Early Geothermal Exploration in the Netherlands 1980 - 2000

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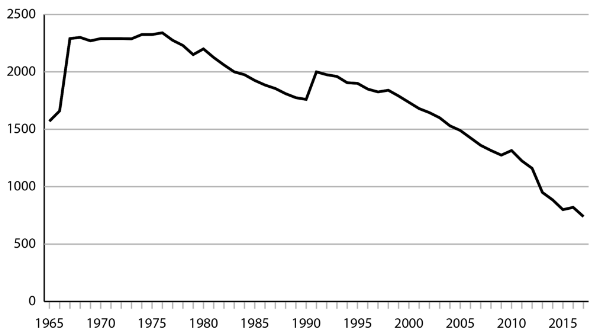
1. INTRODUCTION

From the point of view of introduction of geothermal energy in the Netherlands, the period, presented in this paper, was characterised by the following influential aspects.

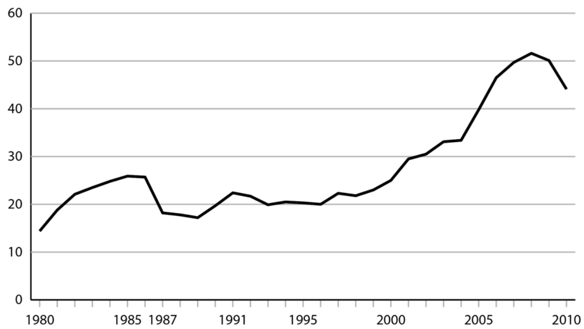
- Geothermal energy had to be an **economic attractive alternative** for the existing energy sources. Environmental aspects became an aspect of influence only after 1993.
- Very restricted knowledge of reservoir characteristics of those formations with a potential for exploitation of geothermal energy was available.
- Lack of any cooperation or support by the operating oil companies to submit the necessary more detailed information regarding reservoir characteristics in the period under consideration.
- Lack of any cooperation or support by the existing energy supply companies to give room to a demonstration project or to an introduction in housing areas under construction in the period under consideration. It was only in cooperation with 'Nutsbedrijf Westland N.V.' NBW that an energy supply company fully cooperated in the preparation of a geothermal project (1992).
- Restraint with respect to the possibilities to exploit sandstone reservoirs for geothermal energy, based on experiences in France, where production occurred from carbonate reservoirs and tests of siliciclastic reservoirs had failed.
- A large of amount proven reserves of natural gas, with a significant increase in 1990 - 1992.
- A significant drop in price of natural gas in 1986 - 1987 (Figure 2), especially in the rate for large scale consumers such as greenhouses (Figure 3).

Figure 1: Proven gas reserves in 10^9 m^3 in the Netherlands (1965 - 2015)



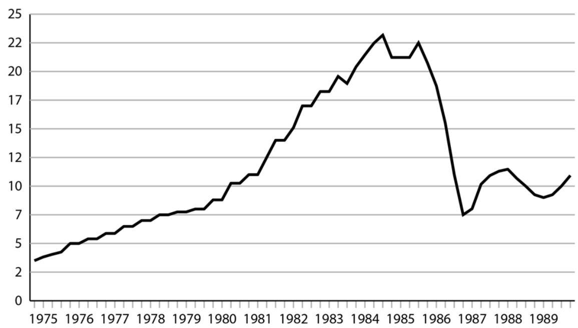
Source: TNO - ECN

Figure 2: Development of consumer price of gas in €ct per m^3 in the Netherlands (1980 - 2010)



Source: Several. Based on CBS

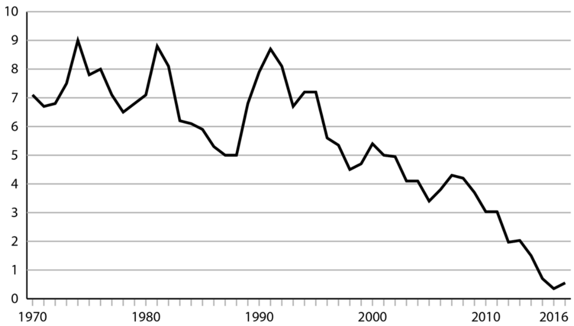
Figure 3: Greenhouse gas price in €ct per m^3 in the Netherlands (1975 - 1989)



Source: N.V. Nederlandse Gasunie (publ.), 1990.

- Large investments necessary for a reliable and secure realisation of a doublet and related surface installations.
- High and fluctuating rates of long term interest. Including a considerable inflation rate (Figure 4).
- Lack of any private party or company interested in investing in geothermal energy.
- The high investment required for a demonstration project would have had a serious impact on the available budget for research in the field of 'alternative sources of energy' at the Ministry of Economic Affairs.
- A very critical approach by inhabitants to district heating in urban areas.
- Existing heating networks were designed for and applied with relative high temperatures (above 70 °C).
- Waste heat from industrial areas was considered a very competitive alternative.

Figure 4: Long-term interest rates in % in the Netherlands (1970 - 2016)



Source: DNB

The absence of any knowledge and experience of permits, concessions, licences and so due to the impossibility to include the operations in the Mining Act. Hot water was not defined neither considered as a mineral. Resulting in the fact that the legislative framework to explore and exploit geothermal energy remained unclear and unsolved during the start of this period. It was only in the 1990's that steps were taken to update the relavant legislation.

Consequently, several promising feasibility studies were achieved in the period 1980 - 2000, but due to the above mentioned constraints none of these resulted in a successful geothermal project.

2. FIRST STEPS AND THE DELFLAND DEMONSTRATION PROJECT (1979 - 1985)

The sharp increase of energy prizes due to the so called second oil crisis in 1979 triggered interest in geothermal energy in the Netherlands. This increase of energy prizes continued untill 1986 (See ad1. Figure 2 and 3). An other factor that contributed to the increased interest was as well aroused by the successful new geothermal energy projects in the Paris Basin. In 1980 four doublets were operational, Melun l'Almont (started in 1969), Creil I with two doublets (started in 1974) these wells were not operational any more in 1991, Villeneuve La Garenne (started in 1976) and La Mee sur Seine (started in 1978).

The first step to investigate the possibilities of geothermal energy exploitation in the Netherlands was made (done) through presenting the first program (NOA - I) by PBE (Project Bureau Energieonderzoek TNO) in 1979. The period envisaged was five years. The budget, made available by the Ministry of Economic Affairs, was € 7,43 x 10^6 (1979), including a 40% support by the the EEC.

The main aim of this first phase was to find an optimal location for a demonstration project. The location had to be the most suitable from the point of view of the required temperature, reservoir characteristics as well as a location with a nearby market for the energy made available by the doublet.

The main partners in this phase were Groundwater Survey TNO and the Geological Survey of the Netherlands.

An inventorization of the most suitable formations was done by mr. G. Milius, who at that time was retired from Shell / NAM. From this inventory it became obvious that form the point of view of reservoir characteristics exploitation of the Lower Cretaceous sandstone formations (Berkel Sandstone Member and Rijswijk Member, both belonging to the Vlieland Sandstone Formation was the most promising option (Van Adrichem Boogaert& Kouwe, 1993-1997).

In view of an extensive area of greenhouses in the so called Westland, situated West of Rotterdam and South West of The Hague, this area looked prosperous for the exploitation of geothermal energy from the above mentioned Lower Cretaceous formations. At that time the yearly energy consumption in greenhouses was 35 m^3 gas per m^2 glass. This corresponds to 1.108 MJ per m^2 glass per year. This figure was brought down in the last 40 years.

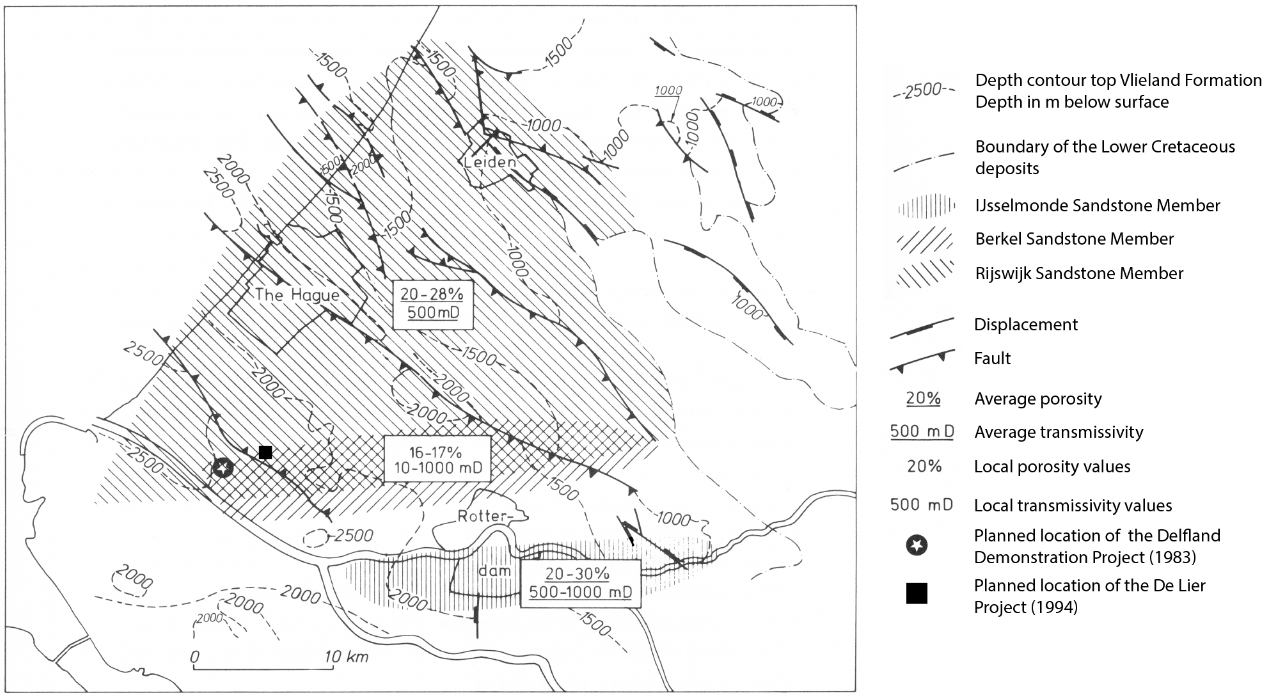
The project-approach had to be very careful due to the fact that the Westland is situated in a NAM oil and gas concession. Although oil production from these 'West-Nederland' production fields was in several areas not any more active, NAM was extremely reluctant to support a geothermal project in their concessions.

PBE - TNO commissioned Groundwater Survey TNO in cooperation with Comprimo Energiconsult B.V. to create a complete feasibility study for a demonstration project to exploit geothermal energy from the Lower Cretaceous sandstone formations in the Westland.

To be able to be informed regarding the developments in the Paris Basin visits were paid in cooperation with the French consulting company Geotherma S.A. to several locations. The attention was focused on those projects aiming to develop the Triassic sandstone formations. An attempt to exploit these formations for greenhouse energy supply, had failed at Melleray situated South of the Paris Basin. An attempt at Achères within the Paris Basin failed as well. This well at Achères was subsequently completed at the higher situated and well known Dogger Limestone formations. These experiences were the reason the team of Groundwater Survey TNO was extremely cautious in their approach to the development of sandstone formations in general. Especially with regard to the design of completion and testing of the wells. Treatment of formationwater, obtained by testing the production well, had to be stored in a way that it could not be contaminated or chemically transformed. A permission to discharge the surplus of formation water, produced during the test phase of the production well, in the 'Nieuwe Waterweg' was obtained. Under the conditions: only at a fluid temperture below 30 °C, at low tide and with a maximum of 20.000 m^3.

The study started with a purchase from NAM of 31,75 km seismic lines shot in the area just North-East of the Nieuwe Waterweg, in the municipality of Naaldwijk. Nowadays (2019) known as Westland. Well logs of Gaag-1, Gaag-2 and De Lier-1 were purchased as well. Interpretations of the seismic lines were available at NAM and at the Geological Survey, but due to confidentiality both parties were not willingly to make the results available for this demonstration project.

Figure 5: Depth, porosity and transmissivity of the Lower Cretaceous deposits in the province of Zuid-Holland



Source: Source: Mot, E. et al., 1984 based on RGD, 1983

The reinterpretation of the lines was executed by Geo-Logic B.V. in Leiden. Based on this reinterpretation and on information in an article by J.W.F. Bodenhausen & W.F. Ott (1981) a preferred area for a location was selected.

The selected area was situated between the Nieuwe Waterweg and the 'De Lier Fault', South of the village Maasdijk in the Oranjepolder (coordinates of the selected location: 51^0 56' 56.83" N and 04^0 13' 20.52" E) (Figure 5).

Acquisition of an open site of 2,4 ha for the geothermal plant was arranged, a 25 years rent was legally recorded at a notary.

The heating system temperature requested in greenhouses in 1983 was 80 °C. As the temperature drop over each heat exchanger was at that time 3 - 5 °C, the formation water temperature had to be 90 °C or more. Consequently the depth of the reservoir to be exploited in this area was required to be between 2250 m. and 2500 m. below surface. The required distance between production well and injection well within the reservoir was 1000 m.

The net amount of gas saved by implementation of this geothermal doublet was based on a presumed connected load of 1,8 MW/ha and a base load of 30% corresponding with 70% of the average heat consumption per year. This at an operation of 4000 hrs per year. The assumed lifetime of the doublet was 25 years.

Table. 2.1: Following data characterize the Delfland Demonstration Project - all figures are related to the specific location in the Municipality of Naaldwijk, South of Maasdijk in the Oranje Polder as selected by the project team. (Figure 5)

Depth of the top of the reservoir = top of Berkel Sandstone Member	2300 m below surface
Depth of the bottom of the reservoir = bottom of Rijswijk Member	2460 m below surface
Calculated thickness of the reservoir	160 m
Estimated average permeability	500 mD
Estimated average transmissivity	80 Dm
Estimated porosity	18 %
Estimated sand / shale ratio	10
Estimated temperature of formation water at reservoir depth and at wellhead production side	90 °C
Delta T at wellhead	40 °C
Salt content	100 - 120 gr / l
Required volume (flow) to obtain a probable economic feasibility	200 m^3 per hour
Calculated pressure reduction (draw down) in the production well. Minimum and maximum	4,1 x 10^5 Pa - 7,5 x 10^5 Pa
Calculated required pressure in the injection well	13,1 x 10^5 Pa (at 50 °C)

Required pressure in the injection well as applied for the pump design	19×10^5 Pa (at 50 °C)
Maximum pressure of the injection pump (overdimensioned for safety reasons)	40×10^5 Pa
Surface of greenhouse to be connected to the geothermal source. For this area there was an agreement with the greenhouse owners to be connected to the geothermal plant	15,9 ha
Net amount of gas saved by implementation of this geothermal doublet	$3{,}7 \times 10^6$ m^3 per year = 32.470 MWh = 130×10^6 MJ per year
Estimated (quoted) **minimum** and **maximum** costs of the complete doublet including all related costs for the required subsurface operations as well for the preparation of the location.Testing of the wells and the investment of the pumps are included. In € x 10^6	7,56 - 10,44 (1983) *
Estimated (quoted) total costs of the surface installations including the surface heat network and distribution network in the greenhouses. In € x 10^6	5,70 (1983) *
Total **minimum** and **maximum** required investment including insurance coverage of all risk. In € x 10^6	13,26 - 16,14 (1983) *
Estimated cost of maintenance. In € x 10^6 per year	0,30 (1983)*
Applied discountfactor to evaluate the feasibility study	8,15 % (consisting of 5 % inflation and 3,15 % net interest)
Economic evaluation expressed in cost per saved m^3 gas. ** In 1983 the greenhouse owners, as large-scale consumers, paid € 0,18 per m^3 gas (See ad 1, Figure 3)	€ 0,30 - € 0,43 per m^3 gas
Calculated internal rate of return. ** The figures are related to one of the energy price scenarios as supplied by the Ministry of Economic Affairs in 1983. The existing long term interest rate was 8,15% in 1984.	1,05 % till (minus) 0,17%

* Exclusive VAT and 1 € = 2,02 Dfl. When the purchasing power is taken into account: €1,00 (1983) = €1,95 (2018)
** In the agreement with the greenhouse owners, to be connected to the doublet, was stipulated to sell the geothermal heat at an equal or lower price than the price set for prevailing alternatives such as gas.

Source: Dufour, F.C. & Vierhout, R.M., 1983 and CBS.

Above figures for the investment seem to be extremey high, but one has to keep in mind that these costs are related to a demonstration project in which all possible risks had to be avoided. The drilling operation was designed according ‘good oil-practice’ as was required and applied in the Netherlands.

In an attempt to improve the financial-economic feasibility of the project Comprimo Energiconsult B.V. designed as well the option to install in the surface plant a heat pump system or to install an isolated storage capacity. Both additional options did not improve the financial-economic feasibility in a significant way.

With the purpose to reduce the cost of drilling of the injection well, the possibilities to inject the formation water in a less deep formation was investigated. This turned out not to be a suitable option (Huurdeman, L., 1982).

By considering the possibilities to realise this Delfland Geothermal project we have to take into account that NEOM had developed a proposal for energy supply of industrial waste heat from the area of Botlek into the greenhouse area of Westland in the same period. In the opinion of NEOM this alternative was far more promising than the exploitation of geothermal energy.

The decision to decline the realisation of this demonstration project was taken by the Ministry of Economic Affairs in July 1984.

The main reasons were:
- High investments in an energy field that was at that time not well known in the Netherlands. High investment related to site preparation, drilling, completion and well testing due to the necessity to prevent any risk and any chance of critics by the operating oil companies, especially NAM, in the Netherlands.
- Doubts related to potential problems at injecting a large volume of 200 m^3 per hour in sandstone formations.
- Availability of large reserves of natural gas (See ad. 1, Figure 1)
- Lack of any support by NAM. We have to keep in mind that the incident at a drilling location in Drenthe close to the village of Sleen was only 15 years earlier. This may explain that NAM and oil companies in general, became very concerned that companies, not familiar with the operations neither with the soil conditions and safety rules in the Netherlands, should operate in their concessions, with the risk of accidents such as happened near Sleen.
- Lack of any cooperation from the side of the Nederlandse Gasunie and Gemeentelijk Energiebedrijf ’s Gravenhage. These parties required compensation for their loss of market for their gas supplies.
- Very disappointing predicted return on investment. An internal rate of return far below the existing long term interest rate.
- Absence of private parties interested in participation in the development of this demonstration project and geothermal energy in general.
- Preference of NEOM for the alternative to supply industrial waste heat from the area of Botlek.

3. INVESTIGATION OF THE GEOTHERMAL RESOURCES IN THE CENTRAL GRABEN AREA (1985 - 1990). THE ASTEN PROJECT

3.1. Introduction

The Netherlands Agency for Energy and the Environment PEO commissioned Groundwater Survey TNO to carry-out a programme and study for a follow-up geothermal research programme for the period 1985-1989. This resulted in the National Research Programma on Geothermal Energy and Energy Storage in Aquifers the NOAA (1985-1989).

Whereas the NOA focused on the research and development of deeper geothermal resources at depths around 2.500 m below surface, this second research programme focused on medium deep geothermal resources at depths up to 1.500 m below surface. Besides geothermal research the second research programme included energy storage in aquifers. Management of the National Information Centre for Geothermal Energy and Energy Storage in Aquifers, which was established during the NOA and based at the library of Groundwater Survey TNO, was included in this programme as well. This Information Centre was very regrettably neglected and dissolved in the years after 2000.

The total budget for the second National Geothermal Research Programme (NOAA 1985 - 1989) amounted to € 22,0 x 10^6 (1985).

3.2. Implementation of the exploration well

Within the NOAA framework the first exploratory well in the Netherlands was commissioned in 1986. The purpose of the test well was, firstly, to investigate the geothermal potential of three lower Tertiary sand formations, two of them belong to the Breda Formation. At that time those members were named: Zand van Berg and Zand van Voorst. The third, the Basaal zand van Dongen is older than the Breda Formation. Among the oldest Tertiary sand deposits, belongs the Heers Sand, a member of the Landen Formation. Some of these stratigraphic names are not used any more in the modern Tertiary stratigraphy of the Netherlands (Van Adrichem Boogaert & Kouwe, 1993-1997) and secondly, based on test well results, to investigate the technical and economic feasibility of a realised geothermal power project with application of the produced energy in nearby greenhouses.

The drilling of this first exploratory geothermal well in the Netherlands started in 1986 and was completed in 1987. The well was drilled under project management of TNO Institute of Applied Geoscience (previously called Groundwater Survey TNO). The drilling company was de Smet from Dessel (Belgium). In 1988 a second drilling operation was undertaken to restart drilling and test the Zand van Berg formation. In case the pumping test should have confirmed that geothermal energy could be exploited economically, it was planned to complete this well as one of the wells for a future geothermal doublet.

Preparation, implementation and assessment were carried out in close cooperation with the Netherlands Geological Survey (RGD), the University of Utrecht (RUU) and Comprimo BV consulting engineers. The research was founded in part by the EEC.

This possible future geothermal doublet was planned to serve the greenhouses of the threeVan Aarts brothers at the Bleekerweg in Asten (province Noord Brabant). Also the local energy distributor CoGas supported the use of geothermal energy for these greenhouses.

The following criteria were used in the test well design;
- the probable geological structure based on drilling data from exploratory hydrocarbon wells drilled in the region - i.e. in Asten -1 and Nederweert';
- optimum acquisition of data on the geology and reservoir characteristics;
- a production and an injection (or reinjection) test in the deepest formation;
- after the geothermal potential of the investigated formations had been established the well must be capable to be used as a production or injection well of a possible future geothermal doublet.

The final depth was originally planned at 1.550 m below surface. But detailed study of the Asten -1 well-logging data revealed adequate reason for continuing to a final depth of roughly 1.673 m below surface. This offered an opportunity to test a fourth formation, an Upper Cretaceous Formation (the Houthem Formation), as well. This formation had proven to be successful as a source of geothermal energy at Merksplas, Belgium.

Table 3.1: Geological characteristics of the different formations (Asten 1 and 2).

Formation	Top below surface level (m)	Bottom below surface level (m)	Thickness (m)	Temperature in °C
Breda Formation	939	998	59	35,5
Voort Sand	1.196	1.415	219	49,2
Berg Sand	1.494	1.513	19	59,5
Basal Dongen Sand	1.513	1.550	17	60,0
Heers Sand	1.628	1.636	8	62,3
Houthem Formation	1.647	1.665	15	62,9

Source: Heederik, J.P. et al., 1989

Implementation of the exploration well and research of the reservoir characteristics of the various formations took place in two periods. Between November 1986 and March 1987, the drilling and planned research programme was carried out with airlift. The operation included drilling into the deepest targeted formation, the Houthem Formation (1.636-1.656 m below surface).

To verify the favourable results of the preliminary reservoir evaluations of the Berg Sand (1.494 - 1.513 m below surface) a production test was done. For this purpose, the well was opened at the relevant depth and completed with a prepack filter in the period March to May 1988. The production test was done using nitrogen (N_2) lift.

Table 3.2: Results exploratory geothermal well Asten (Asten 2)

Formation	Permeability		Productivity index based on a test in the well Asten 2, in (m^3/hr/bar)
	Prognosis in mD	Results core analysis in mD	
Breda Formation	1.000	820	13,7
Voort Sand	100 - 1.000	7	0,5
Berg Sand	100	370	2,9*; from well test 0,5
Basal Dongen Sand	500	3	0,02
Heers Sand		240	1,1
Houthem Formation		25	0,6
	Productivity of the total well PI = approximately 0.2 (m^3/hr)/bar In pre-feasibility study a PI was assumed of 10 (m^3/hr)/bar, pump at 200 m - surface Assuming a production (flow) of 200 m^3/hr		

* Caculated on the basis of well-logging and core-analysis (Formation evaluation)

Source: Heederik, J.P. et al., 1989

During the drilling of the Asten Geothermal exploratory well (Asten - 2) the following complications occurred:
– During the testing of the blow-out preventer (30-11-1986) the mast of the drilling rig (Edeco H525) was bended. It took the drilling company 5 weeks to find a replacement mast and to resume the drilling (04-01-1987);
– In January 1987 temperatures fell under 17 °C below zero, this in combination with a strong wind from the East the operating conditions were such that all drilling activities in the Netherlands were completely stopped, except this drilling at Asten. The main reason for this was financial- economical, nor the drilling company, neither TNO as operator could afford to stop the drilling. Due to the severe winter conditions the drilling was hampered, equipment, pipes, hoses and pumps had to be regularly defreezed. During a second drilling operation by DST (a well-established German drilling company), starting in the existing well, aimed at the Berg Sand;
– In March 1988 the setting off of the screenfilter failed, damaging the screen beyond repair;
– In April 1988 the drill string got stuck in the Boom Clay, the fishing operation was unsuccessfull, 200 m of string got lost and a second side track became necessary.

Fortunately the extra costs related to this drawback totalling € 619,0 x 10^3 (1988) were covered by the insurance company.

3.3. Conclusions of the Asten geothermal exploratory well investigations

– The investigations in the geothermal exploration well resulted in an extensive quantity of relevant geological and reservoir technical information on the potential reservoirs occurring in the Asten fault block also elsewhere in the Central Graben (Roer Valley Graben);
– The cost of the first drilling operation by De Smet amounted to € 1,2 x10^6 (1985), the cost of the second drilling operation by DST was budgeted at € 0,4 x 10^6 (1988). However, the total cost of both drilling operations amounted to € 2,2 x 10^6 (1988), including the cost of damage and € 1,6 x 10^6 (1988), excluding the additional cost due to the drilling damage during the second drilling;
– From the calculated productivity indices it was concluded that only two formations could be considered suitable for geothermal energy exploitation, i.e. the Breda Formation as a whole with a productivity index of PI Breda = 13.7 (m^3/hr) / bar and a temperature of 35.5 °C and the Berg Sand with a PI of 2.9 (m^3/hr) / bar and a temperature of 59.5 °C. It is however striking to note that the productivity of the Berg Sand obtained from the welltest turned out to be much lower than the productivity index obtained form core analysis. The project therefore showed that great caution should be taken when using geological inventory studies for estimating geothermal reserves and potential;
– The research in Asten showed that the Asten Fault block may contain a total of 217,3 x 1015 J geothermal energy reserves, which equals 5 x 10^6 TOE oil equivalent and 6,7 x 10^6 Nm^3 natural gas equivalent.
– Using the results of the geothermal test drilling Comprimo B.V. investigated the application possibilities for low enthalpy geothermal energy in the Central Graben (Roer Valley Graben).

This economic study showed that at that time (1988) geothermal energy production, with or without co-generation was economically only feasible (competitive) with a natural gas price of at least € 0,25 (1988) per Nm^3 for greenhouses with a minimum area of 20 ha.

4. GEOTHERMAL EXPLORATION AND EXPLOITATION ACTIVITIES CARRIED OUT WITHIN THE NOAA II PROGRAMME (1990 - 1995)

4.1. Introduction

At the end of the National Research Programme on Geothermal Energy and Energy Storage in Aquifers the NOAA I (1985-1989), NOVEM commissioned Groundwater Survey TNO to formulate a follow-up geothermal research programme for the period 1990 - 1995.

Early 1990 the ambition of the Ministry of Economic Affairs (Nota Energy Saving 1990) was;
– priority should be given to the realization of one full scale geothermal demonstration project, and
– prior to 2000 two full scale geothermal projects should be realized, including the first geothermal demonstration project, and
– before 2010 a total of 10 geothermal projects should be realized.

A remarkable event was the appointment of Frans Walter as Professor of Geothermal Energy at the Faculty of Mining and Petroleum Engineering at the University of Technology at Delft in 1991. He played an important role in the geothermal developments in the Netherlands in the period of the NOAA II and was the author of the evaluation report of the National Research Programme on Geothermal Energy and Energy Storage in Aquifers the NOAA II (1990 - 1994). Frans Walter passed away on July 1996 at the age of 63.

The total budget for the National Geothermal Research Programme II (NOAA II, 1990 - 1995) amounted to € 11,3 x 10^6 (1990) at the price level of 2019 this would have been appr. € 22,0 x 10^6.

The Directorate General of the European Commission DG XII and XVII played an important role in the financing of geothermal projects in the European Union since 1979. It was the intention to stop the financing of geothermal projects in the EU at the end of 1989. This due to the very disappointing developments in exploitation of geothermal energy in Europe in the previous years. It were especially the developments in the Paris Basin in the period 1985 - 1990 which were so disapointing that low enthalpy geothermal energy had to be considered as an example of an economically unacceptable vulnerable energy source (Dufour, F.C. & Ungemach, P., 1991). However, after the fall of the Berlin wall and the reunion of West- and East Germany, the EU re-opened the possibilities for financing geothermal R&D focussed on R&D projects in the former DDR. This opened possibilities for TNO to propose geothermal R&D projects in close cooperation with East-German parties.

In the framework of the NOAA II Groundwater Survey TNO carried-out and / or participated in the following geothermal projects;
– Improvement of the Injectivity Index of Argillaceous Sandstone, this study was carried out in cooperation with the Bureau de Recherches Geologiques et Minières (BRGM from France), Delft University of Technology (TUD from the Netherlands), Geothermie Neubrandenburg GmbH (GTN from East Germany) and the University of Bremen as sub-contractor to GTN;
– Demonstration Project Geothermal Exploitation De Lier, commissioned by Nutsbedrijf Westland BV (NBW), a public utility company and carried out in cooperation with GeoProduction Consultants (France), the Geological Survey of The Netherlands and Delft University of Technology.

4.2. Improvement of the Injectivity Index of Argillaceous Sandstone

The purpose of the above mentioned project ‘Improvement of the Injectivity Index of Argillaceous Sandstone’ was to obtain a better understanding of the mechanisms and phenomena occurring during (re)injection of cooled formation water in argillaceous sandstone.

Sand members of three European reservoirs have been evaluated for geothermal purposes on their geological framework, rock textural characteristics and petrophysical qualifications:
– The Lower Cretaceous Vlieland Sandstone Formation group in the Netherlands; This Vlieland Sandstone Formation is a.o composed of the Berkel Sandstone Member and the Rijswijk Member (Van Adrichem Boogaert& Kouwe, 1993-1997).
– The Lower Triassic Buntsandstein in France (Alsace)
– The Upper Triassic (Keuper) Contorta Formation in Germany

The conclusion of the investigations was:
From the point of view of porosity and permeability the investigations showed that the Contort Formation (Germany) shows good perspectives. The Berkel Sandstone Member (The Netherlands) and the Vosdian Member (France) are moderate to good reservoirs.

4.3. Demonstration Project Geothermal Energy Exploitation De Lier

The utility company ‘Nutsbedrijf Westland N.V.’ (NBW) commissioned TNO Institute of Applied Geoscience (TNO-GG) in 1992 to evaluate the possibilities of geothermal exploitation for greenhouse horticulturists in the Westland area, near the town of De Lier. This area was, as the Delfland location (see under 2 of this paper), particularly suitable for a geothermal energy project. Apart from large-scale greenhouse complexes, the area possesses abandoned oil and gas wells that provided data on the subsurface. This would make a geothermal venture less uncertain. The reservoir properties of the Lower Cretaceous sandstone in this area are similar to the reservoir previously investigated in the framework of the Delfland study (see ad. 2 of this paper). The area is situated within a NAM concession area.

Around 1993 the situation became more favourable for the exploitation of geothermal energy. Due to environmental reasons, the Dutch government became more in favour to cut down on the use of fossil fuels. The government supported the aim of the energy distribution companies in the Netherlands, which had expressed their intention to replace 3% of their present energy sales (= 3 TWh/yr) with sustainable energy and to decrease or fix CO_2 emission at the 1991 production level.

NBW had become one of the largest Dutch distributors of natural gas. Its main group of clients were the greenhouse horticulturists in the Westland area southwest of The Hague. As the energy distribtion companies had agreed to reduce their consumption of fossil fuel based energy for the horticultural sector by 30% before the year 2000.

The aim of the project 'De Lier' was to apply geothermal energy for the heating of approximately 17 ha of greenhouses near De Lier. The objective was to demonstrate on a practical scale the technical and economic feasibility of the exploitation of low enthalpy geothermal resources (the reservoir temperature was estimated to be: 87 °C). The reservoir was situated at a depth between 2.205 m and 2.368 m below surface. The selected location was situated at the Burgerweg - Scheeweg (see ad. 2, Figure 5).

The main aspects of the project were:
– low enthalpy heat extraction from deep sandstone aquifers for greenhouse heating purposes;
– maximum heat depletion through application of innovative greenhouse heating systems working at relative low temperatures, inlet temperature 81 °C - outlet temperature 40 °C;
– application of the results obtained with R&D with the aim of investigating and, when possible, improving the injectivity index of argillaceous sandstones;
– reduction of CO_2 emission.

Table 4.1: Major petrophysical properties of the Rijswijk Member, the Berkel Sand-Shale belonging to the Berkel Sandstone Members at location 'Scheeweg', a.s used for the reservoir modeling. The values are extrapolated from data obtained from well site Gaag-1.

Properties	Berkel Sand-stone Member	Berkel Sandston e- Shale	Rijswijk Member	Total Reservoir
Depth of top (m) below surface	2.205	2.247	2.322	2.205
Depth of bottom (m) below surface	2.247	2.322	2.368	2.368
Gross thickness (m)	42	75	46	163
Net thickness (m)	39	56	24	120
Shale content (%)	1,9	15,7	4,9	9,1
Porosity (%)	16	14	16	15
Permeability (mD)	332	124	330	232
Transmissivit y (Dm)	13	7	8	28

Source: Meer, M van der, Heederik, J.P. & Straaten, R. van der (1994)

Table 4.2: Calculated geothermal capacity W and related parameters.

Symbol	Value	Unit	Description
ΔT	41,3	^{0}K	Temperature difference between injection and production water
pwcw	4,06 10^6	J/m^3.^{0}K	Heat capacity formation water
Q	8,33 10^{-2}	m^3/s	Discharge
W	1,40 10^7	W	Geothermal capacity

Source: Meer, M van der, Heederik, J.P. & Straaten, R. van der (1994)

Table 4.3: Geothermal capacity (+) and pumping capacities (-) for a discharge of 300 m^3/h, a pump efficiency of 70%, a skin factor of 0, and injection/production liners with a diameter of 8"5/R (219 mm) and a roughness <f 0.5 mm.

	+/-	Capacity (kW)
Injection pump	-	271
Production pump	-	404
Circulation pump	-	40
Total pumping capacity	-	715
Geothermal capacity	+	13.973
Gas savings gas expander	+	900
Total gross geothermal capacity	+	**14.873**
Net geothermal capacity	+	**14.158**

Source: Meer, M van der, Heederik, J.P. & Straaten, R. van der (1994)

Economic evaluation

The economic evaluation of the geothermal project 'De Lier' was based on the prevailing energy prices, the investment estimated, the maintenance and operation costs and the prevailing long term interest. It was assumed that the geothermal energy plant will operate from 1996 untill 2020, i.e. a lifetime of 25 years. Electricity and gas prices are based on the 'energy price scenario' of the Ministry of Economic Affairs, in which a gas price rise by 2,2% per year and the electricity price by 1,5% was predicted. Maintenance and operation costs (including replacement of the deep well pump every 5 years) will grow by 3% per year to compensate for inflation. Costs, income and economic profitability are shown in Table 4.4.

Table 4.4: Costs, income and profitability of the geothermal project 'De Lier'. M&O stands for maintenance and operation costs. Two cases have been considered: one without 'environmental' funding and one with a 50 % 'environmental' funding of the total investments.

Costs and profits	No funding	50% funding
Costs:		
Investments (€ 10^6)*	16,03	8,15
Energy costs in 1996 (€ 10^6)*	0,29	0,29
M&O in 1996 (€ 10^6)*	45	0,45
Income:		
Gas savings in 1996 (€ 10^6)*	1,22	1,22
Profitability:		
Internal rate of return (%)	1,18	3,18
Net present value (€ 10^6)*	10,54	2,39
CO_2 reduction (€/tonne CO_2)	43,07	8,91

* € 1,00 (1996) = € 1,55 (2019)

Source: Meer, M van der, Heederik, J.P. & Straaten, R. van der (1994)

Conclusions

The intallation of a geothermal doublet near 'De Lier' was technically feasible. Given the proposed conditions, it would have been possible to construct an installation with a net capacity of about 14 $MW_{(th)}$ which corresponds to an annual energy production of approximately 65 $MW_{(th)}h$. However, the geothermal enterprise would not have been profitable under the prevailing energy prices (gas) in 1992. The ultimate loss would have amounted to about € 10,74 x 10^6 (2019) and the average production costs would have amounted to about 0.04 €/$kWh_{(th)}$.

5. GEOTHERMAL ACTIVITIES REALISED IN THE PERIOD 1995 - 2000

5.1. Conservation of geothermal knowledge and expertise (1995-2000)

The ambitions of the NOAA II (1990-1994) were high and it was anticipated that a first geothermal demonstration would have been realized or at least would have been initiated in that specific period. However this was not realised. At the end of the NOAA II the Ministry of Economic Affairs (EZ) realized that realization of a first geothermal demonstration project was not to be expected before the year 2000. In order to preserve the geothermal knowledge and expertise gained in the course of three consecutive national geothermal R&D programmes covering the periods of 1979-1995, EZ requested TNO Institute of Applied Geoscience (TNO NITG), to formulate a proposal for the conservation of the geothermal knowledge and expertise within TNO-NITG, the National Geological Survey (RGD) and the University of Delft (TUD).

5.2. Pre-Feasibility - and feasibility studies for VINEX locations

The Dutch Ministry of Housing, Spatial Planning and the Environment (Ministry of VROM) released their 'Fourth Memorandum Spatial Planning Extra' ("Vierde Nota Ruimtelijke Ordening Extra" or VINEX) in 1991.

Prof. Dr. Frans Walter took the initiative to approach local authorities of numerous appointed VINEX-locations where the geological conditions seemed promising for geothermal development and offered to prepare pre-feasibility studies. As a result the following pre-feasibility - and/or feasibility studies were carried out by Prof. Walter's private consulting firm Delft GeoVentures (DGV) in close cooperation with TNO-NITG: It concerns the locations at:

- Wateringse Veld and Ypenburg;
- Monster;
- Pijnacker;
- Almere, Lelystad en Heerenveen;
- Hoorn, Enkhuizen en Stedenbroek.

5.3. Feasibility studies commissioned to TNO-NITG by various energy distribution companies

- Evaluation of reservoir characteristics at borehole location Heerenveen-01 (1997), commissioned by energy distribution company NUON;
- Study of suitability of aquifers (permeability) in the area Almere-Lelystad and Heerenveen for geothermal exploitation (1997), commissioned by energy distribution company NUON;
- Feasibility study in the area Wateringse Veld and Ypenburg, commissioned by energy distribution company ENECO;
- Investigation of the potential for geothermal development in the ENECO distribution area, commissioned by energy distribution company ENECO;
- Investigation of the potential for geothermal development in the Energie Delfland distribution area commissioned by energy distribution company Energie Delfland;
- Investigation of the potential for geothermal development in the North and centre of the province of Noord Holland commissioned by energy distribution company Energie Noord West (EWN).

5.4. International cooperation

As a spin-off of the NOAA II programme good working relations were developed between TNO NITG and the consulting firms Geothermie Neubrandenburg GmbH (GTN, Germany) and GeoProduction Consultants (GPC, France). This resulted among others in the following project cooperations;

- 'Geotechnical assistance in assessing the Geothermal potential in NW Poland and notably for the Cities of Szczecin and Stargard Szczecinski. This project was financed by the EU and the World Bank. The total budget for the first face of the project amounted to € 225,0 x 10^3 excluding the cost for carrying out a High Resolution Seismic survey, estimated at € 965,0 x 10^3;
- Reinjection of cooled brines into sandstone reservoirs (REBRISAR) - A field application study for geothermal sites in Hungary, in cooperation with GTN and GPC, budget € 87,5 x 10^3;

- The Arendsee Geothermal project - A new concept for the exploitation of geothermal energy based on optimum (horizontal) well trajectory, in cooperation with GTN;
- Development of a GIS-supported Method for Site-related Evaluation of the Utilization of Geothermal Heat, in cooperation with GTN;
- Geothermal energy for heating in Szolnok (Hungary), in cooperation with the municipality of Sznolnok (Hungary) and TNO Building and Construction Research.

REFERENCES

- Bodenhausen, J.W.A. & Ott, W.F., 1981. Habitat of the Rijswijk oil Province, onshore, The Netherlands. In: *Proceedings of the Second Conference on Petroleum Geology of the Continental Shelf of North-West Europe.* Institute of Petroleum, London.
- Boogers, Peter, 1993, *Voorstudie Geothermisch Project De Lier. Gebruik van te abandonneren putten (in Dutch)*, Faculty of Mining and Petroleum Engineering at the University of Technology at Delft, The Netherlands.
- Dufour, F.C. & Vierhout, R.M., 1983, Voorbereiding Aardwarmte Demonstratieproject Delfland, Dienst Grondwaterverkenning TNO, Delft (in Dutch). *Report OS - 83 - 29.* Three volumes. Total of 383 pp., + several appendices.
- Dufour, F.C. & Ungemach P. et al., 1991. Evaluation of the exploitation of Geothermal Energy in the Paris Basin during the period (1969) - 1978 - 1990. Delft. *TNO Environmental and Energy Research. Report OS - 91 - 14A.* Pp. 51 and a large number of appendices.
- Egberts, P., & Heederik & J.P., Meer, M. van der, & Vernoux, J.F., 1995, 'Modelling of permeability changes in argillaceous sandstones due to fluid injection', in *Proceedings of the World Geothermal Congress 1995*, Florence Italy, 18-31 May 1995, vol. 3, p. 1979-1983.
- Haak, A.M. & Heederik, J.P. & Vierhout, R.M., 1985. Vooronderzoek Geothermisch proefproject Asten (in Dutch). *Report OS 85-36*, 37 pp.. Dienst Grondwaterverkenning TNO, Delft, The Netherlands. Total of 383 p.p.
- Heederik, J.P. et al., 1989. Geothermal Resources in the Central Graben Area, The Netherlands. Exploration and Evaluation (both in Dutch as well in English). *Report OS 89-18*. Dienst Grondwater-verkenning TNO, Delft, The Netherlands. Total of 115 pp., + several appendices.
- Heederik, J.P. & Meer, M van der & Straaten, R. van der., 1995, 'Demonstration project geothermal exploitation De Lier: Exploration and evaluation geothermal resources in the Western Netherlands', in *Proceedings of the World Geothermal Congress 1995*, Florence Italy, 18-31 May 1995, vol. 3, p. 2263 - 2268.
- Heederik, J.P. et al., 1997. Improvement of the Injectivity Index of Argillaceous Sandstone, Final Report, Reseach funded in part by The European Commission in the framework of the JOULE II Programma, Sub-programma Non Nuclear Energy, contract no JOU 2-CT92-0183, *report NITG 97-260A*, Netherlands Institute od Applied Geoscience TNO - National Geological Survey, Delft, The Netherlands.
- Heederik, J.P. & Huurdeman, A.J.M., 1988. Geothermal study of the Central Graben (North Brabant); Evaluation of the results of an exploratory Geothermal well in Asten. In Proceedings and Information 40, *Geothermal energy and heat storage in aquifers, page 77-97*; TNO Committee for Hydrological Research, The Hague, The Netherlands. Total of 107 pp.
- Huurdeman, L., 1982, *Onderzoek naar mogelijkheden tot injektie van afgekoeld formatiewater uit het Berkel - en Rijswijk-zandencomplex in ondiepere pakketten in het kader van het demonstratieprojekt Delfland (in Dutch)*. Dienst Grondwaterverkenning TNO, Delft. 27 pp.
- Meer, M van der & Heederik, J.P. & Straaten, R. van der., 1994, Geothermisch Doublet De Lier (in Dutch), *Report OS 94-35*, TNO Institute of Applied Geoscience, Delft, The Netherlands
- Mot, E. et al., 1984, *Verslag van het Nationaal Onderzoekprogramma Aardwarmte en Warmte-opslag, 1979 - 1984. (in Dutch)*, Projectbureau Energieonderzoek TNO, Apeldoorn. 118 pp.
- N.V. Nederlandse Gasunie (publ.), 1990, *Aardgas in de tuinbouw. (in Dutch)*, Groningen. 24 pp.
- Van Adrichem Boogaert, H.A.& Kouwe, W.F.P. 1993–97. Stratigraphic nomenclature of the Netherlands, revision and update by RGD and NOGEPA. *Mededelingen Rijks Geologische Dienst*, 50.
- Vierhout R.M. & Heederik, J.P. 1989. Geo-thermische reserves Centrale Slenk, Nederland, Toepassing van geothermische energie, (in Dutch). *Report OS 89-19.* Dienst Grondwaterverkenning TNO, Delft, The Netherlands. Total of 38 pp.
- Visser et al., Voorstudie Geothermie project De Lier, (in Dutch), *Report OS 93-70-C*, TNO Institute of Applied Geoscience, Delft, The Netherlands.
- Walter, Frans, 1993, Evaluatie van het Nationaal Onderzoekprogramma Aardwarmte en Energie-Opslag in Aquifers 1990 - 1994, *NOAA II (1990 - 1994), (in Dutch)*, Delfland Geo-Venture (DGV), Nootdorp, The Netherlands.
- Walter, Frans, 1995, 'The status of geothermal energy in the Netherlands', in *Proceedings of the World Geothermal Congress*, 1995, Florence Italy, 18-31 May 1995.

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