speeding up of the energy transition.

ARTIS stands for Availability and Reliability Tracking Information System. ARTIS is a cloud application for calculating the available capacity of continuous production systems. The tool can calculate large and complex systems that consist of large numbers of components that can all be subject to fluctuations in capacity, inspections, testing, maintenance, failure and repair.

The results are presented in te form of a website with graphs and tables that provide a hierarchical overview of the losses in energy supplied at the system level and all levels below, with a breakdown and ranking of their causes.

Managers and project developers use the tool for fine-tuning the project plans to the demand of products, for example, in the oil and gas industry, LNG export projects, the petrochemical industry, electricity production and space travel.

The user interface is accessible at www.artis.la/V25/models/artis.html and works in most major web browsers, hence no software installation is required, see also [15].

2 System configuration

This chapter describes the calculation model of the energy network of De Markerwaard. The introduction explains the ingredients of a production availability model that includes both supply and demand. The network model of De Markerwaard covers five energy sectors: electricity, built environment, industry, agriculture and mobility. There are five energy carriers: natural gas, electricity, fossil fuels, hot water and hydrogen.

The population of De Markerwaard is 400 000, distributed over four cities.

2.1 Introduction

A production availability model describes whether the system is operating, not operating, or possibly running at reduced capacity, depending on the status of its components. Components can consist of one or more items. In a simple case, the model is created by arranging the relevant items in series or parallel, depending on their effect on the capacity of the system upon an ‘event’ such as a failure (see [12] and [13]):

- Items are arranged in series if their operation is critical to plant performance. I.e. when such an item fails that the system stops operating or operates at a lower (by-pass) capacity level.
- Items are arranged in parallel if upon failure of one item the other parallel items can continue production, and the system can continue to operate, possibly at a lower capacity level.

The model can include both supply and demand and resembles a network of chains, each with individual nodes in it. Each node is critical to meeting demand. Rather than following the physical flow in a process flow scheme, the model follows the ability to produce. Hence, utilities like power generation and biological treatment of process water are just as much part of the network model as are the production, conversion, transport and storage facilities.

In this study, the unit of power for all energy carriers is megawatt (MW) or gigawatt (GW), the unit of energy is kilowatt-hour (kWh) or gigawatt-hour (GWh) and the unit of mass for CO_2 emissions is kiloton (kton) or megaton (Mton).

2.2 Network model of De Markerwaard

This section introduces the location of the five energy sectors and their connectivity for the various energy carriers.

Normally, SecuoS uses the actual geographical location of the infrastructure. However, for the study of the imaginary polder De Markerwaard, the authors chose for an abstract and easily recognisable location of the infrastructure. Figure 2.1 shows the sectors as ovals which are surrounded by their nodes of supply and demand.

The colours of the nodes and links indicate the energy carriers:

- grey: natural gas,
- purple: electricity,
- teal: fossil fuels,
- red: hot water,
- blue: hydrogen

Where there is a conversion between energy carriers, the node of the resulting carrier is placed inside the node of the original carrier.

Figure 2.1 shows the five sectors mobility, agriculture, built environment, electricity, and industry in clockwise direction.

Figure 2.1: the network model of De Markerwaard with the 5 sectors

The network also includes the transport and transmission links inside each sector and between the different sectors. Storage is indicated as a small circle in the middle of a link. This structure is easy to understand, flexible, and scalable.

The energy network of the electricity, built environment, industry, agriculture, and mobility sectors of De Markerwaard is representative for the networks of the other regions of The Netherlands.

The main characteristics of the model are:

- utilising all five energy carriers
- all five sectors are active
- the built environment comprises four cities
- balanced supply and demand, taking all expected losses into account
- wind power generation varies over time
    - annually increasing capacities
    - wind speed has a stationary probability distribution
    - wind farm capacity depends on wind speed
- solar power generation varies over time
    - annually increasing capacities
    - seasonal and daily fluctuations
    - cloud cover has a stationary probability distribution

2.3 Supply and demand

This section explains which energy carriers are produced and consumed by each sector and clarifies nomenclature.

The demand nodes represent the final consumption. All other nodes are supply nodes. For example, a gas-fired power station consumes natural gas and is nevertheless a supply node because the electricity that it generates is consumed elsewhere in the network. The model accounts for any energy losses, see section 3.1

Table 2.1 shows which energy carriers are produced and consumed by each sector.

Where do supply and demand arise?					
carrier / **sector**	**electricity**	**hydrogen**	**natural gas**	**fossil fuels**	**heat**
electricity	supply		demand		
built environment	supply and demand	supply and demand	demand		supply and demand
industry	supply and demand	supply and demand	supply and demand	supply	supply and demand
agriculture	supply and demand		demand		supply and demand
mobility	demand	demand		demand	

Table 2.1: sectors, energy carriers, supply and demand

The energy carrier 'heat' is defined as low-temperature heat, say up to 100 degrees Celsius. This carrier includes the unpurified biogas that is produced in the agriculture sector by fermentation as this is suitable for low-temperature heating. By contrast, power generation can use purified biogas.

A biomass installation produces gas that subsequently is treated to have a composition similar to natural gas. The energy carrier 'natural gas' includes this biogas. Such a process can only be economically attractive on a large scale, in industry.

2.4 The sectors

For the next 10 years, De Markerwaard has concrete plans to develop additional solar and wind energy, geothermal energy, the 50 kV distribution net, a new hydrogen network, and heat pump applications.

This section describes the five sectors in more detail, both in terms of the starting configuration in 2020 as well as the steps taken by each sector in their energy transition. The model assumes a population of 400 000 for De Markerwaard. The stepwise development of supply and demand are input data for the model and forms the basis for the model to compute the transport and conversion losses and the impact of storage.

Table 2.2 shows the maximum capacity of the supply and the energy demand, in MW, in 2020 and 2030.

demand 2020	demand 2030
supply 2020	supply 2030

		electricity		hydrogen		natural gas		fossil fuels		heat		total	
		2020	2030	2020	2030	2020	2030	2020	2030	2020	2030	2020	2030
electricity	demand												
	supply	200	300									200	300
built environment	demand	150	220		20	220	60			40	110	410	410
	supply	160	240		20						100	160	360
industry	demand	40	50	20	40	60	30					120	120
	supply	40	80	20	60					50	50	110	190
agriculture	demand	20	50			140	10				120	160	180
	supply	40	80								150	40	230
mobility	demand		60		10			470	360			470	430
	supply												
import		130	190			440	170	470	360			1040	720
total	demand	210	380	20	70	420	100	470	360	40	230	1160	1140
	supply	570	890	20	80	440	170	470	360	50	300	1550	1800

Table 2.2: maximum capacity of the supply and the demand, in MW, excluding losses and storage

2.4.1 Electricity

The electricity sector consists of two parts. The Schardijk power generation area has a future wind farm, an existing gas-fired power station and a 150 KV transformer station that connects to the national high voltage grid. The regional 50 KV distribution network of De Markerwaard has seven substations, one for each of the four cities, one for the Enkerdijk industrial area, one for the agricultural area and one for the mobility sector.

On 1 Jan 2020, Schardijk already has a gas-fired power station with a maximum capacity of 200 MW. De Markerwaard uses this conventional power station to accommodate fluctuations in supply and demand in the region itself, as far as possible. This power station continues to operate beyond 2030. In Figure 2.1, this is the grey-purple node.

On 1 Jan 2024, Schardijk starts the power production from a 100 MW wind farm. On 1 Jan 2025, the expansion of the distribution network and the substations will be completed, see Table 2.3.

capacity substations	**2020-2024 (MW)**	**2025-2030 (MW)**
to Enkerdijk	300	600
to Markerdam	200	400
to Groenburg	200	400
to Middelstad	100	200
to IJsselhaven	100	200
to mobility	50	100
to agriculture	50	100

Table 2.3: capacities of the 50 KV distribution network

Schardijk has negligible final energy demand.

With the above first proposal, the study assumes that De Markerwaard doesn't need to import electricity to meet all of its demand. Section [4.1] shows the results of this first proposal. In a second proposal, De Markerwaard has put contracts in place for the supply via the national grid to cover the peak demands. The contracts are for peak capacity that needs to be available the whole time. Over time, the demand gradually increases and therefore the size of contracts increases from 41 MW in 2020 to 50 MW in 2030.

2.4.2 Built environment

2.4.2.1 Demand

De Markerwaard has four cities, each with different populations, starting points and development plans, see Table 2.4. Figure 2.2 shows the development of the demand.

Markerdam has a population of 160 000, Groenburg has a population of 120 000, Middelstad has a population of 80 000 and IJsselhaven has a population of 40 000.

Thee cities in De Markerwaard have different plans to reduce their CO_2 footprint. Markerdam changes from natural gas to industrial residual heat from Enkerdijk and geothermal heat. Groenburg and Middelstad change from natural gas to heat pumps. IJsselhaven aims to substitute natural gas by hydrogen. The details are explained in the next paragraph and include the specification and expansion of the solar generation that each of the cities already has.

Considering the changeable influence of weather conditions, the region is seeking reassurance that their ambitious plans will meet all CO_2-emission, security of supply, and transition cost requirements.

City	Population	Development plan to reduce the CO_2 footprint	Planned projects
Markerdam	160 000	Change from natural gas to industrial residual heat from Enkerdijk and geothermal heat.	On 1 Jan 2020, Markerdam has 64 MW solar generation, which expands in four steps of 8 MW each to 96 MW on 1 Jan 2024. On 1 Jan 2024, Markerdam starts production of the municipal 30 MW geothermal heat project. It connects to the existing network for the industrial residual heat.
Groenburg	120 000	Change from natural gas to heat pumps.	On 1 Jan 2020, Groenburg has 48 MW solar generation, which expands in four steps of 6 MW each to 72 MW on 1 Jan 2024. On 1 Jan 2020, Groenburg starts using heat pumps in the homes, offices and public buildings and adds 7.3 MW of new heating capacity every year.
Middelstad	80 000	Change from natural gas to heat pumps.	On 1 Jan 2020, Middelstad has 32 MW solar generation, which expands in four steps of 4 MW each to 48 MW op 1 Jan 2024. On 1 Jan 2020, Middelstad starts using heat pumps in the homes, offices and public buildings and adds 4.9 MW of new heating capacity every year.
IJsselhaven	40 000	Substitute natural gas by hydrogen.	On 1 Jan 2020, IJsselhaven has 16 MW solar generation. The solar generation expands in four steps of 2 MW each to 24 MW on 1 Jan 2024. On 1 Jan 2024, IJsselhaven starts production of a 20 MW water electrolysis plant and replaces all use of natural gas by hydrogen within a short period. The hydrogen network connects to the hydrogen production at Enkerdijk.

Table 2.4: overview of the energy transition plans of the cities in De Markerwaard

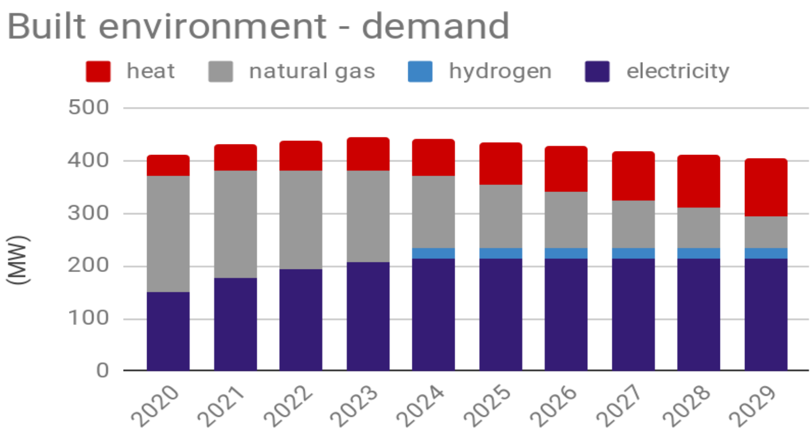

Figure 2.2: the development of the demand in the built environment, per energy carrier

SecuoS

2.4.3 Industry

The industrial sector consists of five parts. All companies have their production in Enkerdijk industrial area. The industry sector also has the import and distribution of fossil fuels, production and distribution of industrial residual heat and the distribution of natural gas and hydrogen via two separate networks.

The industry sector is preparing investment plans to reduce natural gas demand. It will lead to a slight increase in the electricity demand and a stepwise increase in the hydrogen demand, see Figure 2.3.

During the entire period from 1 Jan 2020 till 1 Jan 2030, the Enkerdijk companies produce industrial residual heat at a maximum capacity of 50 MW. On 1 Jan 2020, Enkerdijk already has a 40 MW wind farm. The plan provides that this wind farm expands to 80 MW on 1 Jan 2028. On 1 Jan 2020, Enkerdijk also already has a steam methane reformer for the production of hydrogen from natural gas at a maximum capacity of 20 MW. On 1 Jan 2023, Enkerdijk starts production of a biomass installation of 20 MW. The biogas is treated to make its composition comparable to natural gas. The gas network transports the treated biogas, combined with the natural gas. On 1 Jan 2024, Enkerdijk starts a 40 MW water electrolysis plant. From then onwards, the steam methane reformer is the back-up.

The industrial sector has contracts for the supplies of natural gas and fossil fuels from outside De Markerwaard. These import contracts are for peak capacities.

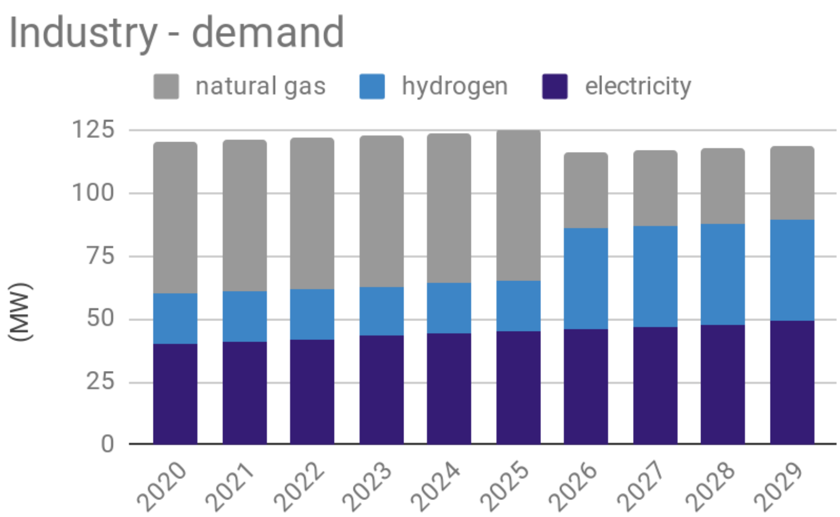

Figure 2.3: the development of the demand in the industry, per energy carrier

2.4.4 Agriculture

2.4.4.1 Demand

The agriculture sector plans to reduce the consumption of natural gas, most importantly by reducing the consumption of natural gas in the greenhouses by switching to geothermal heat, see Figure 2.4.

On 1 Jan 2020, the agriculture sector already has a 40 MW wind farm. The expansion to 80 MW will start operating after the upgrade of the distribution grid operation on 1 Jan 2025. On 1 Jan 2022, production from a new 40 MW biomass fermentation plant starts. The biogas will be used for heating, to reduce the demand for natural gas. On 1 January 2025, production from a 150 MV geothermal heat project will start, to enable further stepwise reductions of natural gas demand.

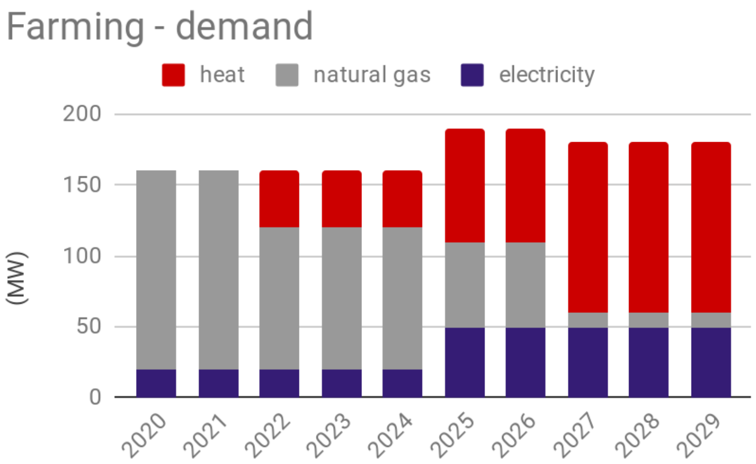

Figure 2.4: the development of demand in agriculture, per energy carrier

2.4.5 Mobility

2.4.5.1 Demand

The mobility sector starts a gradual change from fossil fuel to electric vehicles, see Figure 2.5. Part of the public transport changes over to hydrogen. The mobility sector has no dedicated supply.

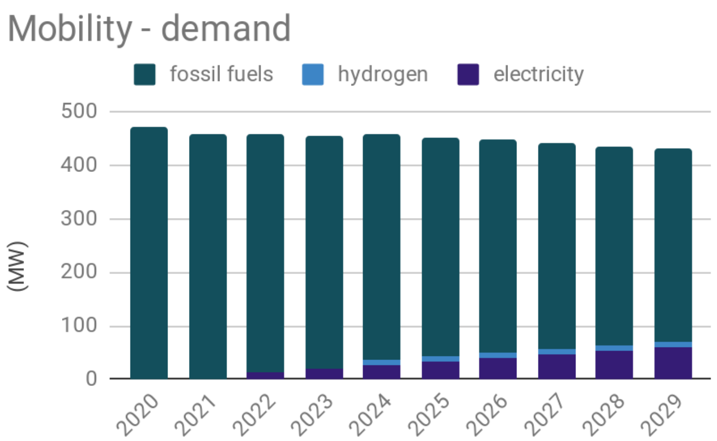

Figure 2.5: the development of demand in the mobility sector, per energy carrier

3 Assumptions

This chapter provides an overview of the key assumptions that underpin the computations. These include the weather influences, the conversion losses, the size of the heat storage, and the CO_2 emission factors.

The energy conversion efficiencies of facilities such as heat pumps, the gas-fired power station, electrolysers, and the steam-methane reformer originate from industry publications and open sources. The CO_2 emission factors for the different energy sources originate from open sources.

3.1 Stochastic models of the weather

This study uses stochastic models of the weather. They have been developed based on actual weather data and are used to quantify the expected power production of the wind turbines and solar panels.

This study uses KNMI weather data for Schiphol of the last 20 years.

KNMI wind data for Schiphol, see Figure 3.1, show an excellent fit with a Rayleigh distribution for the relevant wind speed range, that is above 1.5 m/s.

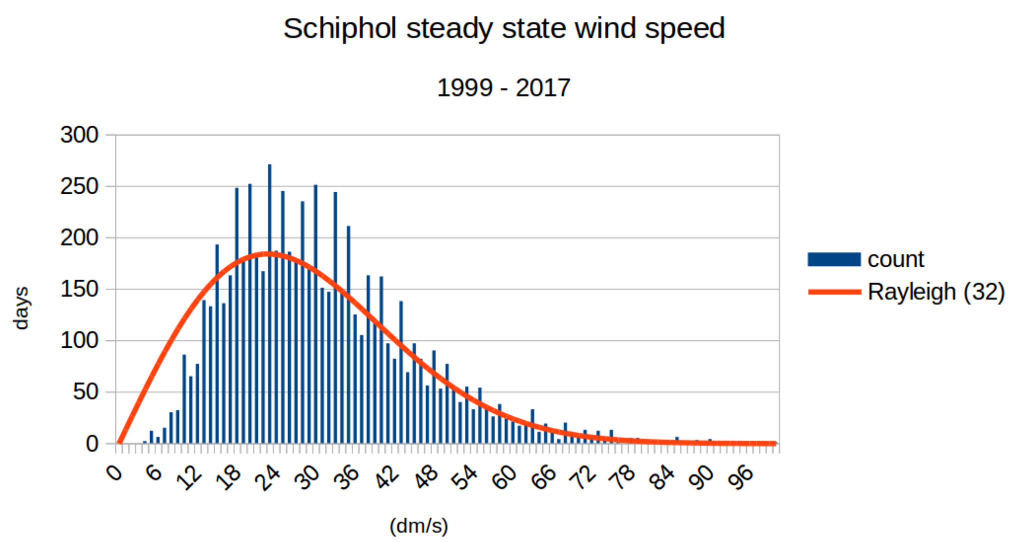

Figure 3.1: Schiphol wind speed, KNMI data, steady state distribution, 1999-2017

In this study, the wind speed has a Rayleigh distribution with an assumed scale parameter to correct for altitude. The capacity of the wind turbines has been based on this steady-state distribution, taking into account the cut-in and cut-out and a 25% turbine efficiency.

The capacity of the solar panels has been modelled as cyclic yearly profiles, taking account of the seasons and of day and night. An alternating pair of mutually independent exponential processes model the cloud cover.

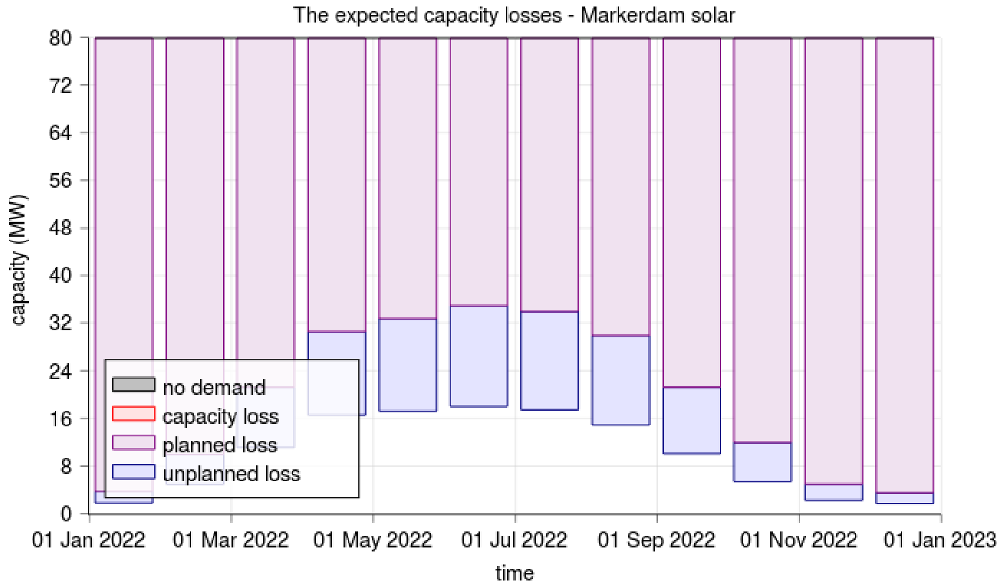

Figure 3.2: example of the distribution of the available capacity of the solar panels, with seasonal and daily fluctuations and cloud cover

3.1 Conversion, transport, and storage losses

Conversion, transport and storage consume some of the energy. This consumption is not part of the final energy demand. It is taken into account separately, using efficiency factors that express the amount of secondary energy produced as a fraction of the total amount of primary energy.

This study ignores losses from transmission through the 50 kV grid and from voltage transformation. The study also ignores the losses from transport and storage of heat, because these can depend strongly on the local circumstances, transport distance, and storage time. Overall, these losses may be relatively small anyway. Moreover, the study doesn't consider the possible dependence of the efficiency on throughput.

Heat pumps have an efficiency far exceeding 1.0 because the produced amount of heat is significantly larger than the amount of electrical energy used.

Table 3.1 lists the efficiency factors that this study assumes.

Facility	**Efficiency**	**Source**
heat pump	4.0	warmtepompplein.nl
gas-fired power station	0.6	RWE, NUON
electrolyser	0.7	Wikipedia
steam-methane reformer	0.7	Wikipedia

Table 3.1: energy conversion efficiency factors

3.2 Storage

The steam-methane reformer is the back-up for the electrolysis, and therefore this study has no plan for additional hydrogen storage.

The geothermal heat project in the farming sector has a storage facility of 7.5 * 24 * 120 = 21.6 GWh, which corresponds to about one week of production at maximum capacity.

3.3 CO_2 emission factors

For all imported energy, this study includes the CO_2 emissions from its production and transport, even though these emissions do not take place in De Markerwaard itself. This study is not using the published electricity emission factor for 2020; instead, it uses an expected value for 2030, because the results will show that the import of electrical energy will become most significant from 2025 onwards.

For the import of natural gas, electricity and fossil fuel, this study adds all emissions from-well-to-flame at the point of final consumption.

Table 3.2 lists the CO_2 emission factors that this study assumes.

Carrier	**CO_2 emission factor (g/kWh)**	**Source**
natural gas (low calorific value)	250	Wikipedia
electricity	183	Planbureau Leefomgeving, assumption for 2030
fossil fuels	350	Wikipedia

Table 3.2: CO_2 emission factors

The CO_2 emissions are computed from the expected energy consumption, as per the GHG guidelines [8].

4 Results

This chapter presents the results of the study in terms of the security of supply, the expected reduction of CO_2 emissions and the costs of the energy transition for De Markerwaard.

SecuoS has studied the supply and demand of all energy carriers in all sectors of De Markerwaard with an ARTIS model. The study covers the period from 2020 till 2030.

The objectives of the study are to get a firm grip on the future security of supply and to achieve a sufficient and affordable reduction of the CO_2 emissions. The study improves the energy transition plan in three incremental steps. The result of the study is the draft regional energy strategy. De Markerwaard will submit its draft strategy to the national planning bureau for evaluation.

1. The first proposal assumes that De Markerwaard generates all electricity itself. Without importing power, there is no security of supply.
1. In the second proposal, contracts are in place for importing sufficient power. These contracts provide an extra buffer of electrical energy to meet the peak demands. Unfortunately, the late start date of the upgrade of the 150 kV transformer station and the 50 kV distribution grid will still hamper the security of supply from 2023 onward.
2. The third proposal resolves this by implementing these upgrades two years earlier. The unavailability of the geothermal project in the agriculture sector, however, causes most of the unplanned losses from 2025 onwards.
3. The final proposal corrects this by adding one-week heat storage to the plan.

The study shows that De Markerwaard does not fully meet the objective to reduce the CO_2 emissions by 2030 with 49%. Evaluation of further additional measures remains necessary. Based on the levelised cost of energy (LCoE), this study calculates that the expected cost of energy will increase during the energy transition.

4.1 First proposal

The first proposal is a baseline scenario that assumes that all electricity is generated in De Markerwaard itself, by the wind and solar projects and the gas-fired power station. There is neither any import nor export of electricity.

4.1.1 Security of supply

Figure 4.1 shows the load duration curves of supply and demand, with the cumulative losses, for the entire period 2020-2030.

The study makes the bottlenecks of the original plans of De Markerwaard clearly visible.

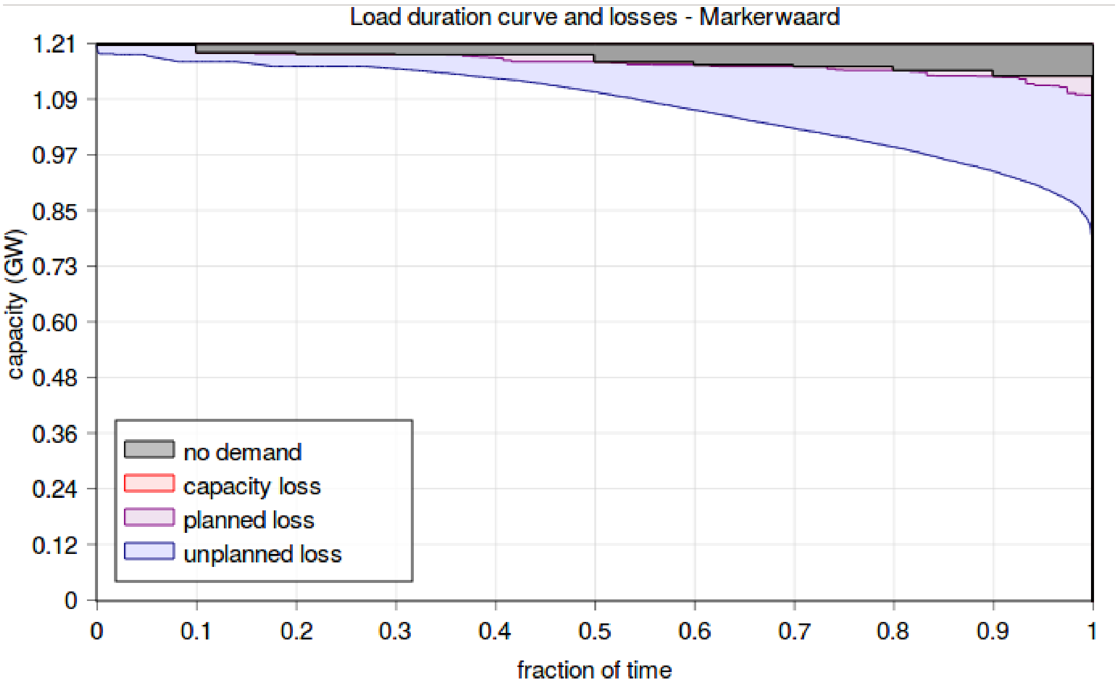

Figure 4.1: first proposal - load duration and losses

The peak demand is 1210 MW and the expected demand is 1175 MW. The expected capacity is 1078 MW and the expected loss, relative to the demand, is 97 MW.

Figure Figure 4.2 shows the expected demand and the expected losses per month.

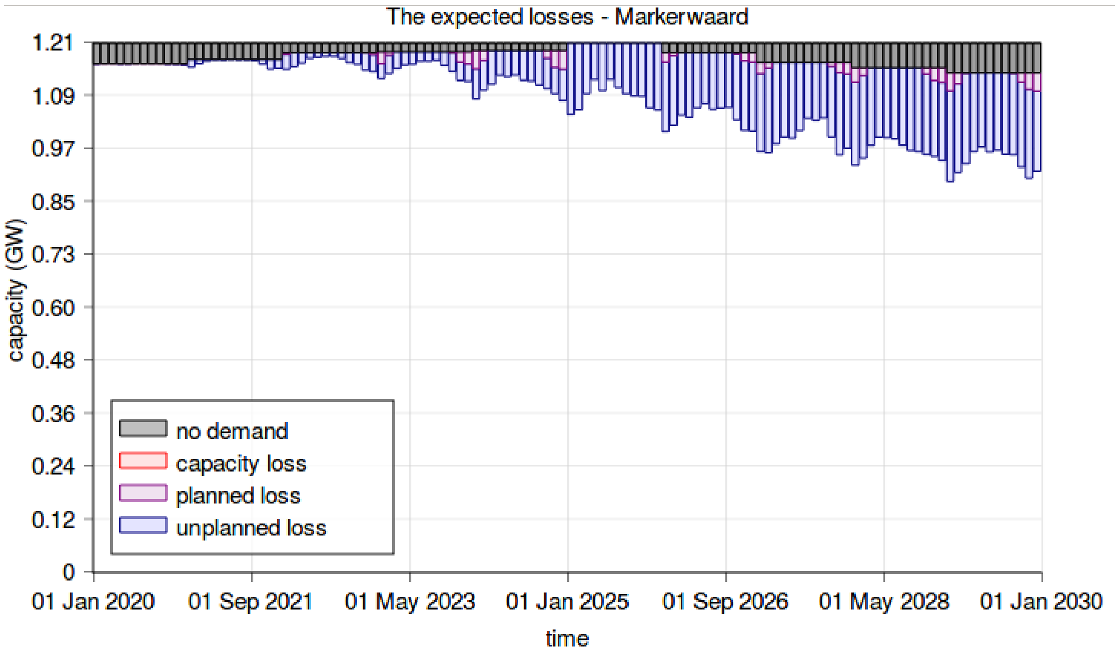

Figure 4.2: first proposal - expected losses

The increase in unplanned losses is mostly the result of the increasing demand for electricity at limited production capacity.

4.1.2 Addressing the risk of losses

How to handle the losses of the first proposal?

The study proposes specific improvements for addressing the risks of energy shortfalls in De Markerwaard.

The unplanned losses of Figure 4.2 need attention. The first question is what approaches to select from Table 4.1 to bring these risks under control.

Take:	do nothing, just leave it to the market
Treat:	execute projects earlier, increase the efficiency, develop storage, arrange backup, increase the production availability, arrange flexibility at the demand side, ...
Transfer:	negotiate agreements for supply from outside De Markerwaard
Terminate:	change to plan B, nuclear energy and hydrogen

Table 4.1: four approaches to risk management

The subsequent improvement steps transfer part of the risk, treat another part, and take the rest.

4.2 Second proposal

The second proposal transfers part of the risk by assuming sufficient contracts for electricity import, at all time. That is the only change relative to the first proposal.

4.2.1 Security of supply

Figure 4.3 shows the load duration curve of the demand and the capacity with the cumulative losses, for the entire period 2020-2030.

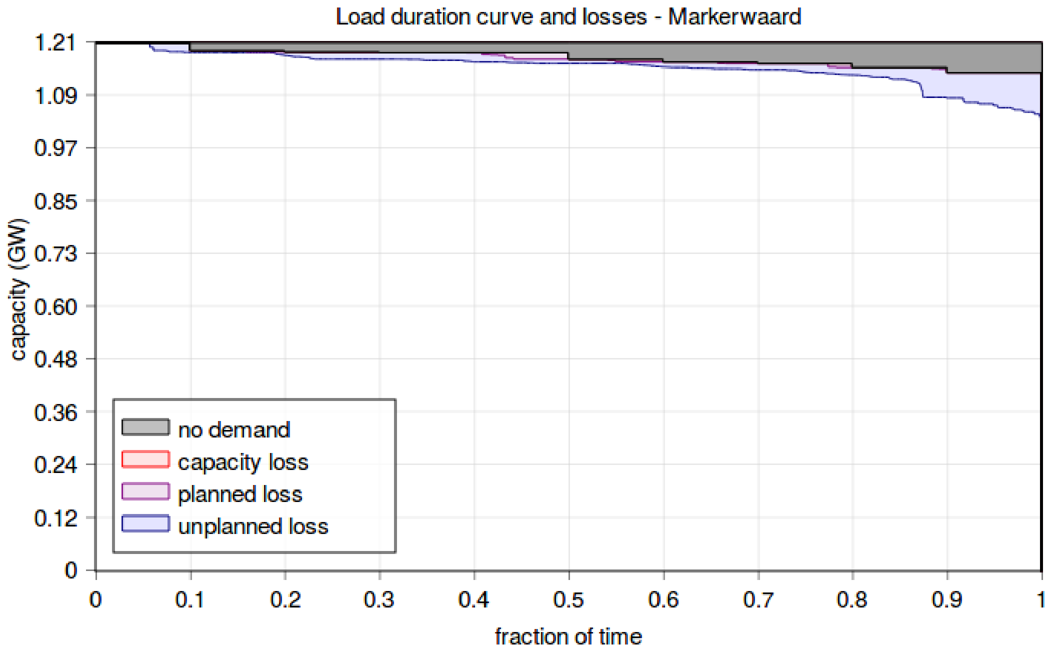

Figure 4.3: second proposal - load duration and losses

The peak demand is 1210 MW and the expected demand is 1175 MW. The expected capacity is 1153 MW and the expected loss, relative to the demand, is 22 MW.

Figure 4.4 shows the expected demand and the expected losses per month.

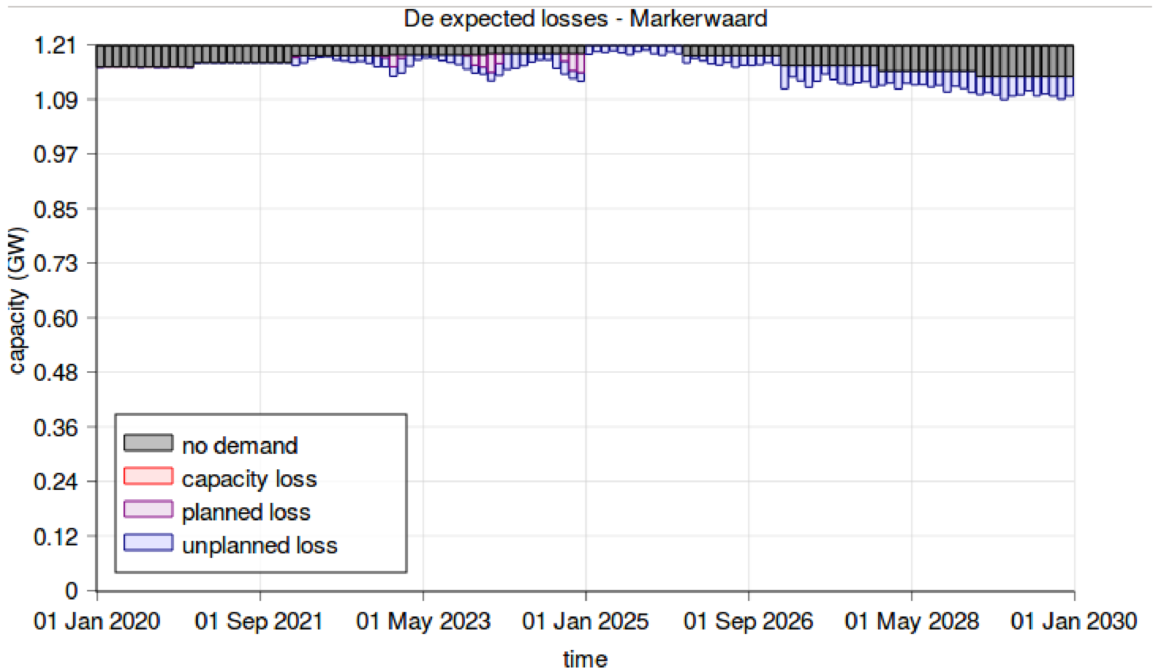

Figure 4.4: second proposal - expected losses

The late implementation of the upgrade of the 50 kV network causes most of the planned and unplanned losses during the period 2023-2025.

The third proposal addresses the timing of the implementation.

4.3 Third proposal

In the third proposal, the upgrade of the 150 kV transformer station and the 50 kV distribution grid are brought forward by two years, see Table Table 4.2. That is the only change relative to the second proposal.

capacity substations	**2020-2022 (MW)**	**2023-2030 (MW)**
to Enkerdijk	300	600
to Markerdam	200	400
to Groenburg	200	400
to Middelstad	100	200
to IJsselhaven	100	200
to mobility	50	100
to agriculture	50	100

Table 4.2: capacity of the 50 KV distribution network

4.3.1 Security of supply

Figure 4.5 shows the load duration curve of the demand and the capacity with the cumulative losses, for the entire period 2020-2030.

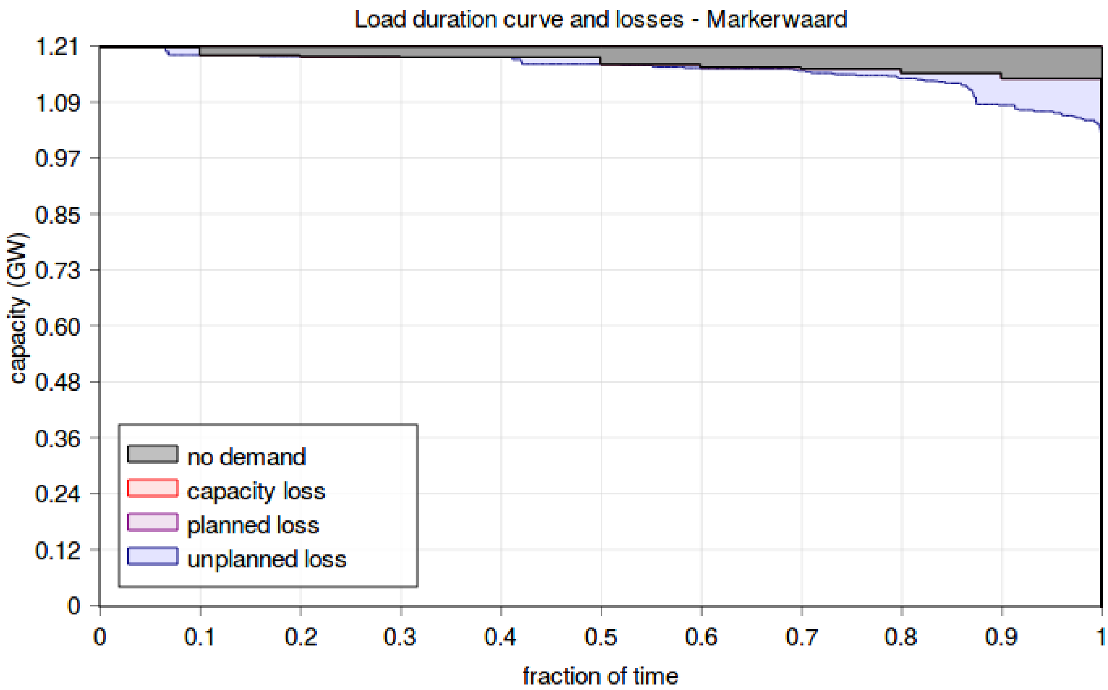

Figure 4.5: third proposal - load duration and losses

The peak demand is 1210 MW and the expected demand is 1175 MW. The expected capacity is 1159 MW and the expected loss, relative to the demand, is 15 MW.

Figure 4.6 shows the expected demand and the expected losses per month.

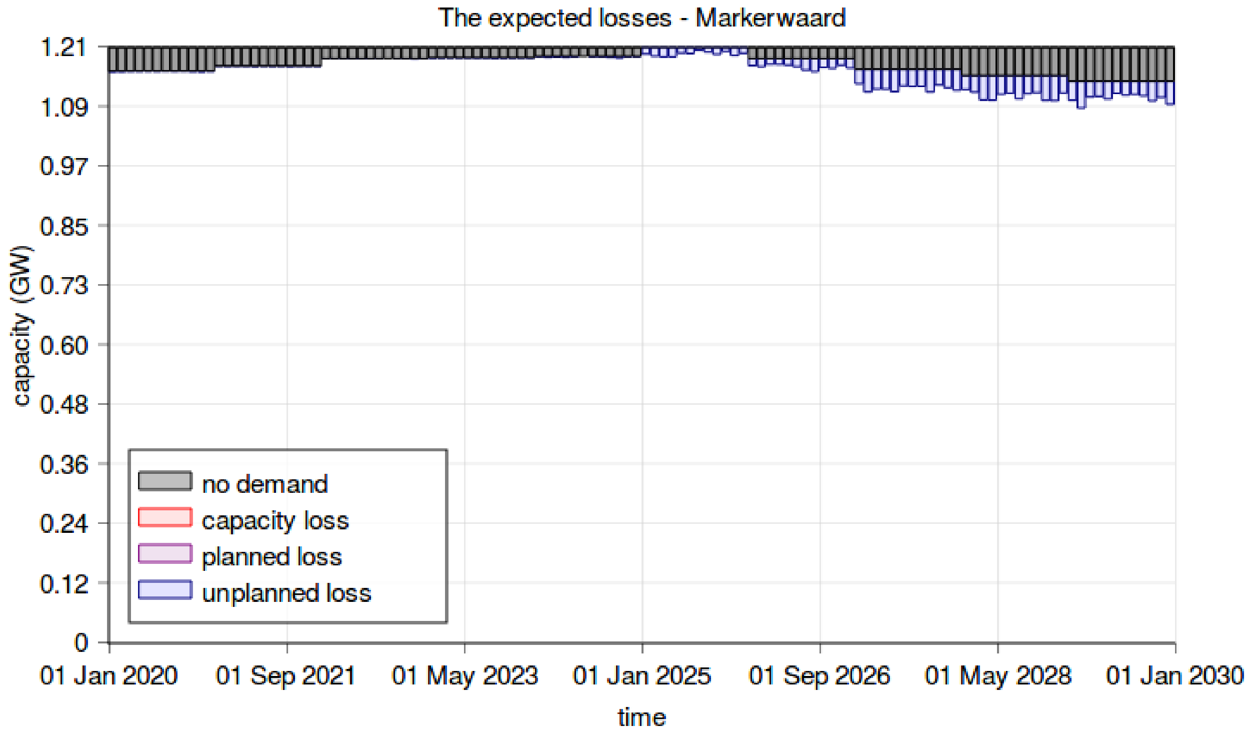

Figure 4.6: third proposal - expected losses

The unavailability of the geothermal project in the agriculture sector causes most of the unplanned losses from 2025 onwards. The final proposal addresses these losses by adding heat storage to the plan.

4.4 Draft strategy

The draft regional energy strategy has 21.6 GWh of heat storage in the agriculture sector. That is the only change relative to the third proposal.

4.4.1 Security of supply

Figure 4.7 shows the load duration curve of the demand and the capacity with the cumulative losses, for the entire period 2020-2030.

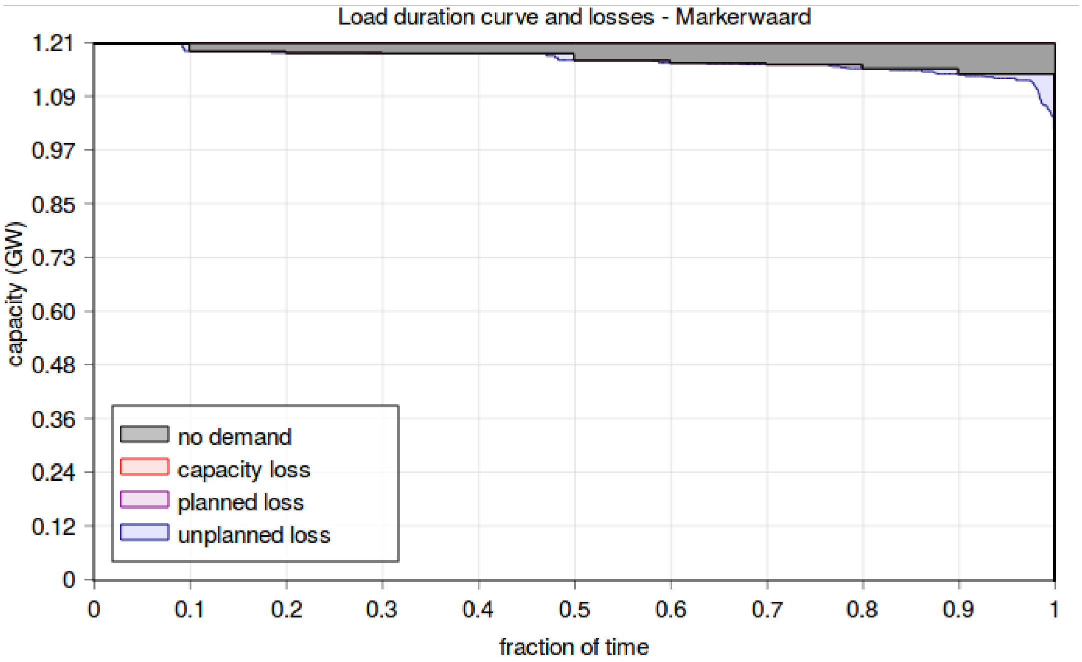

Figure 4.7: draft strategy - load duration and losses

The peak demand is 1210 MW and the expected demand is 1175 MW. The expected capacity is about 1173 MW and the expected loss, relative to the demand, is only 2 MW.

Figure 4.8 shows the expected demand and the expected losses per month.

Figure 4.8: draft strategy - expected losses

This improved plan covers almost 99.8% of the demand, averaged over the period 2020-2030. The remaining small losses are spread out over about 23% of the time and add up to about 2 MW. Although not part of this study, they might be addressed by arranging flexibility at the demand side.

4.4.2 Expected CO_2 emission

The objective is to reduce the CO_2 emissions by 2030 with 49%, relative to 1990. The primary source of CO_2 emissions is from the imported fossil fuels, natural gas and electricity. The study shows that an evaluation of further additional measures is required.

The computation of the future CO_2 emissions follows the IPIECA standard [8], as far as possible.

De Markerwaard produces primary energy from renewable sources only. Its only source of secondary electricity is the gas-fired power station, which uses imported natural gas. Hence, the reduction of the future CO_2 emissions will result from the reductions of the imports of fossil fuels, natural gas and electricity, multiplied with their respective emission factors, see section 3.3.

For making De Markerwaard less energy-dependent, the use of the gas-fired power station takes precedence over the import of electricity, see section 4.4.3.

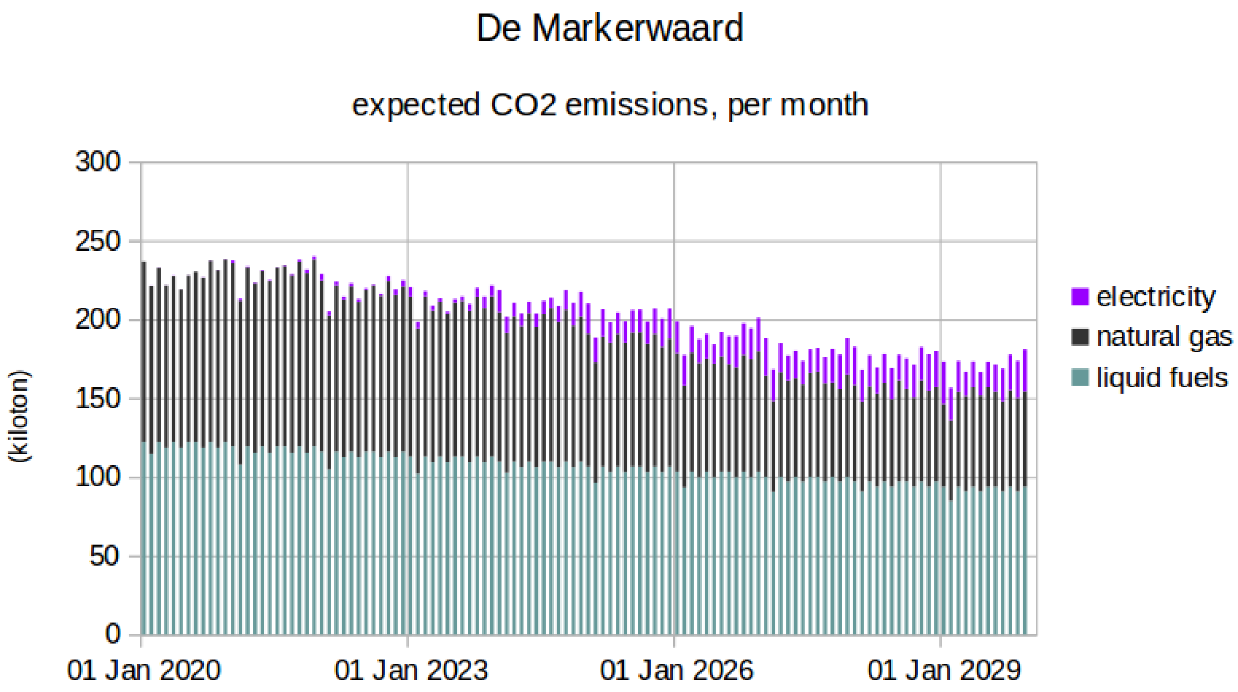

Figure 4.9: expected CO_2 emissions, excluding contributions of other greenhouse gasses

In Figure 4.9, the 230 kiloton per month in 2020 corresponds to an annual emission of 2.8 megaton CO_2. For 2030, the expected CO_2 emissions add up to 2.1 megaton.

For the whole of The Netherlands, nearly all of the CO_2- equivalent reductions in the period from 1990-2020 are the result of the progress with the banning of the other greenhouse gases. Since this study does not consider the period before 2020, an additional assumption is needed to compare 2030 with 1990. This assumption is that De Markerwaard achieves the same reduction in the period 1190-2020 as the whole of the country [4], see Table 4.3,

	NL		DM	
	emissions (MT)	reduction relative to 1990	emissions (MT)	reduction relative to 1990
1990	228		3.7	
2018	189	15%	3.1	15%
2020	166	25%	2.8	25%
2030	116	49%	2.1	44%
2050	11	95%		

Table 4.3: reduction of the emissions, in CO_2-equivalents

With this assumed starting point, the study shows that De Markerwaard is not fully meeting the objective to reduce the CO_2 emissions by 2030 with 49%, calling for the evaluation of further additional measures. Most of the remaining emissions originate from the mobility sector. With even further reductions of emissions in the future, a continued assessment of the security of supply will become increasingly important. Therefore, a timely study of the period 2030-2050 is essential.

4.4.3 Transition costs

Based on the Levelised Cost of Energy (LCoE) see [11], this study calculates that the expected cost of energy will increase during the energy transition. Table 4.4 presents an overview of the costs, both for the individual facilities and for the system integration.

case 3 facility	type	merit	efficiency	LCoE system (€/kWh)	LCoE facility (€/kWh)	source	reference
all demand	demand	0	1.0	0.00	0.00		
hydrogen network	infrastructure	0	1.0	0.01	0.01	gas network	
gas network	infrastructure	0	1.0	0.01	0.01	Engie	invoice Aug 2019
liquid fuel network	infrastructure	0	1.0	0.01	0.01	gas network	
heat network	infrastructure	0	1.0	0.01	0.01	gas network	
electric grid	infrastructure	0	1.0	0.07	0.07	Engie	invoice Aug 2019
biomass conversion	production	1	1.0	0.04	0.03		
solar parks	production	2	1.0	0.13	0.06	Fraunhofer	2018
wind farms on land	production	3	1.0	0.13	0.06	Fraunhofer	2018
geothermal	production	4	1.0	0.08	0.07	IRENA	Fig 6.3: Global 2018
natural gas	import	5	1.0	0.03	0.02	ENDEX futures	2020-2024
gas-fired power station (co-generation)	conversion	6	0.6	0.16	0.04	Fraunhofer	2018
electricity	import	7	1.0	0.12	0.05	ENDEX futures	2020-2023
heat pumps	conversion	8	4.0	0.06	0.03	warmtepompplein.nl	
electrolysis	conversion	9	0.7	0.21	0.01	Shell	H2 study 2017, section 2.6
reformer	conversion	10	0.7	0.06	0.01	Shell	H2 study 2017, section 2.6
liquid fuel	import	11	1.0	0.07	0.05	https://www.unitedconsumers.com/tanken	

Table 4.4: Levelised cost of energy (LCoE) of the individual facilities and the system integration

The basis for the data in Table 4.4 is:

- The LCoE data are preliminary assumptions and can be adjusted when new information is available.
- Costs at the demand side, such as renovation costs and the purchase of an electric car, are not considered.
- All LCoE data exclude all forms of subsidies and taxes.
- The assumed discount rate is 7.5%.
- The column 'LCoE system' takes into account the costs of primary energy and the use of the grids and pipeline networks. The column 'LCoE facility' includes the costs of the facilities themselves only.
- The merit order specifies which facilities have priority for meeting the demand. The given order is an assumption that does influence the transition costs estimate.
- To reduce CO_2 emissions, renewable production takes precedence over electricity import.
- To make De Markerwaard less energy-dependent, the gas-fired power station takes precedence over electricity import.

Figure 4.10 shows that the monthly cost of energy will rise from 56 M€ in 2020 to around 77 M€ from 2027 onwards.

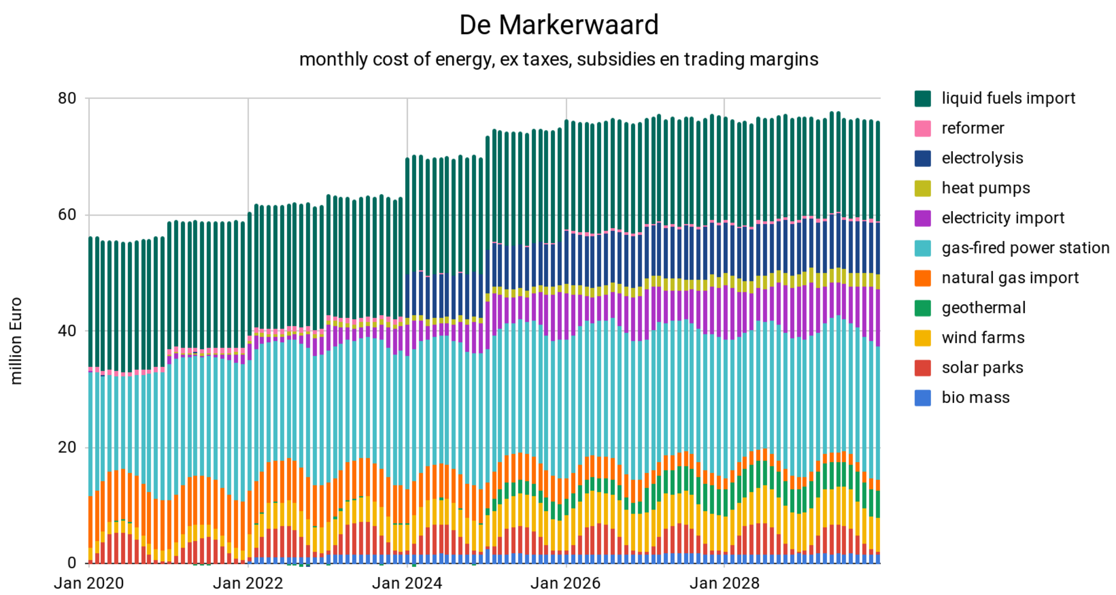

Figure 4.10: monthly cost of energy of De Markerwaard, per facility

Notes:

- For each facility, the costs include the use of the infrastructure.
- The costs of electrolysis and the heat pumps also cover the costs of the electricity used.

- Figure 4.10 uses the average of the costs of the supply from the wind farms, the solar parks and the import, without specifying the origin of the electricity.
- The costs of the gas-fired power station and the steam-methane reformer include the costs of the natural gas burnt.
- The costs of the biomass installation also cover the costs of the biomass.
- All costs are exclusive of subsidies, taxes, duties, costs of CO_2 certificates, trade margins and costs at the demand side.

Because the annual total energy use will not change much, the LCoE as weighted average over the whole of De Markerwaard will increase from 6.6 €cent/kWh in 2020 till 9.3 €cent/kWh in 2030, see Figure 4.11. These rising costs are based on the current price levels and can be adjusted once new information on price trends is available.

The transition plans of De Markerwaard are not cheap. Inevitably, the cost of energy will rise.

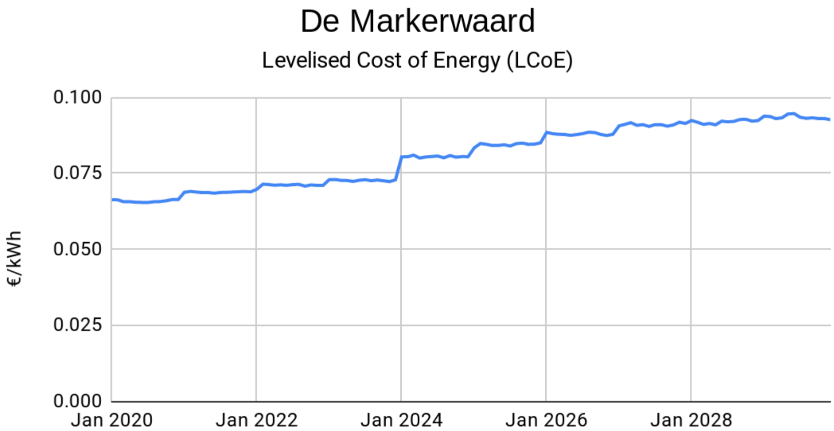

Figure 4.11: development of the cost of energy in De Markerwaard

4.5 Next steps

At the next stage, when the plans are updated, the calculation model of the draft energy transition strategy can be used again, in the same way as in this study:

- Add the additional projects to the network model, or omit no longer desired projects, or adjust the capacity and timing of the already planned projects.
- Adjust the model, if necessary, to stay within the set limits of security of supply, or omit projects that appear to contribute little.
- Use the model results to:
  - calculate the load factors and costs of the individual projects,
  - calculate the costs at the level of De Markerwaard,
  - confirm that the expected reduction of the CO_2 emissions meets the objective.

An ARTIS model for a larger area, or at a national level, can be a transparent platform for the long-term planning of system integration and the balancing of surpluses and deficits between regions.

4.6 Summary

This study is addressing the following questions:

Are the plans of the region sufficient?	No. There will be shortfalls in the supply of electric power and heat.
What are the bottlenecks?	From 2021 onwards, there are increasing shortfalls because the gas-fired power station can no longer adequately meet peak demand. The shortage occurs initially only in winter and from 2025 onwards also in summer. During 2023-2025, the capacity of the 50 kV distribution grid is insufficient. From 2025 onwards, the agriculture sector has a 13 MW shortage of heat, during unplanned downtime of the geothermal project.
How can they be addressed?	Contracts need to cover additional electric power import, mounting to 150 MW in 2030. De Markerwaard must double the capacity of the 50 kV distribution grid two years earlier than initially planned. The geothermal project in the agriculture sector requires heat storage corresponding to 7 days at full production.

References

1.	National Climate Agreement, Government of The Netherlands, 2019
2.	Letter to the House of Representatives, accompanying the Proposal for a National Climate Agreement, Government of The Netherlands, 2019
3.	Coalition Agreement, 'Confidence in the Future, section 3.1, Government of The Netherlands, 2017
4.	Environmental Data Compendium, greenhouse gas emissions, Government of The Netherlands, 2017
5.	Regionale energiestrategy, Nationaal Programma Regionale energystrategie, 2019
6.	Handreiking Regionale Energiestrategie, Nationaal Programma Regionale Energiestrategie, 2019
7.	Netbeheer Nederland, strategy energy-infrastructure impact
8.	Greenhouse Gas Reporting Guide, IPIECA, API and OGP, 2011
9.	Renewable Power Generation Costs in 2018, IRENA, 2018
10.	DE2018_ISE_Studie_Stromgestehungscosts_Erneuerbare_energyn, Fraunhofer, 2018
11.	Project Decision Metrics: Levelized Cost of Energy (LCOE), PeenState, 2019
12.	System Reliability Theory, Models, Statistical Methods and Applications, Second Edition, Hoyland and Rausand, Wiley, 2004
13.	Reliability, Maintainability and Risk, Sixth Edition, Smith, Elsevier 2000
14.	ISO 14224:2006 Petroleum, petrochemical and natural gas industries - Collection and exchange of reliability and maintenance data for equipment
15.	ARTIS user manual

Appendix: Measurement units

GJ	gigajoule
GWh	gigawatt hour
g/kWh	gram per kilowatt hour
h	hour
kT	kiloton
kV	kilovolt
kWh	kilowatt hour
LCoE	levelised cost of energy
MJ	megajoule
MT	megaton

For more information

www.secuos.com