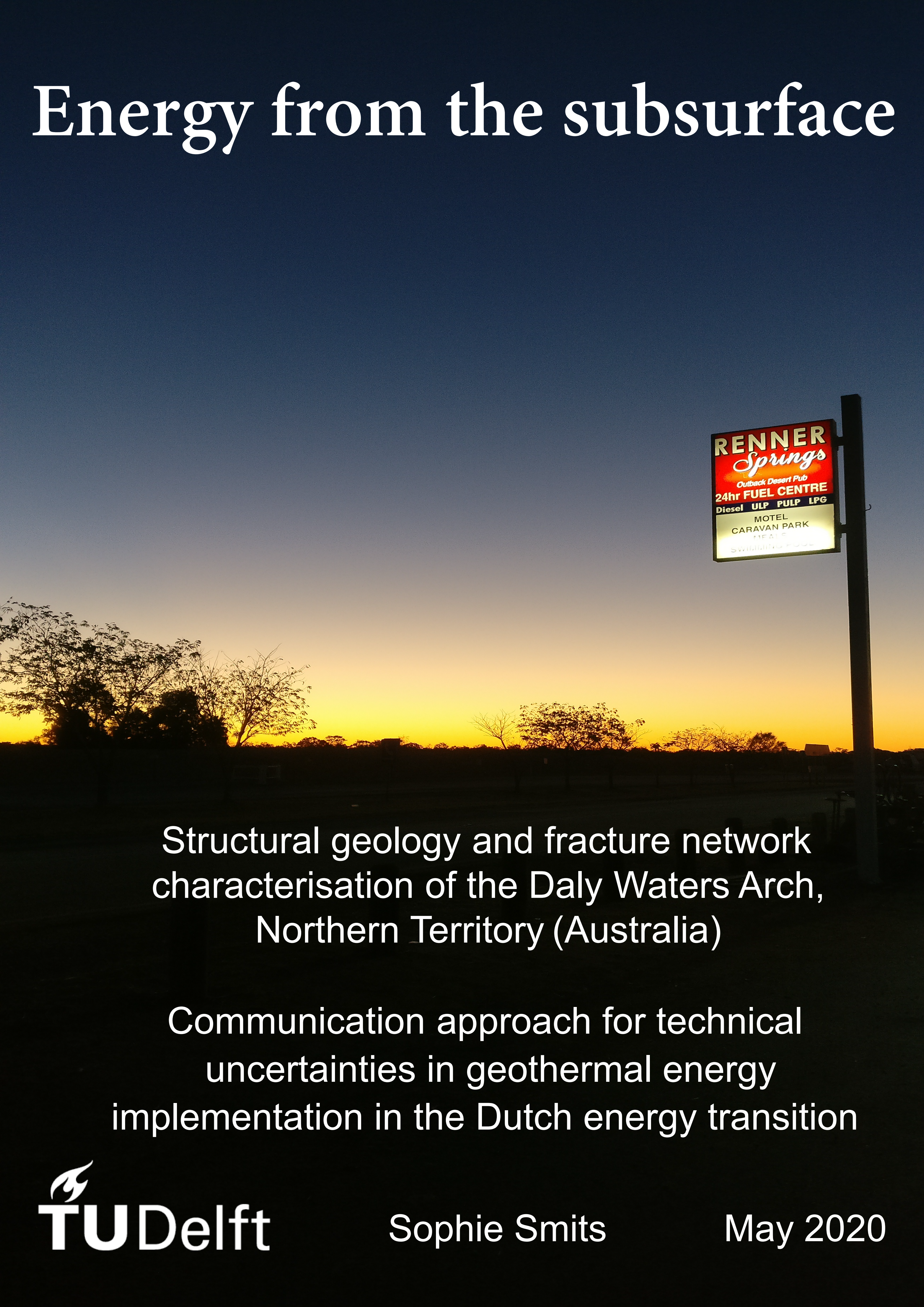
Energy from the subsurface



Structural geology and fracture network characterisation of the Daly Waters Arch, Northern Territory (Australia)

Communication approach for technical uncertainties in geothermal energy implementation in the Dutch energy transition

TU Delft

Sophie Smits

May 2020

Energy from the subsurface

Structural geology and fracture network characterisation of the Daly Waters Arch, Northern Territory (Australia)

Communication approach for technical uncertainties in geothermal energy implementation in the Dutch energy transition

by

Sophie Elisabeth Smits

in partial fulfilment of the requirements for the degree of

Master of Science
in Petroleum Engineering and Geosciences (specialisation Reservoir Geology)

and in partial fulfilment of the requirements for the degree of

Master of Science
in Science Education and Communication (specialisation Science Communication)

at Delft University of Technology, to be defended publicly on Thursday May 14th, 2020 at 03:00 PM.

Thesis committee Reservoir Geology:	Prof. dr. G. Bertotti,	TU Delft, section Applied Geology, supervisor
	Drs. J.C. Blom,	TU Delft, section Applied Geology, supervisor
	Dr. P.B.R. Bruna,	TU Delft, section Applied Geology, supervisor
	Drs. C. Wehrmann,	TU Delft, dep. of Science Education and Communication, committee member
Thesis committee Science Communication:	Drs. C. Wehrmann,	TU Delft, dep. of Science Education and Communication, supervisor
	Dr. ir. S.M. Flipse,	TU Delft, dep. of Science Education and Communication, supervisor
	Drs. J.C. Blom,	TU Delft, section Applied Geology, committee member
	Prof. dr. M.J. de Vries,	TU Delft, dep. of Science Education and Communication, committee member

An electronic version of this thesis is available at `http://repository.tudelft.nl/`.

Dr. Schürmannfonds
Universiteitsfonds Delft
Molengraaff Fund
NORTHERN TERRITORY GOVERNMENT

TU Delft

Preface

'No worries, mate!'

NOT only is this how many Territorians define their attitude towards everyone interested in the way they cope with issues in the Northern Territory, Australia; it was also one of the things I told myself multiple times during the one year that my life was dedicated to writing this thesis. And to be honest – I liked the process of writing a thesis more than I expected in advance.

This report contains the results of the two thesis studies that finalise the MSc–programs of Reservoir Geology and Science Communication. The first part of the report comprises the multi–scale data analysis of a) the large–scale architecture of the subsurface Daly Waters Arch which was obtained from seismic data interpretation; and b) fracture pattern characterisation by outcrop measurements and drone imagery in the Tomkinson Province. Both the Daly Waters Arch and the Tomkinson Province are located in the largely undeformed Palaeo– to Meso–Proterozoic Greater McArthur Basin in the Northern Territory, Australia. In July 2019, a geological fieldwork was conducted in the Tomkinson Province. Some of the photos that were taken during this fieldwork, are included in this report to mark the different parts of the document. The second part of the report focuses on the Netherlands, where ambitious goals have been set for the implementation of geothermal energy in the energy transition. During the gas production in Groningen, a negative social perspective towards mining operations, in general, was developed. For the implementation of geothermal energy, an approach for the communication of technical uncertainties between the initiators and the local public of a geothermal project is designed in this study.

Each of the two researches had its own process and timeline, but in this report everything comes together. Now that these two theses projects are coming to an end, I will defend my research to become a graduate of the Delft University of Technology. I enjoyed all the opportunities that Delft offered me during my development process that spanned over more than seven years. I will take all the experiences from my board year at C.S.R. Delft, the minor Education where I was taught how to be a teacher in Physics, several committees and many more social activities with me for the rest of my life. Equipped with all the scientific knowledge, friendships, self–reflections, critical attitude and enthusiasm for new things, I leave the Delft University of Technology. I feel ready for this next step and am curious to see what the future will bring me.

To you, the reader of this report, I would also like to say: *no worries, mate!* I hope you will enjoy reading this thesis and that you will celebrate my graduation with me!

Sophie Smits

Delft, May 8, 2020

Acknowledgements

BEFORE making a start with the 'real' contents of this thesis report, I would like to thank the people that guided me through this process. First of all, I would like to thanks my supervisors from the section Applied Geology at the faculty of Civil Engineering and Geosciences: Giovanni Bertotti, Jan Kees Blom and Pierre–Olivier Bruna. Many thanks for the interesting, lively discussion and feedback that you provided me with over the process. Giovanni, your expertise and knowledge about structural geology helped me with new insights when I was lost in all the puzzle pieces. Jan Kees, thank you that you were always interested to discuss the bigger picture of the graduation process, to keep me motivated and to help me never forget why I do this; because we just love geology. Thank you, Pierre, for all your time, ideas, motivation, feedback and experiences from Australia. You were a great daily supervisor, and despite your busy schedule of being a husband, a father of two daughters and a post–doc researcher, you always made time to provide me with feedback or to have a discussion. This thesis would not look the way it does without your help.

Many thanks to Caroline Wehrmann, my first supervisor of Science Communication. Our discussions always made me go back to what I thought was interesting or the path that I wanted to go. Thank you so much for our interesting discussions, your critical view when I was tossed around by many ideas and directions. Your feedback helped me to develop a curiosity for the profession of science communication that helped me to stay motivated throughout the process. Also lots of thanks to Steven Flipse as the second supervisor from Science Communication. The feedback you provided in the meetings we had always helped me to stay on the right track.

This thesis would not look the way it does without the help of the people from the Northern Territory Geological Survey in Darwin, Northern Territory, Australia. Dorothy Close, Tania Dhu, Ian Scrimgeour, Timothy Munson and Ben Williams, thank you for the data you provided and the interesting discussions we had during my stay in Darwin. Secondly, my stay in Darwin would not have been possible without the financial support of the Molengraaff Fund, the Dr. Schürmann Fund and the University Fund Delft. Thanks to all the people who helped me to be awarded these grants.

During my thesis project, I was lucky to be surrounded by amazing friends that helped me through both the times where I could use some support and the times when I wanted to celebrate a success. Vivian, Daniëlle, Lisann, Sophie, Eefje and Laura, thanks for all the moments of reflection and relaxing coffee, dinners or walks around the campus. Hanne, Wouter, Tom and Job, thanks for all the evenings of making music, allowing me to leave my thesis behind for a few hours. Linda, Martine, Rik, Bram, Jorrik, Lenny, Leon, Thijs and Marianne, thanks a lot for all the fruitful discussions, motivational speeches, coffee breaks and cookies at 'het afstudeerhok' at the faculty of TNW for the Science Communication part.

Almost last but not least, I would love to express my gratitude to my parents, sister and brother. You helped me during every phase of this thesis, but also with every step I took before this. Without your help, I would not be the person that I am today and I will take your education, support and knowledge with me in every step of my further life.

Lastly, I want to thank Yordi. You are the one who helped me to relax whenever I felt stressed and you encouraged in every step of this thesis. Your objectivity helped me stay focused on the right things. Thanks a lot for that.

Abstract Reservoir Geology

THE Greater McArthur Basin is a largely unmetamorphosed and relatively undeformed onshore Paleo– to Mesoproterozoic basin (~1000 km^2) located in the Northern Territory, Australia. The basin overlies the Archean rocks of the North Australian Craton and is in turn overlain by Phanerozoic cover rocks. The stratigraphy of the Greater McArthur Basin consists of five packages of carbonate and clastic rocks with a cumulative thickness up to 15 km. Two of these packages, the Glyde and Wilton Packages (respectively Paleo– to Mesoproterozoic of age), have a great potential for being both conventional and unconventional hydrocarbons resources. The Greater McArthur Basin contains the relatively undeformed Beetaloo sub–Basin (in the center) and the Tomkinson Province (to the south). The eastern boundary of the Beetaloo sub–Basin is flanked by the faulted and folded Batten Fault Zone, whereas the western side of this sub–basin is dominated by a N–S directed 4–40 km wide deformed area in the subsurface; the Daly Waters Arch. The structural history of the Daly Waters Arch (deformation observed in the subsurface by seismic data) and of the Tomkinson Province (deformation at the surface studied in bedding measurements and drone imagery) is poorly understood; therefore, this study focuses on the geological configuration and structural history of the formations of the Wilton and Glyde Package in the Daly Waters Arch and the Tomkinson Province. The first objective of this research is to determine a geological link between the Daly Waters Arch and the Tomkinson Province. The second purpose of this study is to examine a geological link between the Daly Waters Arch, the Tomkinson Province and the Batten Fault Zone. The third objective of this research is to determine if fracture patterns, observed in outcrops by conventional geological methods and drone imagery, show predictable configurations throughout the Tomkinson Province and whether these fracture configurations can be related to the large–scale architecture. This research forms the continuation of the NT–Work Project, in which the structural history of the Batten Fault Zone has been studied in 2018.

The Beetaloo sub–Basin is characterised by mainly flat–lying formations, whereas the boundaries of the Daly Waters Arch are characterised as being a change in dip angle of the formations and the probable existence of a fault zone in E–W directed seismic sections. In other words, the Daly Waters Arch is a deformed area compared to the Beetaloo sub–Basin. Based on seismic data analysis (both E–W and N–S directed) from the Daly Waters Arch, both folded and faulted structures were interpreted. Major thickness variations in formations along the E–W profile of the Arch are present in the Velkerri and Powell Formations (Wilton Package). The deformed area is narrow (4–40 km) compared to the width of the Beetaloo sub–Basin (>260 km) and is an isolated N–S directed structure. Ground measurements collected during fieldwork were used to construct geological cross–sections of the Tomkinson Province. Based on comparison of deformation patterns observed in the Daly Waters Arch and Tomkinson Province, the first conclusion of this research is that the Daly Waters Arch is the subsurface continuation of the Tomkinson Province. The deformation patterns present in the Daly Waters Arch and the Tomkinson Province have been compared to previous research and other relevant models on the deformation in the Batten Fault Zone. From this study, it is concluded that the Daly Waters Arch deformed area and the Batten Fault Zone do not share a geological origin, although they might have been influenced by the same syn– and post–Wilton Package deformation events. Faults (the Mallapunyah, Scrutton and Emu Faults, with displacements of more than 1,500 meters) play an important role in the configuration of the Batten Fault Zone, whereas no major faults have been observed in the Daly Waters Arch. Deformation in the Daly Waters Arch area is interpreted as being older than both the deposition and deformation of formations in the Batten Fault Zone.

Fracture measurements were collected from outcrops in the field and statistically analysed. Fracture networks become more complex at the limbs of a folded structure, whereas at the hinge of this structure the fracture patterns are simpler. Fracture characteristics – number of fractures, number of fracture sets, length, orientation, intensity (P21) and density (P20) – have been analysed for specific outcrops along a N–S profile in the Tomkinson Province. The fracture orientation is consistent for the Tomkinson Province, whereas the length and number of fractures per outcrop is more variable.

Altogether, the structural origin of the Daly Waters Arch deformed area is linked to movement in different directions during the Murchison (1815–1805 Ma) and Davenport (1790–1770 Ma) events, the Leichhardt (1780–1750 Ma) and Calvert (1750–1650 Ma) Extensions and the Isan Orogenies (1600–1500 Ma). It is concluded that the deformation in the Daly Waters Arch is a reactivation of older terrain boundaries; the reactivation of the basement terrain of Scarlett Hill.

Summary Science Communication

OVER the past thirty years, gas production from the Dutch Groningen field lost its required level of social acceptance, resulting in a production stop from 2022 onward. The lack of social acceptance developed as a result of ignorance of the financial and psychological damage due to earthquakes in the region and a lack of efficient communication with the local public. In the Dutch energy transition, ambitious goals have been set for the implementation of geothermal energy, which is classified as being a mining operation as well. For geothermal energy implementation in the Netherlands, the gas production in Groningen is the primary reference frame for safety and environmental issues in communication and policy–making processes.

Based on the future perspective of two geothermal wells per municipality in 2050 and the developed public resistance to gas production in Groningen, an approach for the communication process of the technical uncertainties between the initiators and the local public of the geothermal project needs to be designed. This communication approach offers the communicators of the initiators of a geothermal project a structured overview of the steps in the communication process and the choices that need to be made for an effective communication process towards the local public.

The main objective of this study is to design an approach for the communication of the technical uncertainties that are present in geothermal energy implementation between the initiators of a geothermal project and the local public, once the technical uncertainties and their influence on the level of social acceptance of the geothermal project have been identified. To achieve this research goal, two sub–objectives for this study have been defined: a) to provide an overview of technical uncertainties that are present in the implementation of geothermal energy, and b) to determine how these technical uncertainties influence the social acceptance of the implementation of geothermal energy in the Netherlands.

Based on the problem statement and research objectives described above, the following research question will be answered:

How can technical uncertainties that are present in the implementation process of geothermal energy be communicated by the initiators of a geothermal project to the local public in the perspective of the energy transition in the Netherlands, to increase the level of social acceptance when taking into account the social sentiments that have been developed with respect to the production of gas in the Netherlands?

To answer this research question, three research methods are applied. First, literature research was conducted to provide a theoretical framework of the energy transition, the role of uncertainty in transition processes and the link between technical uncertainties in transition processes and the level of public acceptance towards this transition. The literature study resulted in a communication model that served as a start for the design process of the communication approach. Second, desk research was conducted to provide the context of the study. Third, nine semi–structured expert–interviews have been organised to identify the technical uncertainties that are present in geothermal energy implementation. During the design process, verification discussions were organised with the interviewees, thereby providing new input for the communication approach.

In this study, 'safety perception', 'distribution of advantages / disadvantages' and 'utilities / necessities' have been identified as the three pillars that determine the level of social acceptance of the public towards geothermal energy implementation. The following technical uncertainties influence one or more pillars of social acceptance:

Safety perception	**Distribution advantages / disadvantages**	**Utilities / necessities**
(Induced) seismicity	Location of geothermal well	Ultra-deep geothermal energy
Well design, well integrity and corrosion	Noise, traffic and heavy equipment	

Safety perception	**Distribution advantages / disadvantages**	**Utilities / necessities**
Unfamiliarity with the subsurface: temperatures, injection pressures and reservoir integrity	Co-production of chemicals, radioactive material, oil and/or gas	
Co-production of chemicals, radioactive material, oil and/or gas	Connection to locally produced heat	
The use of hydraulic stimulation of the reservoir		

Based on these pillars of social acceptance and the technical uncertainties, an approach for the communication of technical uncertainties between the initiators of a geothermal project to the local public has been designed. The decision for the design of a communication approach was made to find the middle between a generic communication model applicable in each type of conversation, and a communication plan that is only applicable in specific situations of geothermal energy implementation. The approach offers guidelines and arguments, but also leaves room for own choices and interpretations.

The communication approach consists of five main elements:

1. **Context and goal:** the context for the communication approach is the level of social acceptance of geothermal energy implementation, and the goal is defined as *'to communicate the different technical uncertainties that are present in the geothermal project in order to increase the level of social acceptance of geothermal energy implementation'*.
2. **Message:** the message that will be communicated in the approach are the technical uncertainties linked to the level of social acceptance.
3. **Communicators:** The initiators and the local public are appointed as communicating actors in the communication process. The communicating initiators of a geothermal project are representatives of the Ministry of Economic Affairs and Climate Policy, the municipality, the operators and States Supervision of Mines.
4. **Reference frames of the communicators:** the reference frames from which these communicators participate in the communication process have been described in link with the concepts of procedural and distributional justice, and the level of trust.
5. **Situation description:** the situation description was described in four different elements: a) the stakeholders involved in the geothermal project, b) the communication channels and noise, c) the timeline of the technical project and the communication process, and d) the setting in which the communication process takes place.

Fresh Orange Juice
Freshly squeeze orange juice
6.5
Watermelon Fresh Crush
Freshly crushed watermelon juice
6.5
Watermelon & Lychee Crush
8.5
Mango* Lemonade
Lychee Soda Crush with coconut water +
8.5
8.0
Cucumber Mint Lemon & Lime Mockarita
9.5
9.0
Avocado Smoothie
Mango* Smoothie
8.5
Juice of the Day*
8.5
Kombucha
8.5
8.5
Soft Drin
Sprite
Noah Juices
Aloe Vera Juice
Lychee/ Peach
Pepsi Glass Bottle
Pepsi Max 600ml
Gatorade 600ml
Monuntain Drew 600ml
Real Iced Tea 500ml
Red Bull
Tonika Kombucha
Capi Sparkling Mineral/ Soda Water

Contents

List of Abbreviations

ATES .... Aquifer Thermal Energy Storage
BFZ.......................... Batten Fault Zone
BTES .... Borehole Thermal Energy Storage
BSB.......................... Beetaloo sub-Basin
DGE .... Deep Geothermal Energy
DWA......................... Daly Waters Arch
EBN .... Energie Beheer Nederland
EP .... Exploration Permit
EZK .... Ministry of Economic Affairs and Climate Policy
GHG......................... Greenhouse Gas
GIIP .... Gas Initially In Place
GSHP........................ Ground Source Heat Pumps
GTE .... Geothermal Energy
HTE .... Hydro thermal Energy
HTS .... High Temperature Storage
Hydraulic fracturing .... Fracking / fraccing
KNMI........................ Royal Dutch Meteorological Institute
MAB......................... McArthur Basin
NAC .... North Australian Craton
NAM......................... Nederlandse Aardolie Maatschappij (Dutch National Oil and Gas Company)
NIMBY .... Not In My Backyard
NT........................... Northern Territory
SodM........................ Staatstoezicht op de Mijnen (States Supervision of Mines)
SGE.......................... Shallow Geothermal Energy
SPG.......................... Stichting Platform Geothermie
SQ .... Sub–question
TP .... Tomkinson Province
UDG......................... Ultra–Deep Geothermal
UTES........................ Underground Thermal Energy Storage
WFZ......................... Walker Fault Zone

List of Figures

List of Tables

Introduction to this report

THIS report is the product of one year of research (March 4th, 2019 – May 14th, 2020) at Delft University of Technology and embodies the final results of two research projects. In Part I, a characterisation of geological deformation structures in the Beetaloo sub–Basin is provided, followed by the results of the Science Communication research in Part II.

The two parts of this report converge to one common denominator: energy production in the future. In the Reservoir–Geology part, deformation patterns in gas–bearing geological formations in both the subsurface and the surface are studied in two geological areas: the Daly Waters Arch and the Tomkinson Province. In the second part of this report, an approach for the communication of technical uncertainties, present in geothermal energy implementation in the Netherlands, between the initiators of a geothermal project and the local public will be designed.

Geological research, conducted over the past decade by both the Northern Territory Government and the gas industry in Australia, showed the great potential for unconventional gas production in especially the Beetaloo sub-Basin [Jarrett *et al.*, 2019; Sheridan *et al.*, 2018; Silverman and Ahlbrandt, 2011; Yang *et al.*, 2018]. Due to a constantly increasing global energy demand, especially due to the rapid development of developing countries [Asif and Muneer, 2007], the production of shale gas from the Beetaloo sub-Basin might play a role in the energy transition, as renewable energy is still not produced at the same scale as conventional (fossil) fuels [Russell-Jonas; Safari *et al.*, 2019; Stephenson *et al.*, 2012]. A large part of the subsurface of the Northern Territory is part of the Greater McArthur Basin [Ahmad and Munson, 2013b; Ahmad *et al.*, 2013; Rawlings, 1999]. This ~1000 km^2 large Paleo– to Mesoproterozoic series of stacked basins [Bruna *et al.*, 2016] contains, amongst other sub–basins [GPM Metals Inc., 2019], the Beetaloo sub-Basin. Over the past decade, large onshore shale gas reserves (over 118 trillion cubic feet) have been found in the formations of the Beetaloo sub–Basin [Jarrett *et al.*, 2019]. Within the Beetaloo sub–Basin, a N–S directed zone of deformation, including the Daly Waters Arch and the Tomkinson Province has been observed by seismic data analysis [Frogtech Geoscience, 2018; Hoffman, 2016]. However, the exact geometry of this deformed area is still poorly understood. Therefore, the objective of this research is to provide an overview of the structural geometry of the Daly Waters Arch and the Tomkinson Province in the Beetaloo sub-Basin. Data have been collected at multiple scales; a) seismic data in the Daly Waters Arch provided information about the deformation in the subsurface at the scale of kilometers to hundreds of meters, and b) at the surface of the Tomkinson Province, where satellite imagery provided information about the scale of hundreds of meters; drone imagery provided information at ten's of metres scale and conventional structural geological fieldwork methods at selected ground stations provided information at the meters scale.

By interpreting and comparing the results of multi–scale data analysis, an overview of a) the extent of; and b) the geometries of formations in these deformed areas both at the surface (Tomkinson Province) and in the subsurface (Daly Waters Arch) will be provided. Secondly, ideas about the link between these two areas, fracture characteristics in the Tomkinson Province and a possible link to the Batten Fault Zone – located at the eastern boundary of the Beetaloo sub–Basin – will be discussed.

The fact that Australia will start producing gas from the unconventional gas reservoir led to an opposition to gas production in the Beetaloo sub–Basin by the population of the NT [Lock the Gate Alliance, 2019; The Scientific Inquiry into Hydraulic Fracturing in the Northern Territory, 2018]. In the scarcely populated areas of the Northern Territory (the total population of the Beetaloo sub-Basin is about 1000 people, ~ one person per 21 km^2 [Australian Bureau of Statistics, 2018; Fulton and Knapton, 2015]), the share of Indigenous Australians in the total population is relatively large; in 2016, 29% of the total population of the NT was of Aboriginal origin, compared to 2.9% of the total population in New South Wales [Australian Bureau of Statistics, 2016, 2018]. In Aboriginal religion and culture, the connection to the sacred land of the population and its ancestors plays a very important role [Murray Berndt, 1974]. These cultural bonds to the land of the Northern Territory, combined with the complex history of the colonisation of the Northern Territory by western societies [Central Land Council; Roberts *et al.*, 1994] between ca 1890–1960, make the activities of hydrocarbon extraction from the subsurface in the Northern Territory a rather sensitive topic. A second motivation for the opposition was the production method to extract the shale gas from the reservoir; hydraulic fracturing will be applied to break the rock and increase the gasflow through the reservoir [Bardon, 2019; The Scientific Inquiry into Hydraulic Fracturing in the Northern Territory, 2016]. Over the last years, the opposition towards the gas production led to a moratorium on all shale gas activities by the industry in the Northern Territory [Cox, 2018]. During the moratorium, a two-years Scientific Inquiry was in place to investigate the potential risks and impacts of shale gas activities on different aspects of the Northern Territory [The Scientific Inquiry into Hydraulic Fracturing in the Northern Territory, 2019a]. After two years, in 2016, the moratorium was lifted on the condition that 135 recommendations [The Scientific Inquiry into Hydraulic Fracturing in the Northern Territory, 2019b] – regarding technical, geological, cultural, cadastral, and other impacts and risks – that were announced by the Inquiry would be implemented by the Northern Territory government before the actual production processes could recommence.

Once back from the fieldwork in the NT, the focus of the research shifted towards the Netherlands where gas production in the northern province of Groningen led to induced seismicity and an increased opposition towards gas production and mining operations in general [De Telegraaf, 1986; Rijksoverheid, 2018; Van der Voort and Vanclay, 2015; Van Thienen-Visser and Breunese, 2015]. At the same time, technologies for producing geothermal energy from the subsurface have a crucial role in the Dutch energy transition [Kemp and Loorbach, 2005; Provoost *et al.*, 2019; Staatstoezicht op de Mijnen, 2017] to meet (inter)national climate goals that include the production of sustainable energy [Europa Decentraal, 2016; European Commission, 2019; Klimaatakkoord, 2019a; Rijksoverheid, 2019b; SER, 2013].

Therefore, research is conducted to identify the technical uncertainties that are present in geothermal energy implementation in the Netherlands, and an approach for the communication of these uncertainties from the initiators of a geothermal project to the local public in the context of the level of social acceptance of geothermal energy will be designed. This communication approach provides an overview of the steps and choices that need to be considered by the communicating actors. The recent opposition to gas production in the Netherlands forms an interesting social perspective in this research.

I

Structural geology and fracture network characterisation of the Daly Waters Arch, Northern Territory (Australia)

1
Introduction

1.1. Rationale of this study

THE formations of the Beetaloo sub-Basin **(BSB)**, one of the sub–basins of the Greater McArthur Basin **(MAB)** in the Northern Territory **(NT)**, Australia (Figure 1.1), contain more than 118 trillion cubic feet of (unconventional) shale gas in place [Jarrett *et al.*, 2019]. Over the last decade, the global interest in the Beetaloo sub-Basin unconventional gas reservoirs has been increasing [Silverman and Ahlbrandt, 2011]. The geological setting of the Daly Waters Arch **(DWA)** and the Tomkinson Province **(TP)** (Figure 1.1), two structures in the Beetaloo sub-basin, is poorly understood.

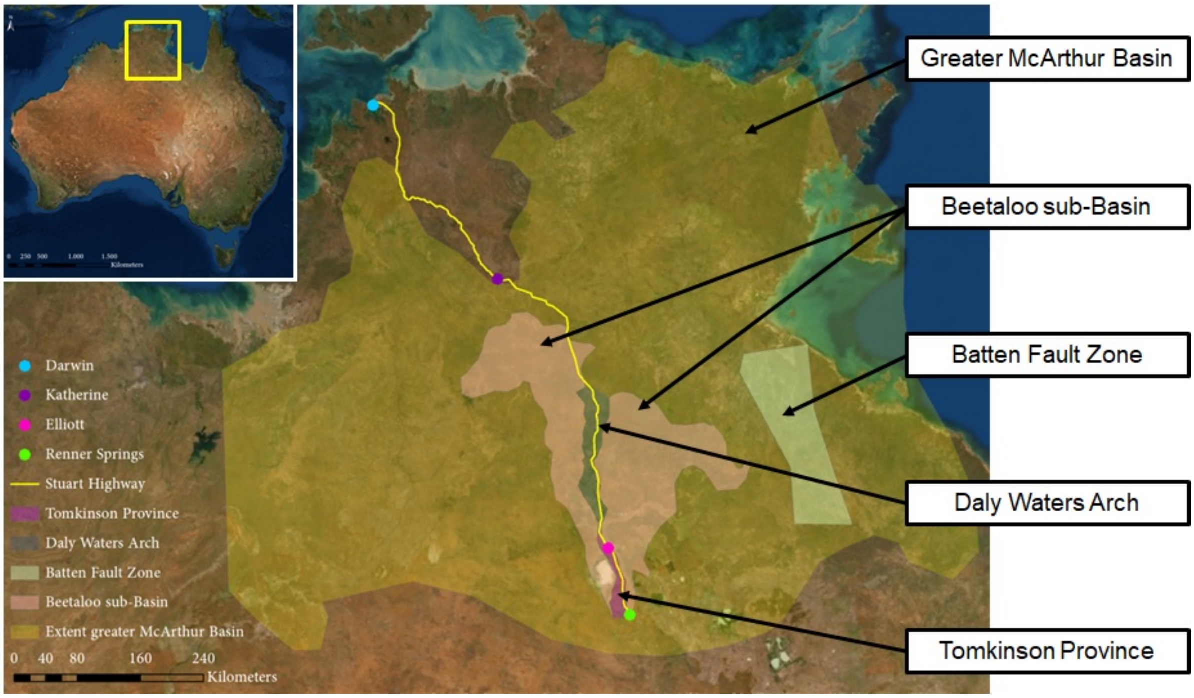


Figure 1.1: Location of the Beetaloo sub–basin, the Daly Waters Arch, the Tomkinson Province and the Batten Fault Zone in the Greater McArthur Basin.

Since 2017, the NT–work project focused on the geometry and reservoir potential of the Greater McArthur Basin. In 2018, research was conducted on the fracture geometry and multi–scale deformation in the Batten Fault Zone **(BFZ)** [Pragt, 2018]. To complement the overall understanding of the deformation areas in the Greater McArthur Basin, the research area was extended towards the westerly located Daly Waters Arch and Tomkinson Province in 2019. In a larger context, understanding the large–scale architecture of the Daly Waters Arch and the Tomkinson Province will provide information on basin–forming mechanisms.

Three research questions will be answered in this study:

1. What is the geological link between the Daly Waters Arch and the Tomkinson Province?
2. What is the geological link between the Daly Waters Arch area and the Batten Fault Zone area?
3. What information do fracture patterns observed at outcrops in the Tomkinson Province provide to make predictions for the subsurface in the large–scale architecture of the Greater McArthur Basin?

To answer these research questions, multi–scale data sources (seismic data, fracture data from measurement stations in the field and fracture data provided by drone imagery) were interpreted.

1.2. Reading guide

In Chapter 2, an overview of the geological setting of the McArthur Basin and the Beetaloo sub–Basin as part of the Greater McArthur Basin is provided. In this chapter, a review of existing literature on fracture drivers and fracture patterns in outcrops is included. In Chapter 3, the results of seismic and fieldwork data analysis are provided, leading to an overview of the present–day architecture of the Daly Waters Arch and the Tomkinson Province. Fracture data collected during the fieldwork are analysed to provide an overview fracture patterns that are present in the Tomkinson Province; drone imagery was used to describe the fracture characteristics, i.e. lengths, orientations, number of fractures and fracture sets. The results are interpreted in Chapter 4, leading to a 3D model of the folded formations in the Daly Waters Arch and the Tomkinson Province. In the second part of Chapter 4, the results will be discussed and linked to existing models to provide a model for the processes that control the fractures in the Daly Waters Arch and the Tomkinson Province. Lastly, the answers to the three research questions and recommendations will be provided in Chapter 5.

2

Geological setting

GREATER McArthur Basin (Figure 2.1) is the informal term for a predominantly sedimentary terrain which stretches across the northern part of the Northern Territory from northeastern Western Australia to northwestern Queensland [Munson, 2016b]. The Greater McArthur Basin (area of approximately 500,000 m^2 [Ahmad *et al.*, 2013], comparable to the size of Spain) comprises the Palaeo– to Mesoproterozoic rock successions of the McArthur Basin, the Birrindudu Basin and the Beetaloo sub–Basin [Munson *et al.*, 2018]. Previous research indicates the presence of an arch–shaped N–S trending deformation zone in the subsurface of the Beetaloo sub–Basin [Close *et al.*, 2016; Frogtech Geoscience, 2018; Hoffman, 2016; Silverman and Ahlbrandt, 2011]: the Daly Waters Arch (Figures 2.1 and 2.2).

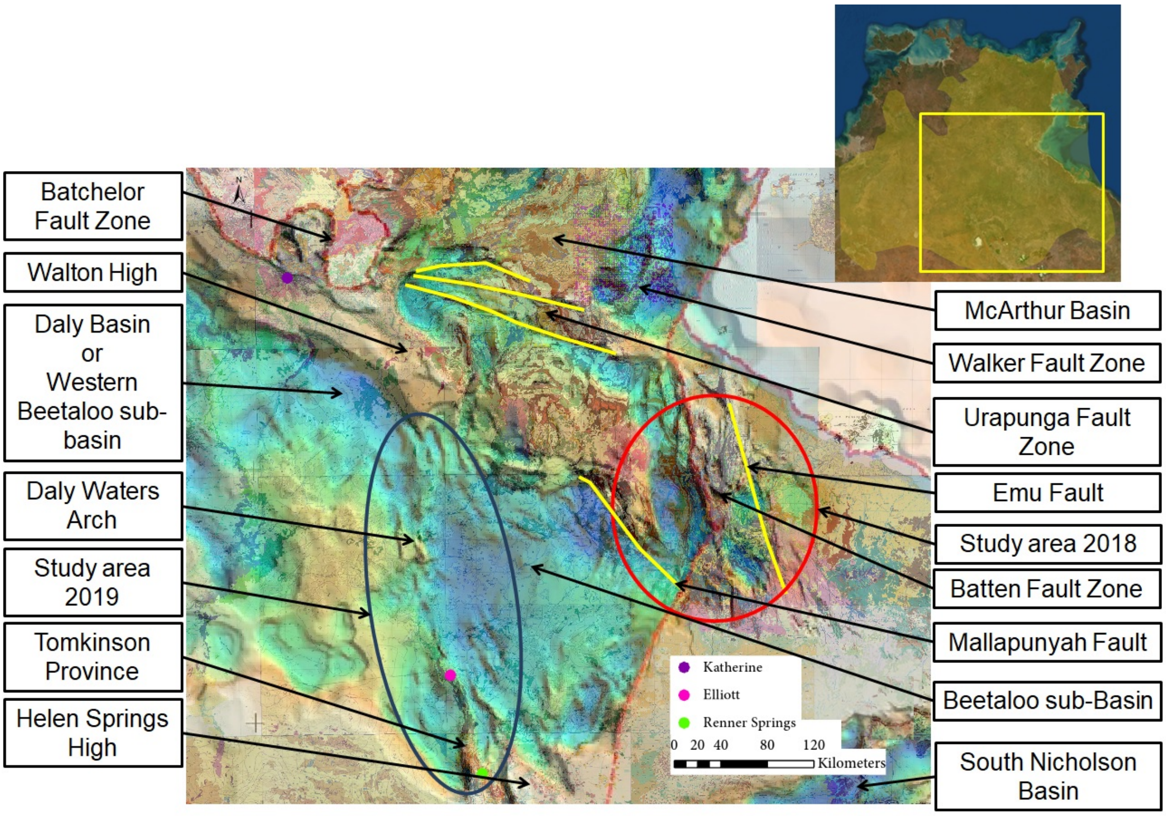


Figure 2.1: The gravity map of the Greater McArthur Basin, overlain by the geological map of the Northern Territory. In the figure, relevant sub–basins, fault zones and faults are shown. The study area of 2018 research in the NT-Work project in located by the red circle, the blue circle represents the study area of the current research. Image modified from [Origin Energy, 2017].

The Daly Waters Arch (study area of 2019, Figure 2.1) is located approximately 260 km to the west of the Batten Fault Zone (study area 2018, Figure 2.1); the two deformed areas are separated by the generally undeformed Beetaloo sub–Basin (Figure 2.2).

The successions of the Greater McArthur Basin unconformably overlie Archaean and Palaeoproterozoic deformed and metamorphosed successions of the North Australian Craton **(NAC)**, and they are in turn unconformably overlain by the Neoproterozoic to Phanerozoic cover rocks (Figure 2.3) or the sea (the Arafura Sea and the Gulf of Carpentaria) [Munson *et al.*, 2018]. The Greater McArthur Basin presents three prominent fault zones: the N–trending Batten Fault Zone and the NE–SW trending Walker Fault Zone **(WFZ)**. These two fault zones are separated by the east-trending Urapunga Fault Zone (**UFZ**) [Rawlings *et al.*, 2004] (Figure 2.1). The Urapunga Fault Zone intersects the northern part of the Greater McArthur Basin from the Beetaloo sub–Basin [Hunter, 1981; Pragt, 2018; Rawlings, 1999]; the Batten and Walker Fault Zones are interpreted to have been formed within intracontinental rift structures [Rawlings, 1999].

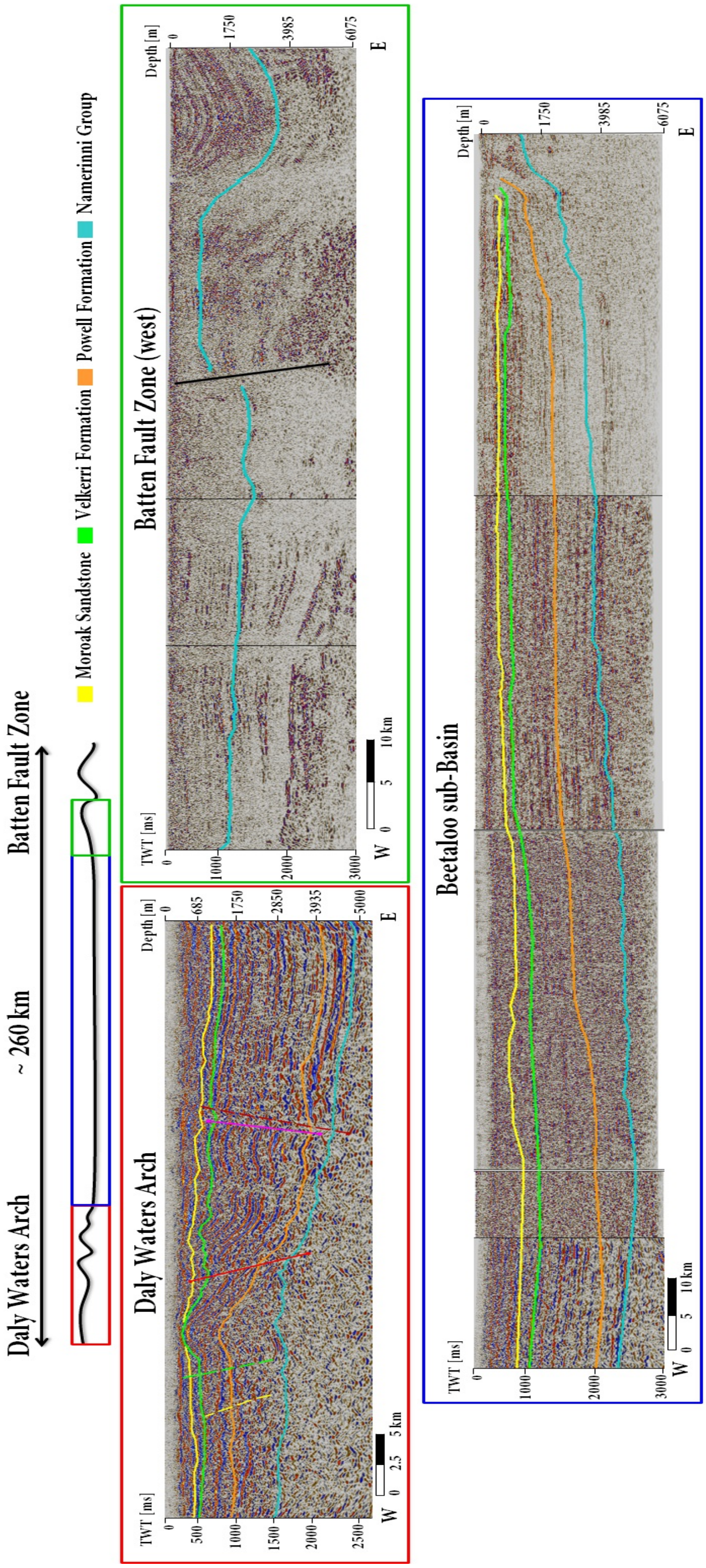


Figure 2.2: Seismic cross–section from the Batten Fault Zone (east) to the Daly Waters Arch across the Beetaloo sub–Basin.

2.1. Stratigraphy of the Greater McArthur Basin

In the Greater McArthur Basin, a series of sub–basins is preserved beneath a regional Cambrian Unconformity (Figure 2.1) [Sheridan *et al.*, 2018]. In literature, the packages and formations of the McArthur Basin are given different names, which are assigned depending on where the rocks are deposited (Figure 2.3).

The stratigraphy of the Greater McArthur Basin consists of four Palaeoproterozoic carbonate packages: the Redbank Package (equivalent to Tomkinson Creek Group in the Tomkinson Province), Glyde Package (equivalent to Namerinni Group in the Tomkinson Province) and Favenc Package (absent in Tomkinson Province), which are capped by the Mesoproterozoic rocks of the Wilton Package (equivalent to Roper Group in the Beetaloo sub–Basin and Renner Group in the Tomkinson Province) (Figure 2.3). The total preserved thickness reaches up to 15 km [Ahmad *et al.*, 2013]. The Kyalla and Velkerri formations (Roper Group) are prospective for the production of unconventional gas in the Beetaloo sub–Basin (Figure 2.3) (Section 2.4). Each sedimentary package is separated by a major unconformity, which can be associated with a major basin inversion event [Betts *et al.*, 2015b].

The four packages that are relevant for this research are, in reverse stratigraphical order:

- The **Redbank Package** (ca. 1815–1710 Ma, 2.5–6 km thick) is the oldest package in the McArthur Basin. The package mainly comprises a sequence of shallow marine to fluvial sandstone [Rawlings, 1999]. The depositional environment is an intertidal environment, with lesser lacustrine deposits in which volcanic intrusions are found [Rawlings, 1999]. In the Batten Fault Zone, the package is unconformably overlain by the Glyde package; on the western shelve of the Batten Fault Zone (the Beetaloo sub–Basin), the Glyde package is absent and the Redbank Package is generally unconformably overlain by the Favenc and Wilton Packages, or even younger cover rocks [Rawlings, 1999].

- The **Glyde Package** (ca. 1670–1600 Ma, 0–5 km thick) is equivalent to the Namerinni Group in the Tomkinson Province [Ahmad and Munson, 2013a; Rawlings, 1999]. The sedimentary rocks of these packages comprise cyclical stromatolitic and evaporitic dolostone, fine siliciclastics and minor sandstone. Igneous rocks are recognized in minor tuffaceous components to some lutites. The depositional environment is shallow to deep water. Depocentres are found in the Walker, Batten and Urapunga Fault Zones. In the Walker and Batten Fault Zone, the package is assumed to be trough–confined [Rawlings, 1999].

- The **Favenc Package** (ca. 1600–1570 Ma, 50–1600 meters thick) is absent in the Tomkinson Province [Ahmad and Munson, 2013a; Frogtech Geoscience, 2018; Rawlings, 1999]. The package comprises cyclical stromatolitic rock, dolostone and sandstone including minor conglomerates. The depositional environment is assumed to be shallow–water to marginal marine [Rawlings, 1999].

- The **Wilton Package** (ca. 1500–1400 Ma, 1–5 km thick) is time–equivalent to the Roper Group (Beetaloo sub–Basin) and the Renner Group (Tomkinson Province) [Munson, 2016a; Revie, 2017]. The Wilton Package is made up of cyclical fine– and coarse–grained siliciclastics and includes some minor conglomerates and carbonates. The depositional environment is shallow marine, located nearshore to shelf [Rawlings, 1999]. The Wilton Package thins towards the Batten and Urapunga Fault Zones and has a depocentre in the Beetaloo sub–Basin [Frogtech Geoscience, 2018].

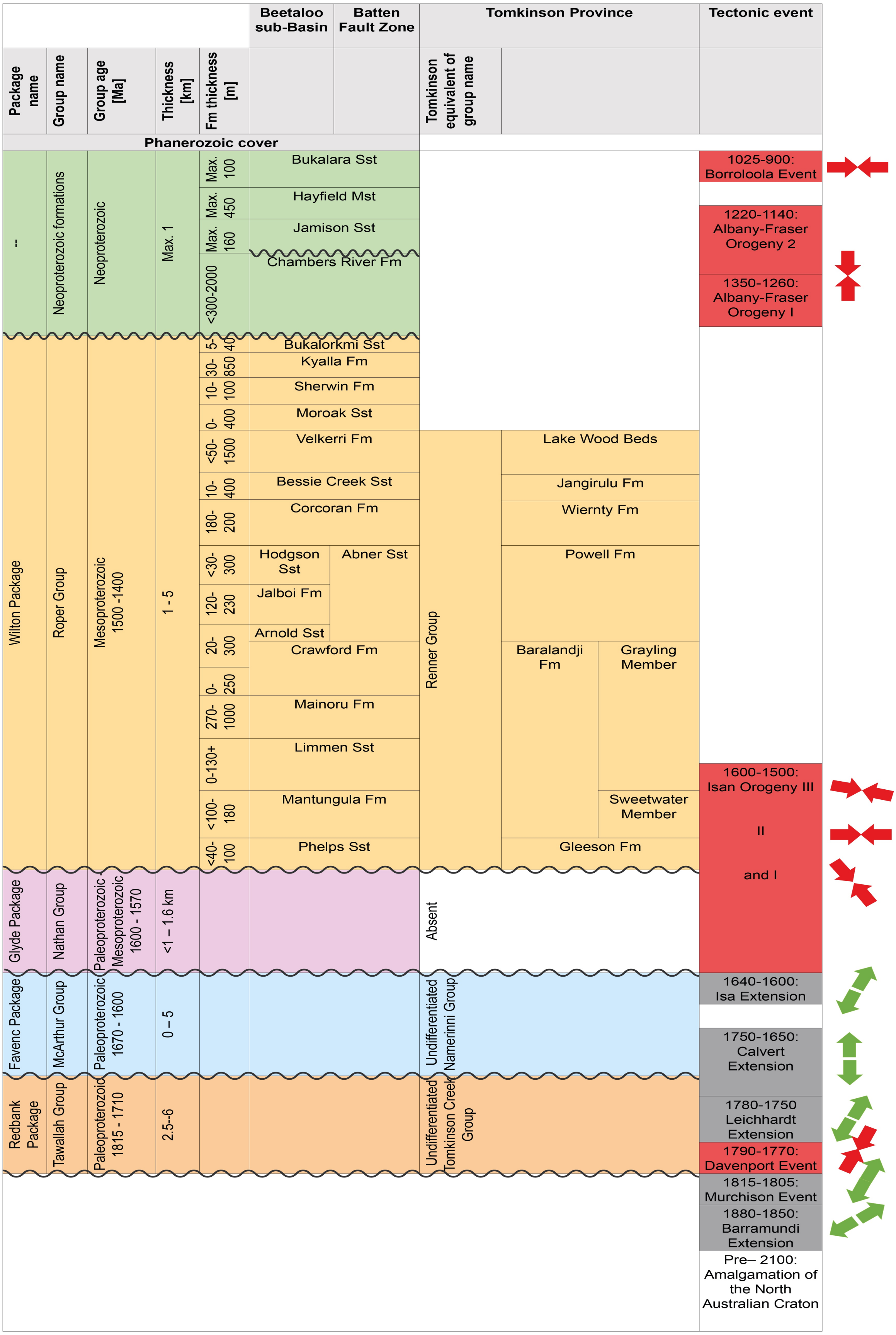


Figure 2.3: Combined stratigraphy of the Greater McArthur Basin. Modified from literature [De Vries et al., 2008; Frogtech Geoscience, 2018; Pragt, 2018; Rawlings, 1999]. Tectonic events and the present stress regimes are displayed on the right side of the figure.

2.2. Present–day setting of the Beetaloo sub–Basin

OVER the western flank of the Batten Fault Zone, the Beetaloo sub-Basin (Figure 2.1) extends over an area of 15,000 km^2 – roughly the same area as ⅓ of the surface area of the Netherlands. The northern boundary of the Beetaloo sub–Basin is marked by the Walton High and the northwest–trending Mallapunyah Fault [Yang *et al.*, 2018], whereas the southern boundary of the basin is marked by the Helen Springs High (Figure 2.1). According to geophysical data, these basement highs are fault–related [Betts *et al.*, 2015b; Yang *et al.*, 2018]. About 250 km to the west of the Batten Fault Zone, a second major deformed area has been observed in seismic data [Close *et al.*, 2016; Frogtech Geoscience, 2018; Hoffman, 2016] (Figure 2.2). The Daly Waters Arch stretches for about 300 km from north to south parallel to and separated from the Batten Fault Zone by about 260 km of basin geometry where no deformation is observed from both satellite and seismic data (Figure 2.2). On satellite imagery, only the Phanerozoic cover can be observed, which appears to be undeformed. This can be verified by the geological map of the Daly Waters Arch area [Randal *et al.*, 1969a], which does not show rocks older than the Lower Cambrian period. In the Beetaloo sub–Basin, a thick (exceeding 3,500 meters), essentially flat–lying succession of the Roper Group has been deposited [Ahmad *et al.*, 2013; Yang *et al.*, 2018] (Figure 2.2). The Roper Group is unconformably overlain by the Neoproterozoic Jamison Sandstone and the Hayfield Mudstone [Ahmad *et al.*, 2013] (Figure 2.3).

2.3. Geological history of the Roper Group in the Beetaloo sub–Basin

MULTIPLE superimposed tectonic events (Figures 2.3 and 2.4) led to the present–day geometry of the Daly Waters Arch.

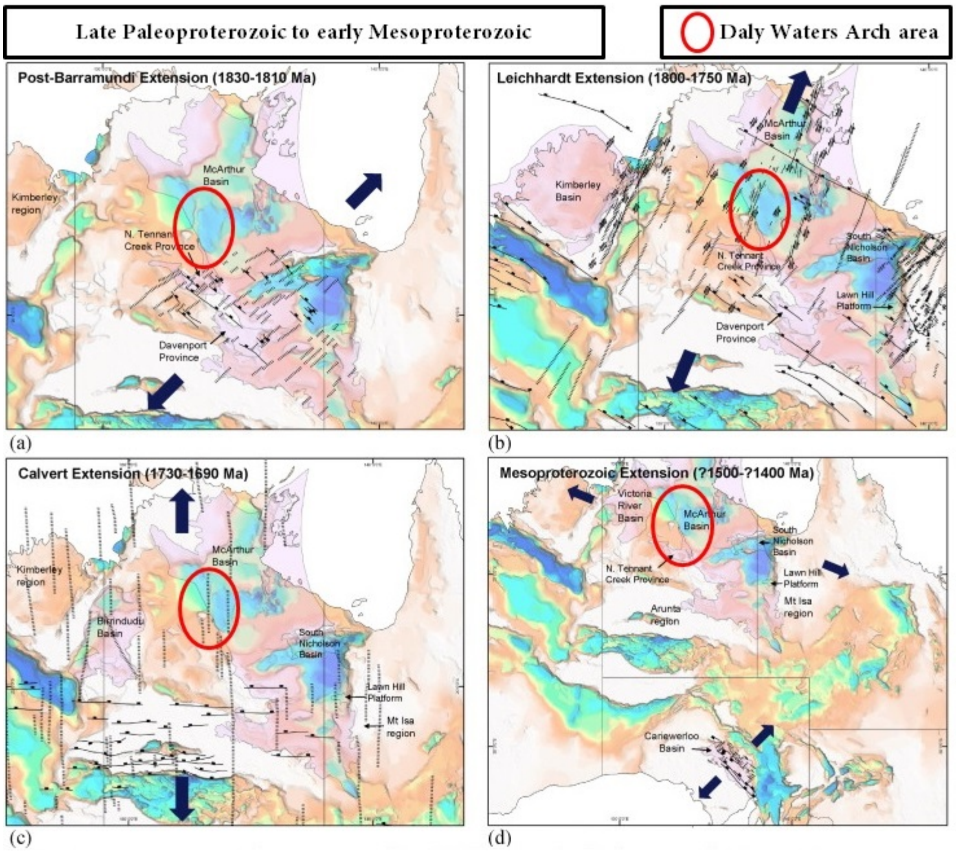


Figure 2.4: Major deformation events in the Northern Territory with the Daly Waters Arch marked by the red circle. Image modified from [De Vries et al., 2008].

After the deposition of the Glyde and Wilton Packages in the Greater McArthur Basin (ca. 1670–1400 Ma) mainly NW–SE and NE–SW directed extensional stress regimes were active in the area. The final stage of inversion is related to the assembly of Rodinia at ca. 1300–1000 Ma [Duddy *et al.*, 2004; Dutkiewicz *et al.*, 2005; Hoffman, 2016]. The structural inversion postdated the intrusion of the dolerite sill (ca. 1325 Ma), of which the emplacement is associated with east–west extension of the Roper Group [Dutkiewicz *et al.*, 2005] during the Albany–Fraser Orogeny (Figure 2.3). The Albany Fraser Orogeny is related to the assembly of the West Australian and the combined South Australian – East Antarctic Cratons [Clark *et al.*, 2000]; this deformation phase resulted in structural reactivation, including wrench–faulting and gentle folding of the overlying rocks [Dutkiewicz *et al.*, 2005]. Since ca. 1000 Ma, the area has experienced relative stability and slow erosion [Dutkiewicz *et al.*, 2005].

2.4. Reservoir potential of the Greater McArthur Basin

THE organic–rich mudrocks of the Greater McArthur Basin have the potential to generate conventional oil and gas deposits, and self–sourced shale oil and shale gas reservoirs are present [Jarrett *et al.*, 2019]. The reservoir potential of the Greater McArthur Basin is summarised in Figure 2.5 [Ahmad and Munson, 2013a,b].

- **Reservoir rock:** at least seven good potential reservoir units have been identified [Ahmad and Munson, 2013a] in the interval from the Bessie Creek Sandstone to the Bukalara Sandstone. The Bessie Creek, Moroak, Jamison and Bukalara Sandstones and thin sandstone intervals within the Velkerri and Kyalla Shales and the Hayfield Mudstone serve as accumulation zones as these formations have both source rock and unconventional reservoir potential [Ahmad and Munson, 2013b].
- **Source rock:** the Upper Kyalla Formation has the potential for unconventional oil production [Ahmad and Munson, 2013b]. Other significant source rocks include the Barney Creek Formation of the Glyde Package, and formations in the Redbank Package [Jarrett *et al.*, 2019].
- **Trap:** structural and diagenetic traps in the Bessie Creek Sandstone and stratigraphic traps in the Hayfield Mudstone form the areas where hydrocarbons accumulate in the Beetaloo sub–Basin [Ahmad and Munson, 2013b].

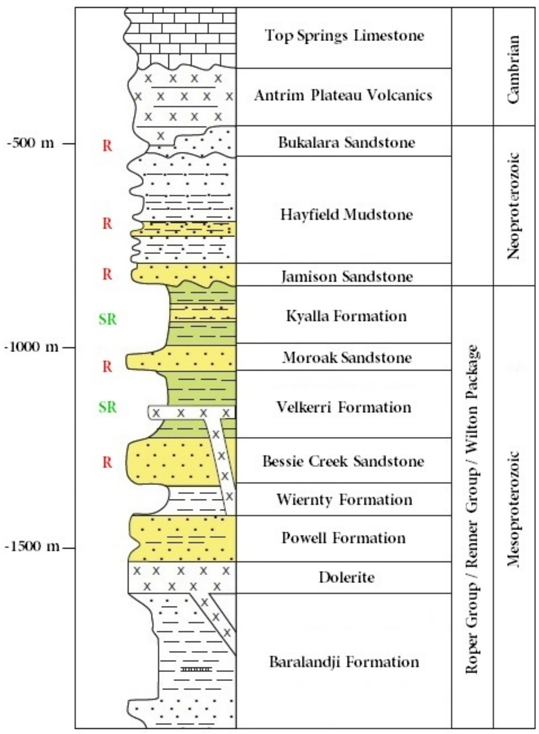


Figure 2.5: Stratigraphic column showing the Renner Group and the overlying Neoproterozoic and Cambrian rocks. R = conventional reservoir, SR = source rock and unconventional reservoir. Image modified from Geology and mineral resources of the Northern Territory (2013), compiled by A. Ahmad and T.J. Munson [Ahmad and Munson, 2013a].

- **Seal:** the Kyalla Shale and Hayfield Mudstone locally act as a seal for the accumulation of hydrocarbons [Ahmad and Munson, 2013b].

2.5. Fractures and their drivers

FRACTURES act as discontinuities in subsurface rocks that affect the strength and permeability of the rock [Bisdom, 2016]. Open fractures are natural pathways for fluids (e.g. hydrocarbons) flowing through rock [Bisdom, 2016; Wilkins, 2007; Zeeb *et al.*, 2013]; cemented fractures form an obstacle for efficient fluid flow [Gale *et al.*, 2014]. Subsurface data only (seismic and well data) are not sufficient to fully characterise fractures, as the resolution of seismic data is too large and well data is too sparse to capture the distribution of fractures. Results of outcrop analogues can be used to complement the subsurface data and thereby provide characteristics of the fractures that could not be obtained from seismic or well data (such as fracture length, spacing and orientations) [Bisdom, 2016]. One limitation of outcrop analogues for fracture characterisation is that the variables for fluid flow in the rock, such as stresses, apertures and fracture geometry have been changed due to the mechanical unloading of overlying material during exhumation [Amadei *et al.*, 1987; Bisdom, 2016]. Fracture network geometries can be studied at outcrops. To make predictions about the behaviour of fractures in the subsurface from outcrop analogues, ideas about how fractures develop in the subsurface and what their relation is to stress directions should be provided first. Fractures develop as a result of certain drivers. Four types of fracture drivers are [Bisdom, 2016; Bourbiaux *et al.*, 2002; Lamarche *et al.*, 2018] (Figure 2.6):

1. Far–field stresses [Bisdom, 2016; Lamarche *et al.*, 2018]; stresses associated with plate tectonic stresses.

2. Fold–related stresses [Gholipour *et al.*, 2016; Stephenson *et al.*, 2007]. Fractures can be related to two types of stress: a) fiber stresses, where deformation is concentrated in the hinge [Cosgrove, 2015] (A in Figure 2.6), and b) flexural slip between layers, when the deformation is the highest in the flanks of the fold (B in Figure 2.6).

3. Regional stress changes related to faults [Fischer and Jackson, 1999]. Faults influence the regional stress fields, thereby potentially leading to fracturing at the following locations: a) relative to the fault in the high stress, low strain region at the tip of the propagating fault (H in Figure 2.6), and b) along the fault itself, due to frictional processes (D in Figure 2.6). inenumerate

4. Burial–related fractures [Bisdom, 2016; Frydman *et al.*, 2016]. Regional fracture systems can be created by burial events; the mass of the overlying material increases the stress in the underlying rocks and creates fractures. Even shallow burial events can cause these fractures to occur.

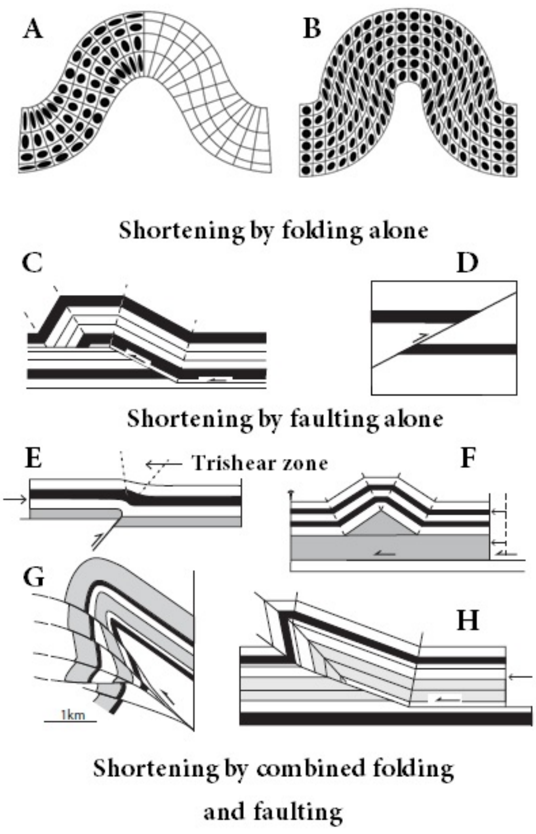


Figure 2.6: Types of folding and faulting due to horizontal shortening: (**A**) folding due to fiber stresses; (**B**) flexural slip between layers; (**C**) fracture development at the top of a propagating fault; (**D**) fracture development along the fault itself; (**E**) thrust fault and forced fold with trishear zone indicated; (**F**) detachment fold; (**G**) thrust out anticline; (**H**) fault propagation fold. Image modified from [Cosgrove, 2015] and [Gholipour et al., 2016].

3

Results: architecture and fracture patterns in Daly Waters Arch & Tomkinson Province

SEISMIC seismic data analysis and the construction of geological cross–sections provide an overview of the large–scale geometries of the Daly Waters Arch and the Tomkinson Province. Time–depth conversion applied during the seismic data analysis in Petrel was based on the data in Appendix B. The gravity map provided in the SEEBASE 2018 research (Appendix C [Frogtech Geoscience, 2018]) was used to correlate the geometries of the formations in the Daly Waters Arch as analysed from seismic to geometries deeper in the subsurface.

3.1. Large–scale geometry of the Daly Waters Arch

BASED on literature [Munson, 2016a] and previous research [Pragt, 2018] (Appendix A), the horizons of the tops of four formations were traced. In stratigraphical order: a) the Moroak Formation; b) the Velkerri Formation; c) the Powell Formation; and d) the Namerinni Group.

3.1.1. Extent of the Daly Waters Arch

The boundaries of the Daly Waters Arch are defined by folding of the Roper Group in contrast to the mainly flat-lying stratigraphy in the Beetaloo sub–Basin (Figure 3.1).

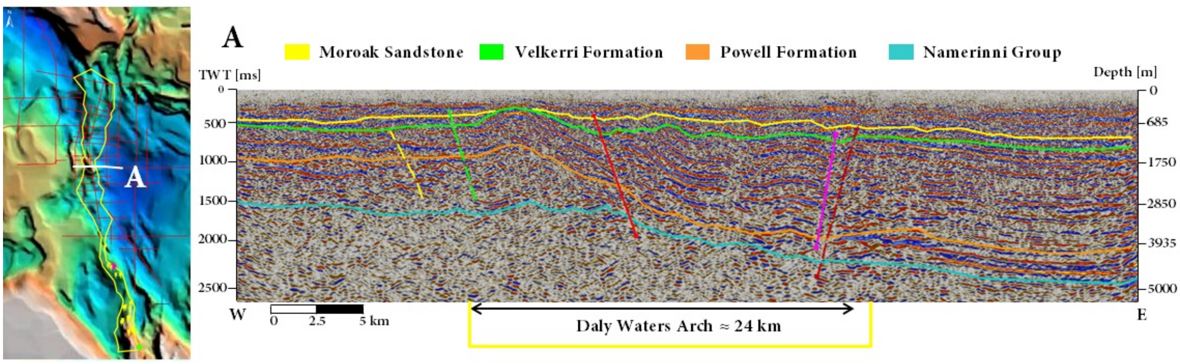
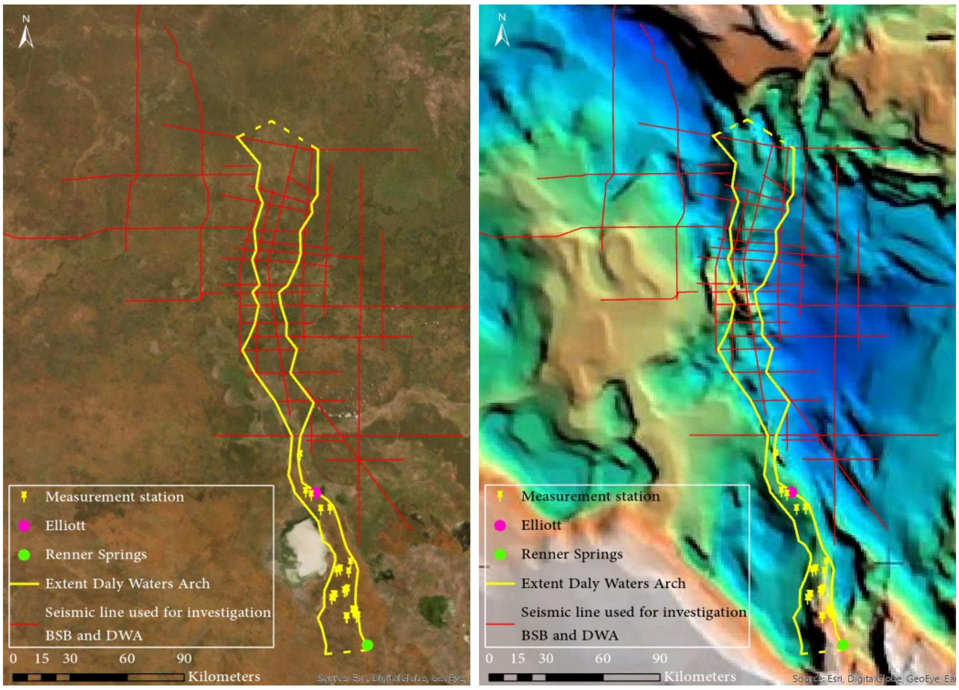


Figure 3.1: 2D Seismic image in the time–domain [HAL2012–122], with scale in depth on the right, showing the E–W extent of the Daly Waters.

The western boundary of the Daly Waters Arch is marked by the increasing dip (fold axes directed N–S, dip angle on average between 5° and 10°) of the horizons. At the eastern boundary, the horizons flattens out under dip angle that increases up to approximately 8°. Despite the limited extent of the seismic section into the Daly Basin (western flank of the Daly Waters Arch, Figure 2.1), the flat–lying configuration of the layers is visible on the western part in Section A (Figure 3.1) for approximately 15 km. **The eastern boundary** of the Daly Waters Arch is marked where the formations have a dip angle between 0° and 2°. In N–S direction (Figure 3.2), the width of the Daly Waters Arch varies from 4 km just north of Elliott to app. 40 km towards the north.



(a) (b)

Figure 3.2: Figure 3.2a shows the extent of the Daly Waters Arch over the topographic map of the area; Figure 3.2b shows the extent of the Daly Waters Arch overlying the base of the Redbank Package in the SEEBASE gravity map [Frogtech Geoscience, 2018]. The northern and southern boundaries of the Daly Waters Arch are marked in dashed lines.

The northern boundary of the Daly Waters Arch is not observed in seismic data: the most northern seismic section of the Daly Waters Arch (Figure 3.3, Section B) shows a deformed Roper Group – fold axes mainly parallel to the Daly Waters Arch (N–S) – whereas in N–S direction (Figure 3.3, Section C) no folds are present, meaning the Daly Waters Arch is located eastwards of this seismic section.

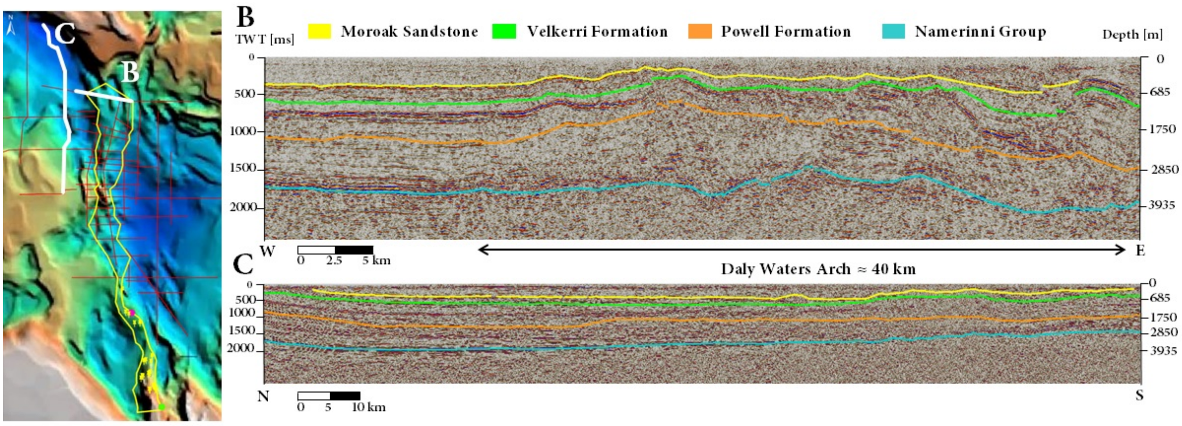


Figure 3.3: E–W and N–S seismic sections in the northern Daly Waters Arch. The northern boundary of the Daly Waters Arch is marked by a dashed line, since the exact boundary of the Arch is unknown.

3.1.2. Monoclinal & anticlinal structures

Figure 3.4 shows the variety of the half wavelengths (L) of the folds from north to south over the Daly Waters Arch. In the Daly Waters Arch, multiple orders of folding have been observed, varying from folding at the scale of the entire Daly Waters Arch (width approximately 40 km) to a much smaller scale (L <2 km). The Powell Formation shows major changes in depth – from ~2,700 meters to ~300 meters depth over a distance of ~1,500 meters (Figure 3.4, Section F). The formations in Sections E and F form a monoclinal structure, whereas in the northern Section D an anticlinal structure is observed.

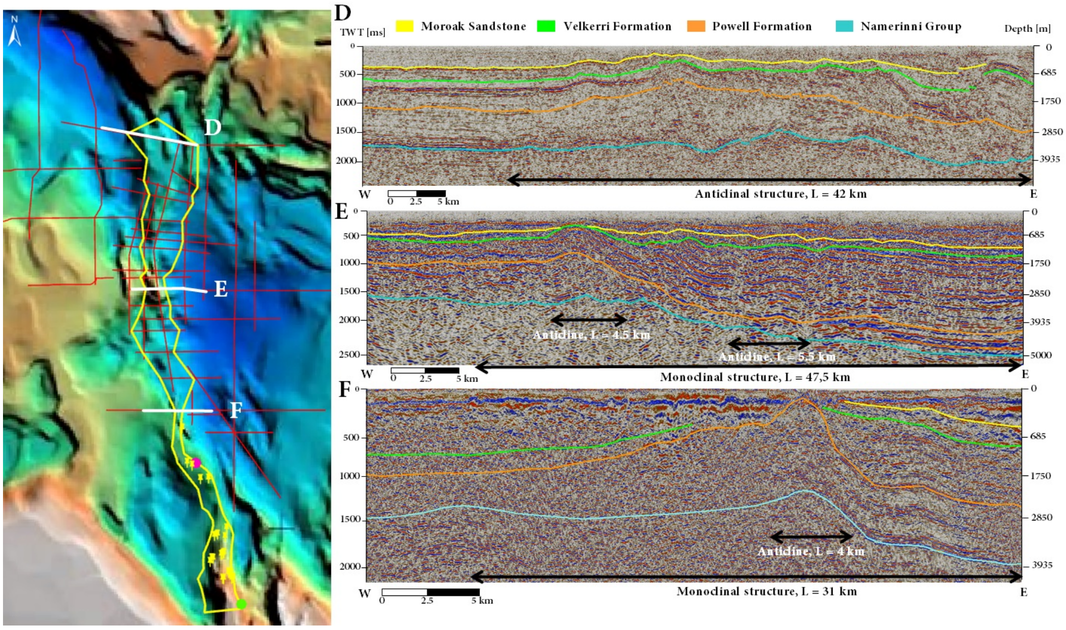


Figure 3.4: Monoclinal and anticlinal structures have different wavelengths L in the Daly Waters Arch.

3.1.3. Deformation in N–S direction

In three N–S directed seismic sections along a N–S profile (Figure 3.5), more faults and folds are observed in the northerly sections. The wavelengths of the folds decrease to approximately 5–15 km in the north. In the south, the folds have wavelengths of approximately 35–40 km. Altogether, folds in N–S sections seems to have longer wavelengths than the folds observed in E–W sections (some folds had a wavelength < 2 km), and the limbs of the folds are more gentle than the folding in E–W directed sections.

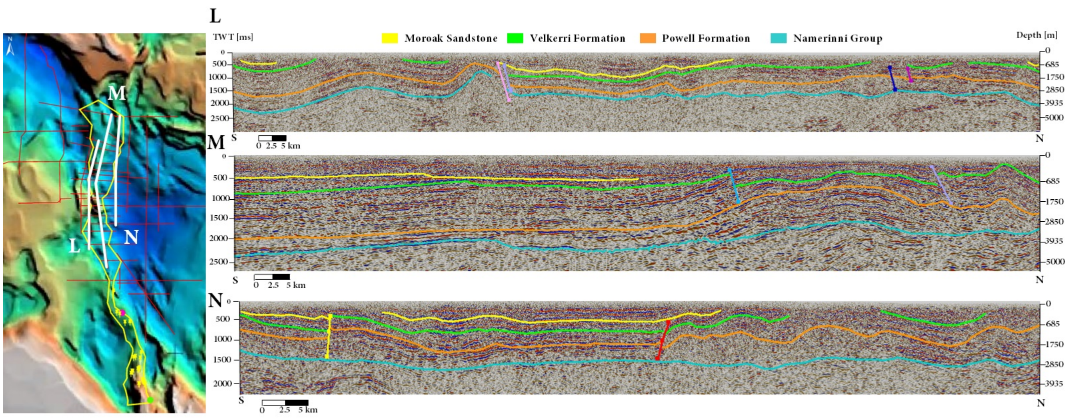


Figure 3.5: Deformation in N–S directed seismic lines in the Daly Waters Arch.

3.1.4. Thickness variations within the Roper Group

The Velkerri Formation and the Powell Formation show major thickness variations on the eastern limb of the Daly Waters Arch (Figure 3.6). E–W seismic sections show thickness increases of the Velkerri Formation (app. 250, 400 or 500 meters on the western limb) to 1,600, 2,000 or even 2,750 meters along the same N–S profile on the eastern limb. Onlapping of formations is observed as the Moroak Sandstone onlaps the Velkerri Formation (Figure 3.6, Section G) and the Velkerri Formation onlaps the Powell Formation (Figure 3.6, Section I).

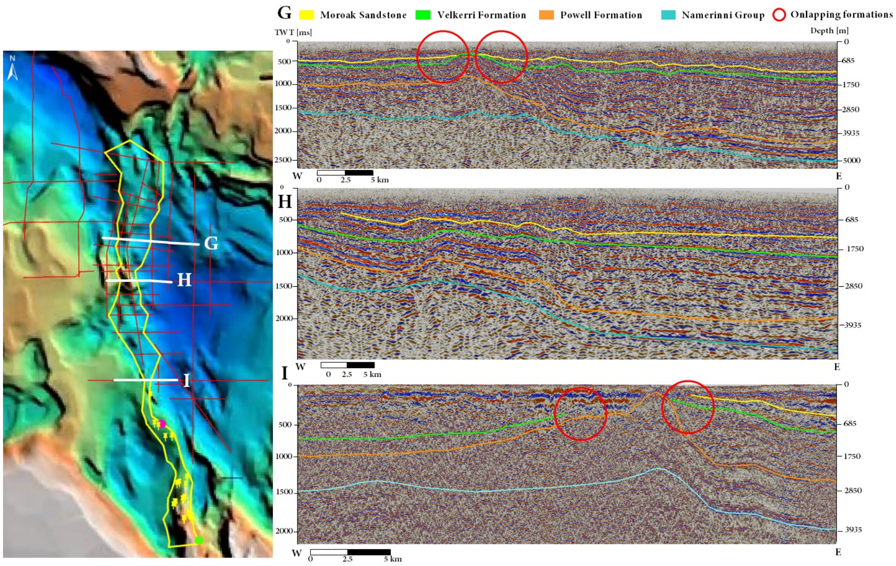


Figure 3.6: Thinning and thickening of formations in E–W seismic sections.

3.1.5. Faulting in the Daly Waters Arch

Faults (dip angles > 60°) are present in the north of the Daly Waters Arch (Figure 3.7, Section J). Most faults cause minor vertical displacement, except for one fault in Section J that shows a displacement of the Velkerri Formation over 300 meters. The southern part of the Daly Waters Arch is characterised by folds (Figure 3.7, Section K).

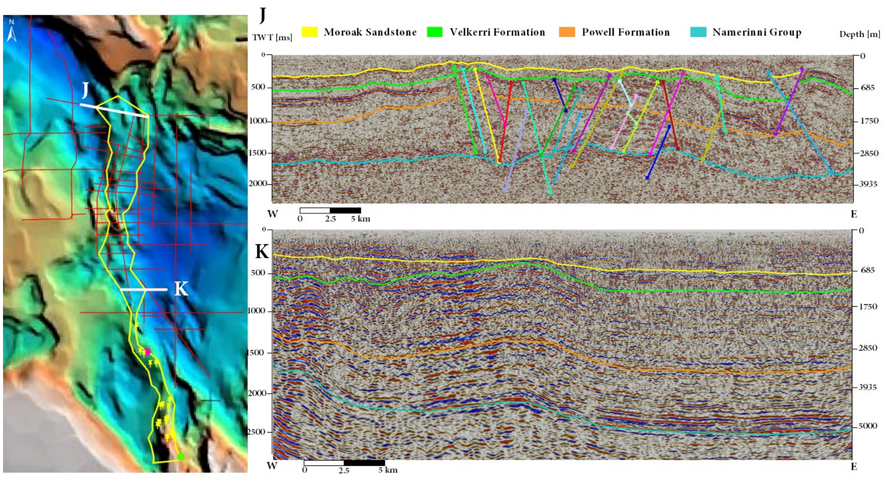


Figure 3.7: Two cross–sections: folds dominant in the southern area of the Daly Waters Arch, faults dominant in the northern area.

3.2. Present–day architecture of the Tomkinson Province

A structural map of the Tomkinson Province, compiled based on existing literature [Hussey *et al.*, 2001; Munson, 2016a; Randal and Smith, 1969; Randal *et al.*, 1969b] and satellite imagery of the Tomkinson Province (Figure 3.8), shows the width of the Tomkinson Province at the surface varying between 4–30 km. This width was defined based on the extent of outcropping Renner Group formations in existing geological maps of the area [Hussey *et al.*, 2001].

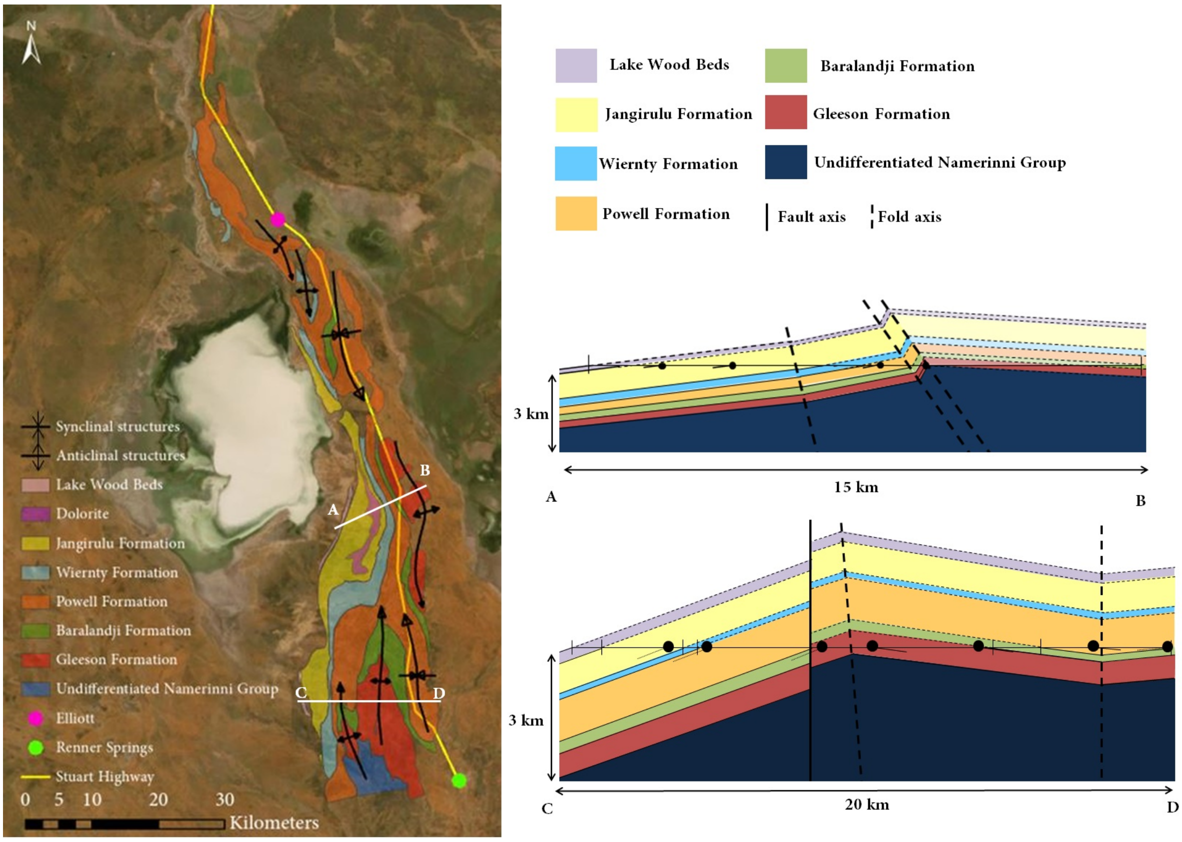


Figure 3.8: The structural map (left) and two geological cross–sections of the Tomkinson Province.

The anticlinal structure (Figure 3.8, cross–section A–B, width more than 15 km) shows no faults. In the southern Tomkinson Province (Figure 3.8, cross–section C–D), faults interpreted as being strike–slip faults with a vertical component of ca. 200 meters in the cross–section C–D have been observed. In cross–section C–D, the Powell Formation is located next to the Gleeson Formation, meaning that this structure is not continuous; the Baralandji Formation is missing. From north (ca. 5 km) to south (>15 km), the wavelengths of the folds in the Tomkinson Province increase, as is the total width of the Tomkinson Province.

3.3. Linking large–scale architecture and fracture data analysis from outcrops

In the field, fractures have been observed and measured at different key locations along the folded formations of the Renner Group in the Tomkinson Province using both conventional geological methods for bedding and fracture data collection and drone imagery.

At outcrop HS2 (Figure 3.9), only one direction of fracturing (strike NW–SE) was observed. Outcrop HS16 shows the same NW–SE directed fracture set, and a second network of NE–

SW directed fractures has been observed; the angle between the two fracture sets is approximately 90°. Both HS2 and HS16 are located on the hinges of an anticlinal structure (Figure 3.8, cross–section C–D). In the central Tomkinson Province (Figure 3.9, outcrops BE2–BE7), beddings dip towards the west on the western limb of an anticlinal structure (Figure 3.8, cross–section A–B). An orthogonal fracture network has been observed in the hinge of the anticline (Figure 3.9, outcrop BE7), whereas on the limb of the anticline (outcrops BE2, BE3 and BE6) the angle between the fracture sets is variable. The fractures are NW–SE and NE–SW (outcrops BE, BE3 and BE6), comparable to fracture sets in outcrops HS2 and HS16 in the south of the Tomkinson Province.

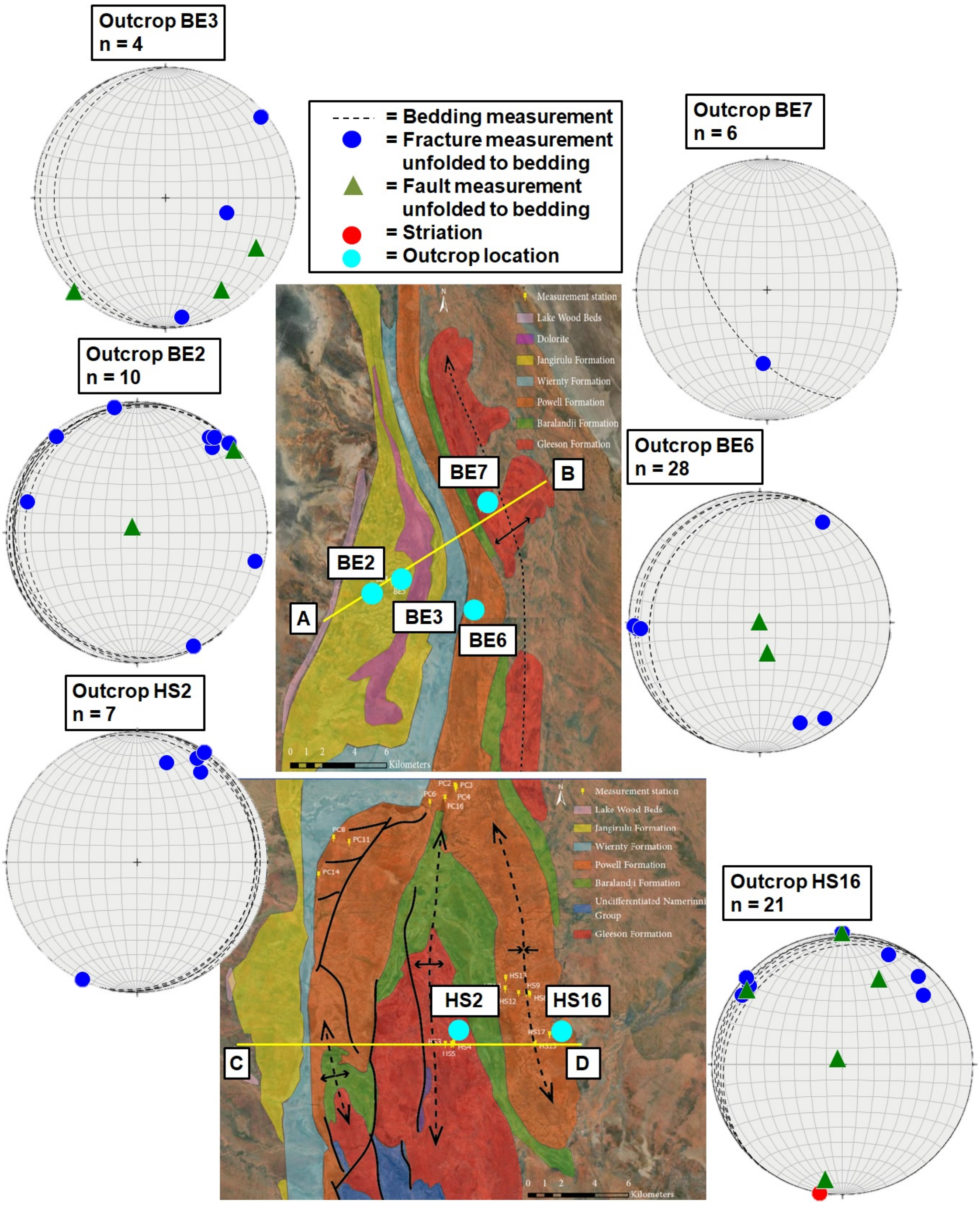
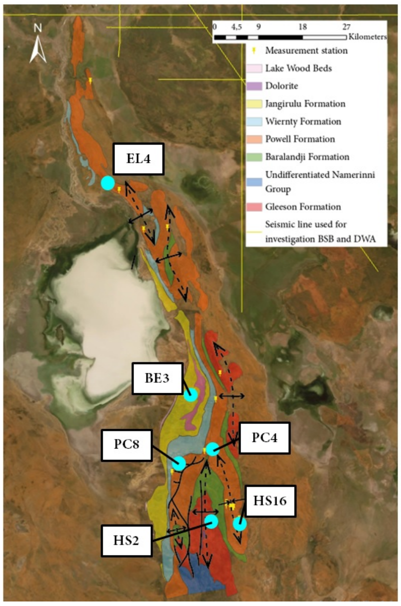


Figure 3.9: The stereoplots of outcrops along cross–sections A–B and C–D.

3.3.1. Fracture data analysis from drone imagery

In addition to the identification of fracture orientations measured in ground–acquired stations, drone imagery was applied to calculate fracture characteristics per outcrop (Figure 3.10) along the folded formations of the Tomkinson Province. These fracture characteristics were identified both at different locations of geological structures as well as in different formations (Figure 3.10).



Outcrop	# Fractures measured	# Fracture sets	Av. length per set [m]	Orientation per set [°]	P21 [m^{-1}]	P20 [m^{-2}]
EL4	58	2	2.7 1.8	60 153	0.054	0.003
BE3	180	3	2.7 2.6 1.9	54 135 2	0.071	0.003
PC4	250	3	1.4 1.2 0.8	130 18 179	0.134	0.011
PC8	126	3	1.6 3.3 2.5	63 180 125	0.095	0.004
HS2	298	3	4.0 2.8 0.9	81 34 135	0.137	0.007
HS16	201	3	1.4 2.1 1.1	80 37 131	0.09	0.006

Figure 3.10: Fracture characteristics at different locations along the N–S profile of the Tomkinson Province. Per outcrop, the following fracture characteristics were obtained from drone image: a) number of fractures per pavement; b) the number of fracture sets; c) the average length of the fractures per set; d) the orientations of the fractures per set; e) the intensity of the fractures per pavement (P21); and f) the density of the fractures per pavement (P20).

In the drone images, fractures were clustered into sets based on their orientations (Figure 3.10). Fracture density and intensity are assumed to be controlled by the curvature of folded beds, the intensity of tectonic deformation, strain or the structural position on a fold [Watkins *et al.*, 2018], and are therefore suggested as reliable fracture characteristics to compare deformed areas in a large–scale study. The fracture intensity (P21) is the highest at outcrops PC4 and HS2 (Figure 3.11), in the deformed central Tomkinson Province, and decreases towards the north. Comparing the values in the tables of Figure 3.10, three fracture sets have been identified at the different outcrops, except for the most northern outcrop. The number of fractures varies from 58 in the area of a relatively low fracture intensity to almost 300 for the folded central area. For one pavement per outcrop, the fracture orientations have been analysed (Figure 3.11). Orthogonal fracture sets are located at outcrops HS16, BE3 and EL4. Fracture sets that share an angle between 40 and 60 degrees are found in outcrops HS16 as well, HS2 and PC8.

The fracture pavement characteristics of Figures 3.10 and 3.11 are discussed in more detail in Appendix F.

3.4. Conclusions of the chapter

In this chapter, the Daly Waters Arch has been identified as an arch–shaped geological structure (width varies between 4 and 40 km) with folding (half wavelengths varying between 2 and >20 km) in both E–W and N–S directions. Faulting (displacement of max. 300 meters) is comprised in the north of the Daly Waters Arch, whereas in the south deformation mechanisms led to folding.

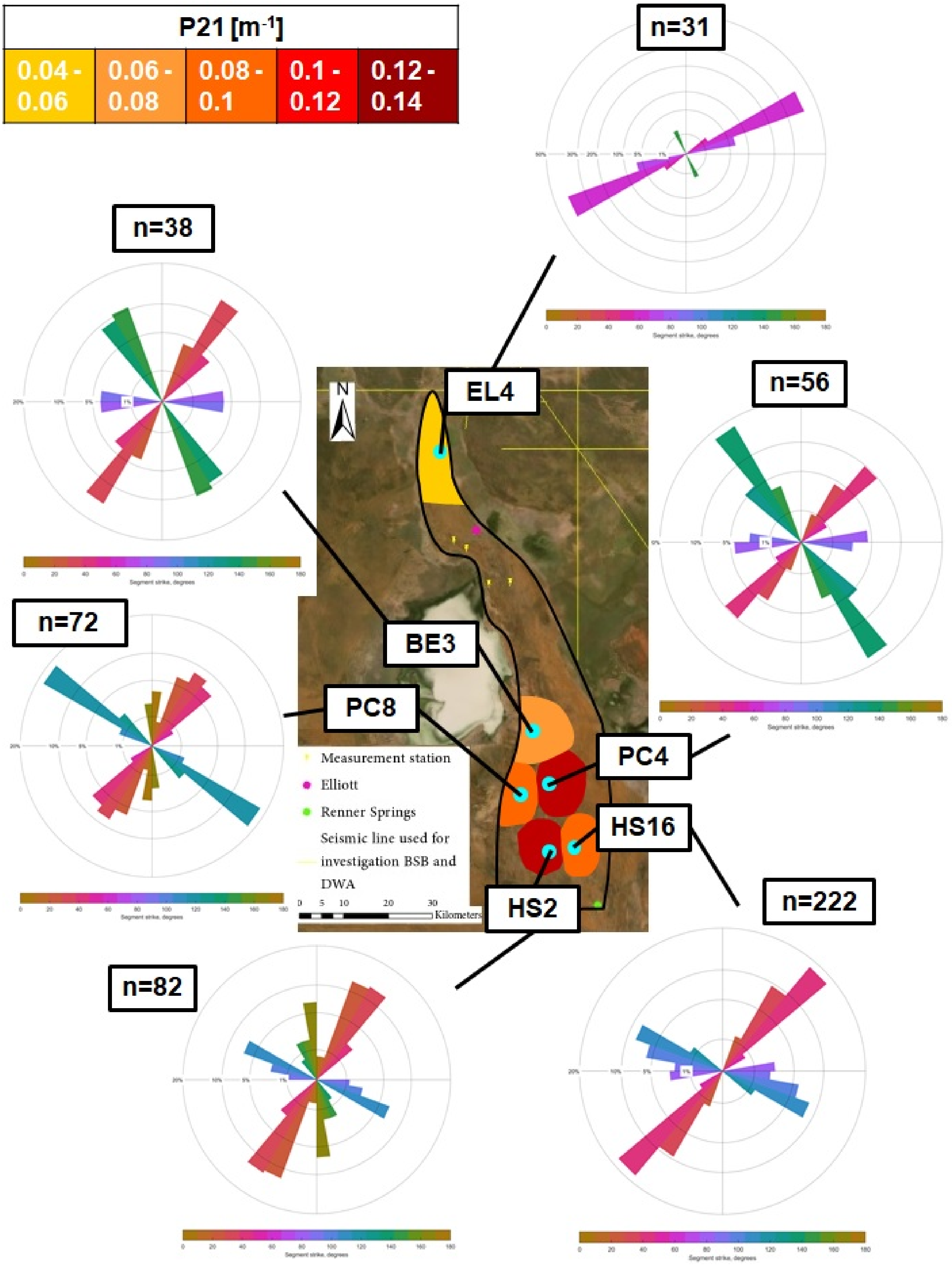


Figure 3.11: Intensity of fractures per pavement in m^{-1} and Fracture set orientation along the Tomkinson Provinces.

In the Tomkinson Province, folding with comparable (half) wavelengths to the Daly Waters Arch is observed. Ground station measurements and drone imagery in the field were used to identify fracture characteristics along a north–south profile of the Tomkinson Province. From ground–based measurements, a orthogonal fracture set (striking NE–SW and NW–SE) has been identified at the hinge of an anticlinal structure (Figures 3.9 and 3.11, outcrop BE3 and HS16). In the central Tomkinson Province (Figure 3.11, outcrops PC4 and HS2) the fracture intensity is higher (between 0.12 and 0.14 m^{-1}) compared to outcrop EL4 (intensity is 0.054 m^{-1}), located closely to the southern boundary of the Daly Waters Arch.

Based on the fracture network analysis performed in this chapter, it is concluded that on the limbs of anticlinal structures, the fracture networks become more complex with angles smaller that 90° between the fracture sets and more fracture sets were present per studied outcrop. As one moves towards the hinge of an anticlinal or synclinal structure, the angles between the fracture sets increases to approximately 90°. In the case of the Tomkinson Province, orthogonal N–S and E–W fracture set orientations are observed.

4

Interpretation and discussion: large–scale geometry and fracture drivers in the Daly Waters Arch and Tomkinson Province

AFTER the multi–scale data (seismic data, bedding and fracture data from ground stations and drone imagery) data analysis, the results are interpreted to draw conclusions on the a) architecture of the Daly Waters Arch and the Tomkinson Province, and b) the processes that control the fractures in these areas. These interpretations will be discussed in the second part of this chapter.

4.1. Large–scale geometry of the Daly Waters Arch and the Tomkinson Province

THICKNESS variations and onlapping of overlying formations occur along the N–S trending 3D model of the Daly Waters Arch and the Tomkinson Province displayed in Figure 4.1. At the top of the Velkerri Formation, no major erosional event has been observed in seismic data of the Daly Waters Arch; this observation suggests that the Daly Waters Arch was deformed before the Velkerri Formation was deposited (between 1361±21–1417±29 Ma [Pragt, 2018]) and that the Daly Waters Arch controlled the deposition of the Velkerri Formation in the Beetaloo sub–Basin. This interpretation is in line with the thickness variations of the Velkerri Formation along the Daly Waters Arch; one the eastern limb of the Daly Waters Arch, the Velkerri formation is thicker (up to more than 2 km) than on the western limb (ca. 500 meters). The underlying Namerinni Group follows the same configuration as the Powell and Velkerri Formations in this section, therefore suggesting the Daly Waters Arch might be older than the deposition of the Namerinni Group (ca 1670–1600 Ma).

Faulting and folding have been observed in both N–S, NW–SE and NE–SW directions in the Daly Waters Arch and the Tomkinson Province (Figure 4.1). In the model, the principal stress directions that influenced these movements have been indicated in red and green arrows. Seismic sections show that the areas where the Daly Waters Arch is at its widest, are associated with faults, whereas the areas where the Daly Waters Arch is at its narrowest are associated with folds. In terms of width, the Daly Waters Arch and the Tomkinson Province are relatively narrow structures (4–40 km) compared to the extent of the Beetaloo sub–Basin, which stretches over more than 250 km from east to west. Orthogonal directions of folding (both E–W and N–S) have previously been observed in the Broadmere syncline [Pragt, 2018], located in the Batten Fault Zone.

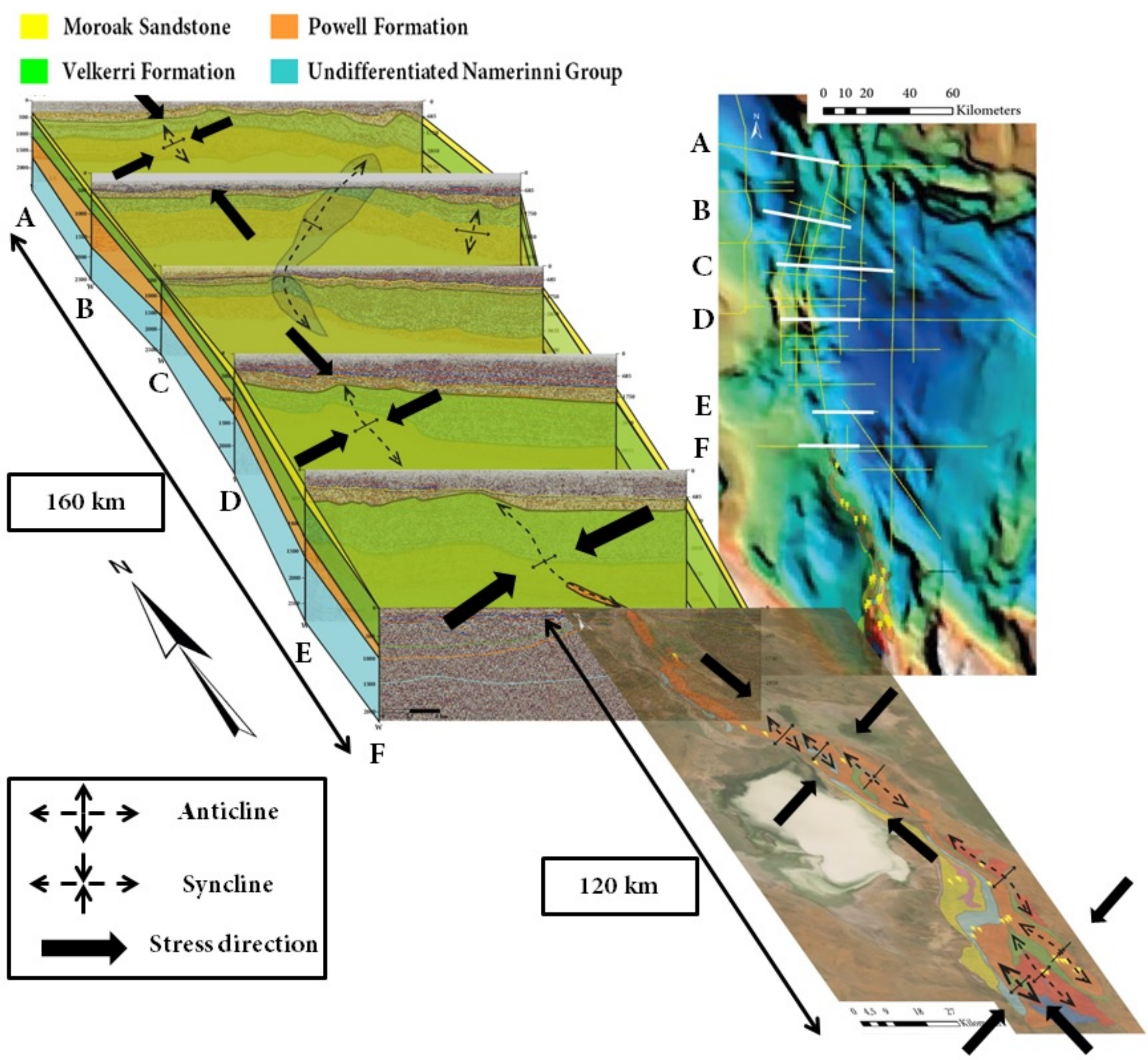


Figure 4.1: 3D model of the formations in the Daly Waters Arch indicating the principle stress directions and resulting folds in the Daly Waters Arch and the Tomkinson Province. In the model, faults have been left out of scope, because the behaviour of faults between seismic sections is unknown. Secondly, the Cambrian cover down till the Kyalla Formation has been left out of scope.

For the northern boundary of the Daly Waters Arch, the deformation might be the result of the interaction of the Daly Waters Arch with the NW–SE trending Mallapunyah Fault, the continuation of the Batchelor Fault Zone or deformation related to the NE–SW to E–W directed Urapunga Fault Zone (Figure 4.2). The faults that are observed in the Daly Waters Arch are steep (comparable to the faulting observed in the Batten Fault Zone by Pragt [Pragt, 2018]), but the observed movement is smaller than observed in the Batten Fault Zone (max. 300 meters in the Daly Waters Arch, whereas the Mallapunyah Fault has a displacement of approximately 1,700 meters [Pragt, 2018]). Based on the observed movement in the faulted areas, no clear regime that is responsible for the faulting can be discriminated.

4.1.1. Geological link between the two areas of interest

Based on the analysis and interpretation of seismic data and bedding and fracture measurement obtained both at ground–measurement stations and from drone imagery, the Daly Waters Arch is concluded to be a subsurface continuation of the Tomkinson Province. Multiple arguments support this conclusion. First, two main stress–directions have been

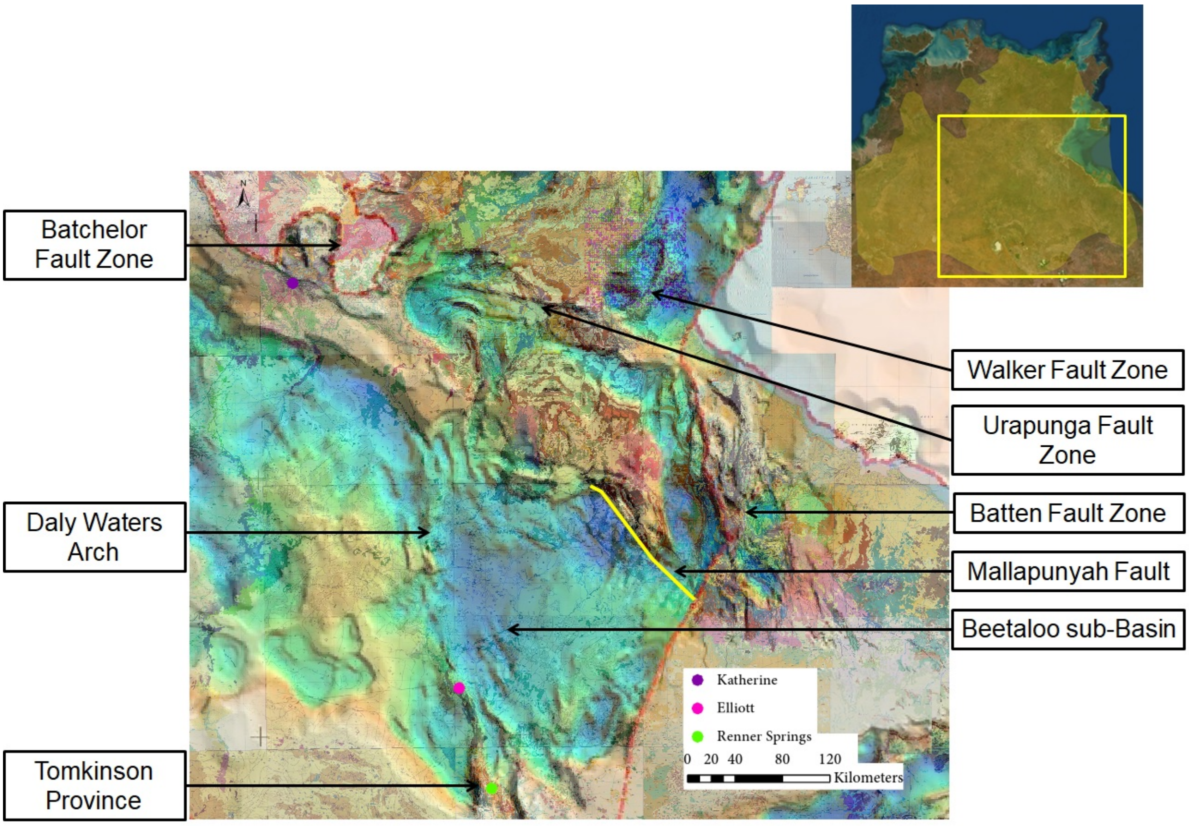


Figure 4.2: The gravity map of the Greater McArthur Basin, overlain by the geological map of the Northern Territory. In the figure, relevant sub–basins, the relevant fault zones and faults are shown. Image modified from [Origin Energy, 2017].

identified based on the interpreted architecture of the Daly Waters Arch and the Tomkinson Province (Figure 4.1): NW–SE and NE–SW. Based on cross–sections that were constructed using fieldwork measurements of bedding and fracture planes, folds in the Tomkinson Province are oriented in the same direction as the folds that have been observed in the Daly Waters Arch using seismic data (both N–S and E–W folds). Secondly, the folds in the Daly Waters Arch and the Tomkinson Province have comparable wavelengths (3–10 km). Thirdly, in the north of the Daly Waters Arch and the south of the Tomkinson Province, where the deformed area is wider (up to 40 km), the geometries are more faulted than in the central parts of the areas. The faults are vertical and show a maximal vertical displacement of ca. 300 meters.

4.2. Comparison between the Daly Waters Arch & the Tomkinson Province, and the Batten Fault Zone

THE Batten Fault Zone (Figure 4.2) was the study area of the 2018 NT–Work Project [Pragt, 2018] (see Appendix A for the composite seismic section from the Batten Fault Zone to the Daly Waters Arch area). Tables 4.1 and 4.2 summarise both similarities and differences between the geometries of the Daly Waters Arch area and the Batten Fault Zone.

Table 4.1: Similarities between the geometries of the Daly Waters Arch area and the Batten Fault Zone.

	Similarities Batten Fault Zone – Daly Waters Arch & Tomkinson Province
Orientation	Both structures are roughly N–S oriented.
Folding	The wavelengths of folds observed in the Daly Waters Arch and the Tomkinson Province show similar wavelengths as the deformation in the Batten Fault Zone (ca. 30 km).

Table 4.2: Differences between the geometries of the Daly Waters Arch area and the Batten Fault Zone.

	Differences Batten Fault Zone – Daly Waters Arch & Tomkinson Province
Boundaries	The Daly Waters Arch and Tomkinson Province are flanked on both sides by a hardly deformed area, whereas the Batten Fault Zone only has a shelf on its western flank. The eastern flank of the Batten Fault Zone is made up by the deformed rocks of the McArthur Basin and the Murphy Inlier [Hunter, 1981; Spampinato *et al.*, 2015].
Width	The width of the Batten Fault Zone (70–100 km) is larger than the width of the Daly Waters Arch (4–40 km).
Exposure	The rocks that are exposed in the Daly Waters Arch and the Tomkinson Province (Roper Group) are of younger age than the rocks in the Batten Fault Zone (Namerinni and older groups). Some literature date the Daly Waters Arch post–Mesoproterozoic, due to the timing of major structural features [Hoffman, 2016]. However, this argument does not prove that the Daly Waters Arch is a younger structure than the Batten Fault Zone, since it is possible that the Batten Fault Zone was more eroded than the Daly Waters Arch, resulting in older rocks at the surface.
Faulting	Faults that are observed in the Daly Waters Arch (displacement app. 500 meters) do not show the same throw as the faults in the Batten Fault Zone (Mallapunyah Fault approximately 1,700 meters [Pragt, 2018]). Major faults like the Emu and Scrutton Faults in the Batten Fault Zone have not been interpreted in the Daly Waters Arch.

4.3. Regional tectonic evolution: discussion of analogues and models

Two hypotheses for the tectonic evolution of the Daly Waters Area and Tomkinson Province are:

1. The Daly Waters Arch and Tomkinson Province are the result of reactivation of basement terrane boundaries.
2. The Daly Waters Arch and Tomkinson Province are the result of far–field stresses which were developed during one of the large–scale compressional or extensional regimes.

4.3.1. Reactivation of basement terrane boundaries as mechanism for local deformation in the Greater McArthur Basin

Existing literature links pre–Roper deformation in the Daly Waters Arch area to movement [Cawood and Korsch, 2008; De Vries *et al.*, 2008; Frogtech Geoscience, 2018] during the

NE–SW Barramundi Extension (1880–1850) [Blake and Page, 1988], the NE–SW Murchison Event (1815–1805 Ma), the NE–SW Davenport Event (1790–1770 Ma) [Blake and Page, 1988], the NE–SW Leichhardt Extension (1780–1750 Ma) [Blaikie *et al.*, 2017; De Vries *et al.*, 2008; Jackson *et al.*, 2000], the N–S Calvert Extension (1750–1650 Ma) [De Vries *et al.*, 2008; Jackson *et al.*, 2000] and the NE–SW to E–W Isan Orogenies (1600–1500 Ma) [Giles *et al.*, 2006; Myers *et al.*, 1996] (Figure 2.3 and 2.4).

Superimposition of these events led to reactivation of the boundaries in the basement terranes that underlie the Daly Waters Arch area [De Vries *et al.*, 2008]. In literature [Frogtech Geoscience, 2018], the Scarlet Hill terrane (Figure 4.3), that underlies the Daly Waters Arch area, is mentioned as probable reactivation zone. Once the aforementioned deformation events took place, the movement was reflected in N–S trending structures as oblique reverse faults. Seismic data to the east of the Daly Waters Arch in the Beetaloo sub–Basin do not show an angular unconformity between the Renner Group and the underlying Namerinni Group; therefore, indicating that the Daly Waters Arch formed a hinge line in the area where the Roper Group was deposited [Frogtech Geoscience, 2018; Hoffman, 2016].

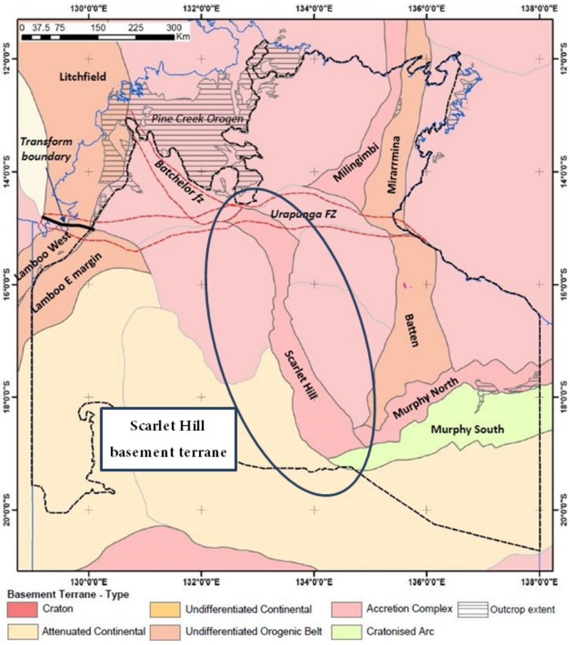


Figure 4.3: The basement terrane of the Daly Waters Arch area, visible as an elongated linear terrane that is roughly NW–SE directed in the Greater McArthur Basin [Frogtech Geoscience, 2018].

After the deposition of the Roper Group, folding and faulting took place in the Daly Waters Arch during NE–SW shortening during the Albany–Fraser Orogeny [Clark *et al.*, 2000; Frogtech Geoscience, 2018]. The model of the reactivation of older transverse and normal faults or a N–S directed fault zone in the subsurface suggests folding of the formations on top along is directed with the fault direction [Betts *et al.*, 2015a]. The Daly Waters Arch can be an example of a NW–trending fault that was reactivated with sinistral displacement. This conclusion is linked to the depocentres for the Roper Group that were developed in the eastern and western Beetaloo sub–Basin; a sinistral strike–slip fault might develop the basin areas in the southeast and northwest Beetaloo sub–Basin due to extension of these areas [Betts *et al.*, 2015a].

4.3.2. Deformation in the Greater McArthur Basin as a result of far–field stresses

Far–field stresses from extensional events can develop intracratonic rifting systems over more than 1,500 km away from the active margin [Bisdom, 2016; Lamarche *et al.*, 2018; Pinet, 2016; Pragt, 2018]. An analogue case where stresses were transmitted from a plate boundary over 100"s of kilometers, thereby deforming the formations in an intracratonic basin, is the NNW-trending Hudson Bay central high on the North American continent [Pinet, 2016; Roksandic, 1987] (Figure 4.4). Overall the North American interior shows generally little deformation in this area, but evidence of significant Paleozoic tectonism is preserved in the fault–bounded central high in the Hudson Bay basin [Pinet, 2016; Roksandic, 1987].

Like the Beetaloo sub–Basin, the Hudson Bay Basin is an intracratonic basin with a sed-

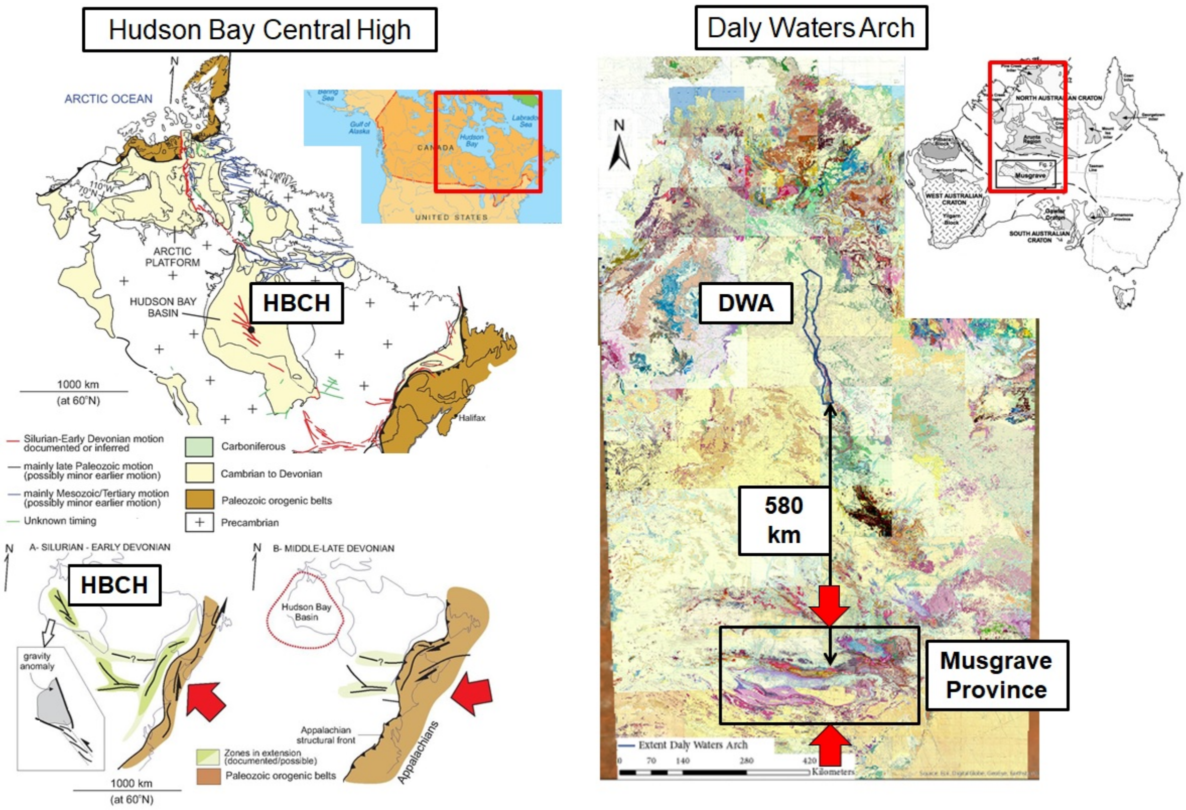


Figure 4.4: Left: Model linking Hudson Bay central high (HBCH) with Appalachian mountain building that occurred at periphery of the craton. Red arrows represent bulk shortening directions. Images modified from [Pinet, 2016]. Red arrows represent bulk shortening directions. Image retrieved from [Pinet, 2016]. **Right:** Model linking the Musgrave Province to the Daly Waters Arch area. The geological map of the Northern Territory with the extent of the Daly Waters Arch (DWA) is displayed. The distance between the two areas is almost 600 km, and the Daly Waters Arch is oriented almost perpendicular to the Musgrave Province. The model links the E–W trending Mesoproterozoic Musgrave Province to the deformation in the Daly Waters Arch area. Map of Australia modified from [Wade et al., 2008].

imentary succession up to 2.5 km thick that was deposited under shallow marine conditions [Pinet, 2016]. Comparable to the Beetaloo sub–Basin, the geometry of the basin contains generally undeformed sedimentary packages. The central high is controlled by NNW–trending, east–dipping normal faults with throws up to ca 500 meters. To the south, the structure includes several secondary highs that are controlled by NW–to–WNW–trending en echelon high–angle faults that might indicate a transtensional motion with a component of left–lateral displacement [Pinet, 2016]. The central high is probably a result of reactivation of an important Precambrian fault zone [Roksandic, 1987].

Comparable to the Daly Waters Arch, constraints of the timing of deformation are provided by thickness variations on both sides of the structure and onlapping relationships on one of the flanks [Pinet, 2016]. The Hudson Bay central high fault array is nearly perpendicular to the NE–trending Appalachian front that is located about 1,400 km to the southeast [Pinet, 2016] (Figure 4.4). Stresses that were applied to the continental margin were transmitted in the continental interiors, where they induced the normal (northern Hudson Bay central High) or transtensional (southern Hudson Bay central High) fault reactivation of older structural discontinuities [Pinet, 2016]. The Musgrave Orogeny (result of the assembly of the North and South Australian Cratons [Cawood and Korsch, 2008; Myers *et al.*, 1996; Wade *et al.*, 2008]) caused both E–W and N–S deformation across the North Australian Craton [Cawood and Korsch, 2008; Wade *et al.*, 2008]. Stresses that were applied on the E–W oriented continental margin of the North Australian Craton were transmitted to the interior of the Craton, around 600 km to the north. Here, the N–S directed stress regime might have resulted in the reactivation of terrane boundaries. The terrane boundaries were reactivated as faults with a strike–slip component, leading to folding of the overlying sedimentary packages in the Daly Waters Arch area. The timing of the Musgrave Orogeny (Mesoproterozoic) coincides with the deposition of the Renner Group in the Daly Waters Arch area.

The Hudson Bay central high shares similarities with other intracontinental extensional zones worldwide. Some of these similarities are a) a location of more than 1,000 km from a plate boundary; b) an early history characterised by low subsidence rates; c) the coexistence of several rift branches of various trends with extensional zones oblique and subparallel to the shortening directions; and d) its location on the edges of an inherited crustal block boundary [Pinet, 2016]. The Daly Waters Arch is located closer than 1,000 km from the Musgrave Province (Figure 4.4), but concerning point (d), the Daly Waters Arch is located on the boundaries of the Scarlett Hill terrane (Figure 4.3 and previous section). In relation to point (c), Section 2.3 of this study introduces multiple extensional events that trended oblique (NE–SW) to the shortening direction during the Musgrave Orogeny (N–S).

4.3.3. Far–field stresses as fracture drivers in the Daly Waters Arch and Tomkinson Province

By discussing an analogue (the Hudson Bay Central High) and a model of the terrane boundaries underlying the Daly Waters Arch area, the fractures observed in the Tomkinson Province are concluded to be controlled by the superimposition of multiple extensional regimes trending in various directions (from NE–SW to NW–SE, N–S and E–W). Stresses that developed at a distance of hundred's of kilometers, in the Musgrave Province, for example, were transmitted into the Beetaloo sub–Basin. Here, the far–field stresses related to these movements reactivated the boundaries of the Scarlett Hill terrane, which reflected in folding oblique (NW–SE and NE–SW) to the N–S trending Daly Waters Arch. Faults that mark the boundaries of the Scarlett Hill terrane have not been studied in this research; these faults are located deeper in the subsurface. The NE–SW and NW–SE folding of the overlying formations of the Namerinni and Roper Group indicate that these faults are strike–slip faults with a minor vertical component.

4.4. Limitations and discussion of fracture pattern analysis in the Tomkinson Province

DURING the process of fracture data analysis from ground measurement stations and drone images, different issues influence the interpretation of the data.

4.4.1. Fracture length measurements – truncation and censoring issues

Not every fracture traced from a drone image is representative of the actual length of the fracture in the subsurface [Baghbanan and Jing, 2007]. This is due to truncation and censoring of fractures, or a limited view on the fractures due to overlying rocks and rubble. Figure 4.5 shows a pavement of outcrop BE3 that contains censored and truncated fractures. Pavements like these cause unreliable interpretations of the lengths of the fractures, leading to a mis–comparison of the fracture characteristics as the lengths are assumed to be too short.

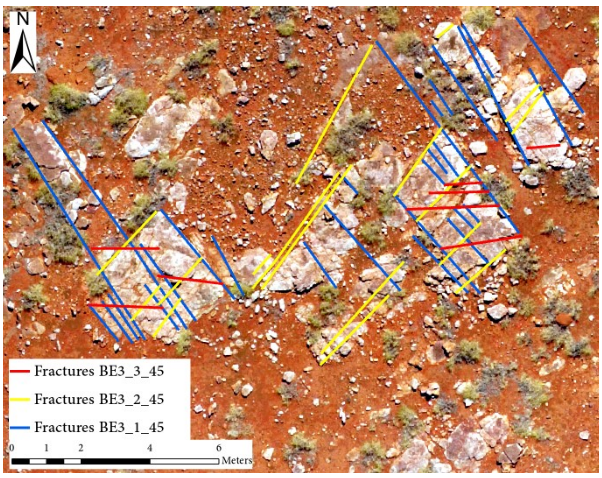


Figure 4.5: Example of a drone image (outcrop BE3) that shows an outcrop that contains censored and truncated fractures. Overlying material (rubble) and bushes decrease the visibility of the fractures.

4.4.2. Discussion: same formation – different fracture patterns

In this study, interpretations of the role of the different formations on the existing fracture patterns can be analysed.

In Figure 4.6, the stereoplots of the outcrop data collected at two outcrops in the Powell Formation have been displayed. This image emphasises the difference in fracture behaviour of two outcrops, which are located about 4.8 km away from each other. At outcrop BE8, only two fracture sets and one fault have been measured, whereas at outcrop BE9 seven fracture sets and five faults have been measured. According to the structural map (Figure 3.9) these outcrops are located in an area where multiple anticlinal and synclinal structures are located. These deformation structures might explain the different behaviour in terms of fractures at two outcrops in the same formation.

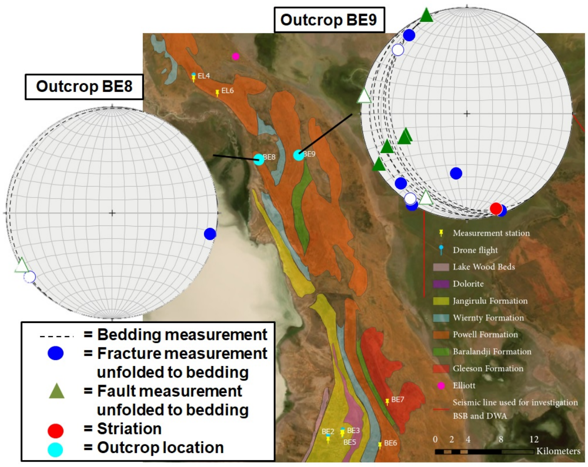


Figure 4.6: Example of two closely located outcrops that have different fracture orientations and number of fractures.

5

Conclusions and recommendations

BASED on the interpretation of seismic data analysis from the Daly Waters Arch and fieldwork data from the Tomkinson Province, the three research questions are answered.

5.1. The Daly Waters Arch and Tomkinson Province are geologically linked

BASED on observations and the study of relevant models in the literature, the Daly Waters Arch is concluded to be the subsurface continuation of the Tomkinson Province. In this study, indications have been found that pre–Roper deformation in the Daly Waters Arch is related to movement in different directions during the NE–SW Barramundi Extension (1880–1850 Ma), the NE–SW Murchison Extension (1815–1805 Ma) and NE–SW Davenport Orogeny (1790–1770 Ma), the NE–SW Leichhardt Extension (1780–1750 Ma), the N–S Calvert Extension (1750–1650 Ma) and the E–W to NW–SE Isan Orogenies (1600–1500 Ma). It is most likely that the deformation in the Daly Waters Arch is a reactivation of older terrain boundaries, such as the basement terrain of Scarlett Hill. As a result of this reactivation, the formations that are deposited on top of the faults that mark the boundaries of the terrane, are folded and faulted along the older deformation. This explanation fits the observations that were done of the deformation patterns in the Daly Waters Arch, e.g. a) folding where the deformation area is narrow, faulting where the structure is wider; and b) faulting and folding both perpendicular and parallel to the direction of the Daly Waters Arch. Secondly, the deformed area is relatively narrow (4–40 km) compared to the intracratonic basin in which it is located (minimum of 250 km) and the deformed zone is relatively straight.

Deformation patterns observed in the Tomkinson Province (the wavelengths of folding and steep faults with minor vertical displacement) are similar to the patterns observed in the seismic data of the Daly Waters Arch. Another similarity is that both E–W and N–S deformation is observed. Along the Daly Waters Arch and the Tomkinson Province, anticlinal structures flat out towards the north and disappear. In the northern boundary of the Tomkinson Province, the Powell Formation and the other rocks of the Renner Group dip into the subsurface, into the Daly Waters Arch. Similar to the Daly Waters Arch, the formations in the Tomkinson Province are more faulted where the structure is wider; south of Renner Springs, the structure becomes less narrow and just as the northern seismic lines in the Daly Waters Arch, the deformation observed in cross–sections becomes more faulted. Lastly, gravity and magnetic data images do not show a clear boundary between the Daly Waters Arch and the Tomkinson Province, which is in favour of a genetic link between these two areas. This observation and the aforementioned arguments are in favour of the theory that the two areas are deformed by the same events and so, share a geological link.

5.2. The Daly Waters Arch & Tomkinson Province, and the Batten Fault Zone not geologically linked

Based on the research work done, the conclusion is drawn that there is no geological link between the Daly Waters Arch area and the Batten Fault Zone area. This answer is based on the fact that even though there are similarities between the two deformed areas – both structures are roughly N–S oriented and the wavelengths of folds observed in the Daly Waters Arch are similar to wavelengths of the folds in the Batten Fault Zone – there are more differences between the two structures. Firstly, the Daly Waters Arch area and the Tomkinson Province are flanked on both sides by a hardly deformed area (the Beetaloo sub–Basin and the Daly Basin), whereas the Batten Fault Zone has a shelf on its western flank, but not on the eastern one. Secondly, the Daly Waters Arch is narrower (4–40 km) than the Batten Fault Zone (70–100 km), making the Daly Waters Arch a more isolated structure than the Batten Fault Zone. Thirdly, in literature, the Batten Fault Zone is almost always linked to the Walker Fault Zone, while the Daly Waters Arch is described as a 'stand–alone structure'. Furthermore, the deformation of the Daly Waters Arch area is linked to the deposition of the Redbank Package, while the deformation in the Batten Fault Zone to the deposition of the Glyde package. Lastly, faults that are observed in the Daly Waters Arch do not show the same displacement as the faults in the Batten Fault Zone.

Due to the active margin in the south (Musgrave Orogeny, that is linked to the Murchison and Davenport Events [Blake and Page, 1988; Wade *et al.*, 2008]), the Tennant Region (of which the Tomkinson Province forms part [Ahmad and Munson, 2013a]) is likely to have remained high during the evolution of the Greater McArthur Basin [Frogtech Geoscience, 2018]. Since the Tomkinson Province was already present when the Redbank Package was deposited in the Batten Fault Zone [Frogtech Geoscience, 2018], the assumption for the older age of the Tomkinson Province compared to the Batten Fault Zone can be argumented.

5.3. Predictability of fracture patterns in the Tomkinson Province for other locations in the Greater McArthur Basin

Based on the analysis of fracture from both ground measurement stations and traced from drone images at outcrops, it is concluded that fracture patterns in the Tomkinson Province become more complex once one moves from the hinge of an anticline towards the limbs of the anticline. In the hinges of the folded structures, (almost) orthogonal fracture sets have been observed, whereas on the limbs of the structures, the angle between fracture sets was smaller than 90°. The behaviour of fractures in terms of length and the number of fractures and fracture sets throughout the Tomkinson Province from south to north is not predictable for the Greater McArthur Basin. These fracture characteristics as analysed in the research show a variable behaviour at different locations in the Tomkinson Province, making it difficult to extrapolate the fracture characteristics to the subsurface. Analysis of the orientation of fractures in the Tomkinson Province prove the existence of two principal stress directions that caused the folds in the Tomkinson Province; these stress regimes are oriented NW–SE and NE–SW. Analysis of fracture pavements in outcrops shows that the NW–SE stress regime was followed by the NE–SW regime that is linked to the extensional stress regimes in NW–SE and NE–SW directions that were present in the Greater McArthur Basin during the Late Paleoproterozoic and the early Mesoproterozoic.

5.4. Recommendations for future research

THE interpretation of the 2D seismic data used in this research, leaves room for discussion: the formation packages often reach depths that can not be reached by petroleum wells or boreholes (Appendix D). Therefore, a well correlation for formations located deeper than the Moroak Sandstone was often lacking. Furthermore, the Daly Waters Arch continued further to the north than the most northern seismic section that was available in the study. Therefore, the northern boundary of the Daly Waters Arch and a potential link to the NW–SE trending Mallapunyah Fault could not be studied in this research. To make a correlation, it is recommended to extend the study area towards the north in the future, to be able to examine the continuation of the formations in the Daly Basin and the northern boundary of the Daly Waters Arch.

A last recommendation for future research is to continue exploring the possibilities for the interpretation of fracture measurements obtained with drone imagery. In this study, five fracture pattern characteristics – number of fractures, number of fracture sets, fracture length, orientation and intensity – have been described and compared. However, there are more characteristics that can be used to conclude on the predictability of fracture patterns over a certain area. The drone images of fracture patterns that have been obtained during this study can be used in future research to collect data on the following fracture characteristics, thereby being able to extend the comparison of characteristics between different fracture pavements:

1. By interpreting the **abutment relationships** between fracture sets at an outcrop, one can make predictions about the relative ages of the fractures that are present in the outcrop; e.g. if one vertical fracture set constantly abuts another horizontal set, one can assume that the horizontal fracture set is younger than the vertical set [Mynatt *et al.*, 2009].

   In two dimension fracture networks, three main **types of nodes** are recognised: isolated (I–nodes), abutting (Y–nodes) and crossing nodes (X–nodes) [Sanderson and Nixon, 2015]. The proportions of these nodes provide a basis to describe the topology of a fracture network and make predictions about the order in which the fracture sets were developed. However, for this research this type of fracture characteristic was left out of scope, due to the sometimes limited visibility of the nodes from the drone images.

2. The role of **fracture aperture** for fluid flow in reservoirs: for fluids, such as hydrocarbons, to be able to flow through a hydrocarbon reservoir, the fractures need to be open in the network. However, one of the mechanisms that change apertures and fracture geometries is the mechanical unloading during the exhumation of the rocks [Bisdom, 2016]. Especially aperture is hard to quantify from rocks, as weathering and exhumation enhance aperture and increase the dissolution of cement [Bisdom, 2016; Zeeb *et al.*, 2013]; secondly, fracture aperture is extremely sensitive to stress [Bisdom, 2016; Ghassemi and Suresh Kumar, 2007].

II

Communication approach for technical uncertainties in geothermal energy implementation in the Dutch energy transition

6

Introduction

In the ongoing energy transition in the Netherlands, geothermal energy production – the production of heat from the Earth's interior – is a crucial technique to replace the use of gas as main energy source in the residential areas and light industry [Schoof *et al.*, 2018]. In social sciences and humanity studies, geothermal energy production has received little attention so far compared to other renewable energy sources, such as solar and wind energy [Gross, 2013]. One potential reason for this, is the ongoing change in the location of geothermal projects; from remote locations at plate boundaries to highly population residential areas [Gross, 2013]. Therefore, the implementation of geothermal energy projects are located closely to people's properties, resulting in an increasing awareness towards the implementation of geothermal energy. This has to do with the energy–bearing capacity of water – water cannot be transported over unlimited distances without losing its energy [Ma *et al.*, 2009]. For geothermal energy to replace to combustion of gas as energy source, many geothermal energy projects will need to be implemented closely to the location where the energy is consumed: the residential areas [Gross, 2013; Popovski, 2003; Stichting Platform Geothermie, 2019].

Based on the climate agreement of Paris in 2015 [European Commission, 2019], ambitious goals for the implementation of geothermal energy have been set by the Dutch government: in 2050, at least 23% of the total heat needed will be produced from ca. 700 geothermal doublets [Schoof *et al.*, 2018]. Considering that one geothermal doublet consists of an injection and a production well, ca. 1,400 wells will need to be drilled by 2050. For the remaining part of this report, 'geothermal doublet' will be referred to as 'geothermal well'. These national goals led to the realisation of regional and local energy policies, which will be executed by municipalities. Considering 355 municipalities in the Netherlands by the end of 2019 [Centraal Bureau voor de Statistiek, 2019], this means that on average two geothermal wells per municipality will be drilled between now and 2050. Since the techniques to produce gas and geothermal energy are comparable from a technical perspective, both activities are classified as 'mining operations'. In this light, it is likely that the public will draw a parallel between the implementation of geothermal energy and the gas production in Groningen, due to the developed social perspective on mining operations in general.

In the Netherlands, the gas production in Groningen forms the social perspective considering safety and environmental issues that are involved in mining operations [Bal *et al.*, 2019]. By the time the gas production techniques were implemented and the produced gas provided a high level of wealth and economic benefit for the whole country, earthquakes occurred in an increasing frequency in the area of gas production [Van Thienen-Visser and

Breunese, 2015]. After ca. 25 years, earthquakes that were registered in the area were linked to the gas production [De Telegraaf, 1986; Van der Voort and Vanclay, 2015] and by the time of this thesis study, more than 55 years after the start of commercial production, it is decided that the gas production in Groningen will be decreased from 2022 onward [Mulder and Perey, 2018]. The initiators of the project (the national government and the operator) only communicated about the certainties of gas production towards the local public [Van Bruggen, 2015]. Matters that involved uncertainty were not addressed in this communication process; uncertainties were ignored, denied or both. Over the last 30 years, the way the communication process around gas production was organised led to resistance amongst the local public, and to a decrease in trust in the initiating parties [Van Bruggen, 2015].

6.1. Problem definition

In Groningen, (technical) uncertainties were not communicated to the public for multiple decades, leading to a lack of trust in the authorities and resistance towards the gas production [Bal *et al.*, 2019]. Regarding the important role of geothermal energy in the Dutch energy transition, the level of social acceptance needs to be high enough to prevent the development of public resistance to the implementation of geothermal energy. Since the implementation of geothermal energy is still in the take–off phase [Loorbach and Rotmans, 2006; Schoof *et al.*, 2018], the technical uncertainties of geothermal energy implementation have not been identified yet. In this study, technical uncertainties are defined by *'uncertainties related to the technical aspects of geothermal energy implementation in the Dutch energy transition.'* Given the scientific unknowns in the drilling techniques associated with geothermal energy, questions related to the communication of the drilling methods and the related side effects are of considerable importance [Gross, 2013].

From the gas production in Groningen, it is argued that there is a link between the way of uncertainty communication towards the local public and the level of social acceptance; the lack of communication towards the local public led to a development of public resistance [Bal *et al.*, 2019; Van Bruggen, 2015]. In the development of geothermal plants close to residential areas, multiple unknowns in production techniques and the side effects of production can be acknowledged [Gross, 2013]. Instead of bypassing these unavoidable uncertainties with risk–assessments, policy–makers have an alternative by the open acknowledgement that uncertainty in geothermal energy implementation cannot be avoided [Gross, 2013]. This study provides a way to describe the technical uncertainties to a local public.

All in all, the problem statement of this study is described as follows:

Based on the future perspective of two geothermal wells per municipality in 2050 and the developed public resistance to gas production in Groningen, an approach for the communication process of the technical uncertainties between the initiators and the local public of the geothermal project needs to be designed. This communication approach offers the communicators of the initiators of a geothermal project a structured overview of the steps in the communication process and the choices that need to be made for an effective communication process towards the local public.

Since this study focused on the communication of technical uncertainties by the initiators of a geothermal project to a local public, the communication processes that take place between the different initiators of a geothermal project have not been studied. This decision was partly made to limit the scope of research, but mainly on the idea that the communication between different initiators does not influence the level of social acceptance of geothermal energy implementation to the same extent as the communication of technical uncertainties between the local public and the initiators.

In the next section, the arguments for the choice to work towards a communication approach in this report will be discussed, followed by a section that describes the steps that form the the content of the communication approach.

6.1.1. Reasoning behind a communication approach

In the near future hundreds of geothermal wells will need to be implemented based on the national goals for geothermal energy in the energy transition. The actors that are concerned with the development of geothermal energy and the identification of uncertainties, are mainly technical or policy experts. To prevent reinventing the wheel at each geothermal project, an approach for the communication to the local public of the (technical) uncertainties will need to be designed. Based on the identification of technical uncertainties in geothermal energy implementation, the design of a communication model would be too generic (Figure 6.1, left side).

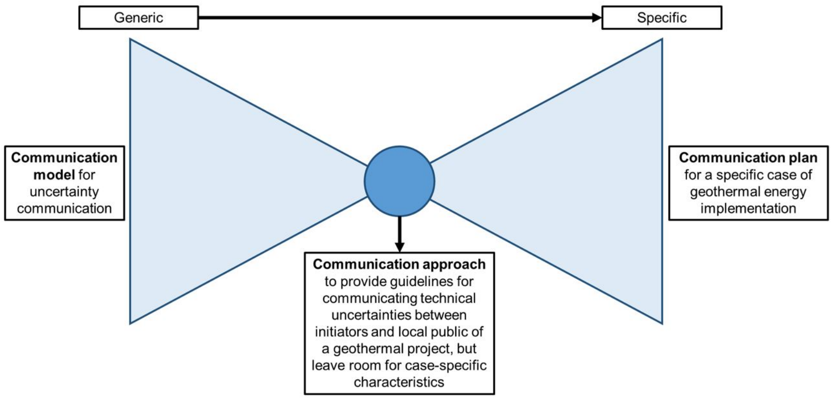


Figure 6.1: The communication approach in between the model and a communication plan for a specific case of geothermal energy implementation.

On the other hand, a detailed communication plan for a case of geothermal energy implementation in a certain neighbourhood would ask for knowledge of the specific characteristics of that case (Figure 6.1, right side). The identification of technical uncertainties and their link with social acceptance for such a specific case was outside the scope of this research. Therefore, the choice was made to find the middle between a communication model and a communication plan for a specific case: a communication approach. In this approach, guidelines for the communication process are based on relevant literature and interviews with experts in the field of geothermal energy implementation.

6.1.2. Contents of a communication approach

In this study, technical uncertainties that are present in the implementation phase of a geothermal project will be identified. Furthermore, a link will be constructed between the technical uncertainties that are present in the implementation of geothermal energy in a neighbourhood, and the level of social acceptance of the local public. From this context, a communication approach will be developed that provides an overview of the choices that need to be made by the initiators of a geothermal project when communicating to the local public. In other words, the context of the communication approach will be fixed, and therefore placed outside the final approach: the context of the communication approach will be the level of social acceptance in geothermal energy implementation. In this context, the goal of the communication approach is to communicate the technical uncertainties that are present in a geothermal project in order to increase the level of social acceptance of geothermal energy implementation.

Based on this context and goal of the communication approach, the communicated messages are the technical uncertainties that are relevant to increase the level of social acceptance in a specific case of geothermal energy implementation. These technical uncertainties are case–specific, but can be identified based on the overview of technical uncertainties that is provided in this study. For each communication process regarding the technical uncertainties in geothermal energy implementation, two main communicators have been identified: the initiators of the geothermal project and the local public. The initiators of a geothermal project will be the national and local governments, the operator and States Supervision of Mines, as will be explained later in this report. The local public is defined as all the people that live within a radius of 5 km distance from a geothermal project location. The radius of 5 km was chosen such that not only the direct neighbours of a geothermal project are included, but also the people that are not affected by the drilling process directly. Both communicators participate in the communication process based on their own reference frames. Different aspects that influence the reference frames of the communicating actors will be identified.

The last step of the communication approach provides guidelines for the communication of technical uncertainties to a local audience in different situations. Each case of geothermal energy implementation holds a specific situation, including a) an inventory of the stakeholders involved in the communication process, b) a setting that, amongst others, determines the location for the communication process, c) an inventory of the timeline of the communication process, and describes the link with the technical timeline of the geothermal project, and d) the communication channels that can be used in the specific situation, and the presence of noise.

In the following section, the research objectives of this study will be described.

6.2. Research objectives

THE problem statement described above results in the formulation of the main objective of this study: to design an approach for the communication of the technical uncertainties that are present in the implementation of geothermal energy between the initiators of a geothermal project and the local public, once the technical uncertainties and their influence on the level of social acceptance of the geothermal project have been identified. To achieve this research goal, two sub–objectives for this study have been defined:

1. To provide an overview of technical uncertainties that are present in the implementation of geothermal energy.
2. To determine how these technical uncertainties influence the social acceptance of the implementation of geothermal energy in the Netherlands.

The identification of the technical uncertainties is an objective for this research, so that the initiators will be able to use this overview in the communication process to address the technical uncertainties that have the most impact on the level of social acceptance; the initiators can identify the technical uncertainties that are relevant in the specific case based on this overview. Once these two sub–objectives have been achieved, the goal of the communication approach is to increase awareness of the technical uncertainties that are present in a geothermal project in order to increase the level of social acceptance of geothermal energy implementation. From the research objective as discussed in this section, the research question and sub–questions will be described in the next section.

6.3. Research question and sub–questions

BASED on the research objective as posed above, the following research question will form the guiding question through this report:

How can technical uncertainties that are present in the implementation process of geothermal energy be communicated by the initiators of a geothermal project to the local public in the perspective of the energy transition in the Netherlands, to increase the level of social acceptance when taking into account the social sentiments that have been developed with respect to the production of gas in the Netherlands?

This research question is split up into the following sub–questions (**SQ**) that will provide guidance during the report:

1. Which objectives for geothermal energy implementation in the Netherlands have been set by the Dutch government?
2. How similar are the techniques for geothermal energy and gas production in the Netherlands?
3. What are the similarities and differences between the technical uncertainties that are recognised in geothermal energy implementation, and the technical aspects of gas production in The Netherlands?
4. How do technical uncertainties influence the level of social acceptance of geothermal energy implementation?

Based on the research questions as formulated in this section, the chosen research approach and data acquisition methods will be described in the next section. Also, a reading guide for this report is presented to describe the common thread for this study.

6.4. Research approach, data acquisition methods and reading guide

THE research will be a qualitative, exploratory research. The three main methods of data collection in this study will be the desk research, literature research and nine semi–structured interviews that were organised with different stakeholders. Figure 6.2 visualises the outline of this study report. In Chapter 7, the used methods are further described.

Chapter 8 provides a theoretical framework that will serve as a knowledge base for the rest of the thesis report. In this framework, relevant topics will be discussed from existing literature. The concept of ‘transition’ and the role of (technical) uncertainties in a transition process will be reviewed. Then, the link between uncertainty and the level of social acceptance by the public towards the transition process will be provided. This level of social acceptance forms the context for the communication approach that will be provided in this study. A base for this communication approach will be described following a communication model. Relevant communication theories will be linked to the different steps in the communication approach in this chapter.

Chapter 9 will provide an extended description of the problem statement and the scope of the research, thereby answering sub–questions 1 and 2 of this research. This description will mainly be based on the review of existing literature and relevant quotes from the interviews will be implemented into the chapter. The characteristics of the energy transition in the Netherlands will be described and the national goals for the implementation of geothermal energy will be provided. Also, the development of the social perspective towards mining operations during the gas production in Groningen will be explained to emphasise the crucial role of social acceptance towards a mining operation.

The main focus of Chapter 10 are the technical uncertainties that are present in the implementation of a geothermal project. Based on the semi–structured interviews, these technical uncertainties will be identified. These technical uncertainties of geothermal energy will be compared to the technical aspects of gas production in the Netherlands, thereby providing an answer to sub–question 3 of the research. In Chapter 11, the technical uncertainties will be linked to three pillars of social acceptance. These three pillars will be identified based on the interviews. In this chapter, the three pillars will be ranked based on their expected influence on the level of social acceptance. This ranking is based on different communication theories.

The final communication approach will be designed in Chapter 12. In this approach, the parts of the previous chapters will be integrated. The applicability of the communication model, approach and plan of Figure 6.1 will be discussed based on the results that are described in earlier chapters. Lastly, the conclusions of the research will be drawn in Chapter 13 and discussed in Chapter 14. In Chapter 15, a personal reflection on the research and on the period of doing a double–degree MSc–thesis is included.

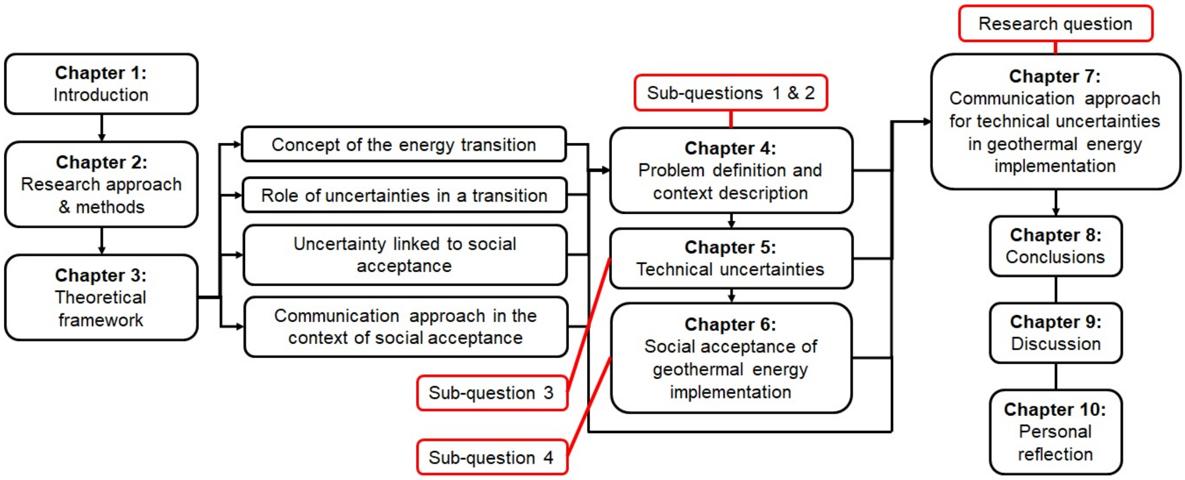


Figure 6.2: Reading guide for this report.

7

Research approach and methods

In Chapter 6, the chosen approach and methods used in this research have been mentioned briefly. In this chapter, the applied research approach and methods that whave been used for data collection and interpretation will be discussed.

7.1. Research approach

The research described in this report is a *qualitative* and *exploratory* research. The qualitative aspect of this research approach can be found in the specific social and technical context of this research. Knowledge of the techniques of gas and geothermal production from the master Reservoir Geology is applied to determine gaps in the literature, that are filled with knowledge collected during multiple interviews. In this research, the technical aspects and uncertainties that are applicable on a generic case of geothermal energy implementation, play a central role. Therefore, this research is conducted from a technical perspective, with a focus on the local public. In the line of the research approach as described in this section, the used data acquisition methods will be discussed in the next.

7.2. Data acquisition methods

The main methods that were used to acquire data for this research are described in this section. The three main types of data collection (Figure 7.1) that were used in this research, are:

1. literature research on the topics of (energy) transitions, the role of uncertainties in transition processes, the link between uncertainty and social acceptance and the construction of a communication approach;
2. desk research to provide the context of the research;
3. semi–structured expert–interviews.

These three data acquisition methods will be described in the following three sections. Figure 7.1 summarises the different methods and shows how the methods combined lead to the final results of this thesis. The dashed lines between the different research methods in Figure 7.1 stresses the fact that information collected by desk and literature research was implemented into the organisation of the interviews.

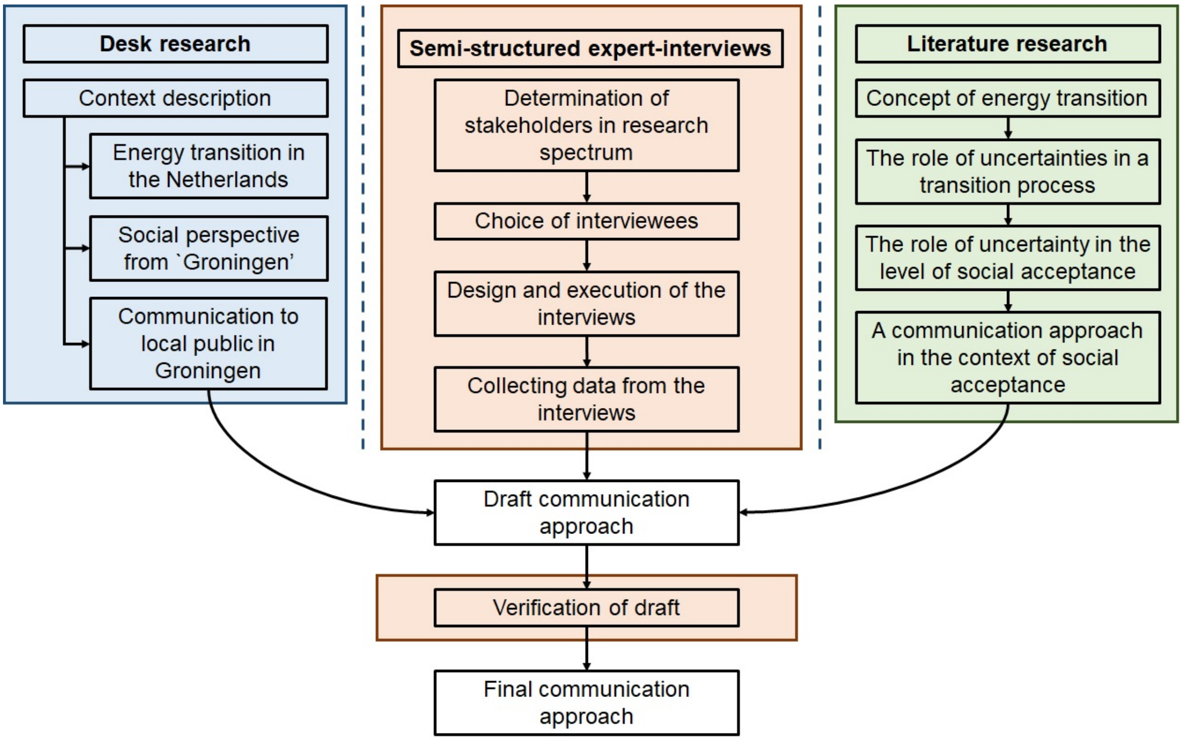


Figure 7.1: The different methods used for data collection in this study indicated with different colours.

7.2.1. Literature research

The first method of data collection that is applied during this study is the method of literature research. In this study, literature about the following subjects is reviewed:

1. The shared concepts of transition processes, with a focus towards 'energy transition', and the four phases of a transition process that are recognised in transition models.
2. The role of (technical) uncertainties in transition processes. In this analysis, different sources and types of uncertainties are identified.
3. The role of social acceptance in transition processes and the impact of technical uncertainties on the level of acceptance.
4. The design of a communication approach that is based on a communication model.

The first step of the literature research was the identification of relevant models to describe the concepts of transition processes. For this study, the model provided by Rotmans and Loorbach [Loorbach and Rotmans, 2006] was chosen, due to its focus on transition management. Although this study focuses on the communication of technical uncertainties, the model for transition management was relevant to provide a background of the different phases of the energy transition, to identify the current phase of the geothermal energy implementation in the Netherlands and to describe the role of technical uncertainties in the implementation.

Once the concept of transition processes is described, the focus is pointed towards the role of uncertainties in transition processes. The link between these two concepts is found in one of the phases of a transition management process, in which the uncertainties that are present in the transition should be mapped. Different types of uncertainties are described, and an explanation for the focus on technical uncertainties is provided. Then, the literature focuses on the role of social acceptance in the success of a transition process; a link between these concepts is made by the idea that a lack of knowledge, or uncertainty, is one of the barriers that can influence the continuity of the transition process as the level of knowledge influences partly how people think about the transition process. The last part of the literature research focuses on the design of a communication approach and the links with different communication theories.

During this literature review, scientific papers were scanned using Google Scholar. In this search engine for scientific literature, the search terms listed in Table 7.1 were used as a starting point.

Table 7.1: Search terms used in Google Scholar during the literature search.

Transition processes	**Uncertainties in transition processes**	**Uncertainties in social acceptance**	**Communication approach**
Transition management	Uncertainty in transition processes	Social acceptance in energy transitions	Communication model
Drivers of transitions	Technical uncertaintiy in energy transition	Technical uncertainty in social acceptance	Reference frame in communication model
Types of energy transitions	Impact of uncertainty on energy transition	Barriers to energy transitions	Communication theory
Models for transition processes	Lack of knowledge as uncertainty	Change in level of social acceptance	
	Uncertainty as barrier in energy transition	Uncertainty communication and level of social acceptance	

Once a search term was used, the title and abstract of resulting papers were scanned to determine their relevance to this research. Once these were found to be relevant for the research, the conclusions was read. If the conclusion provided relevant information, the rest of the content of the article was read. During the reading of the articles, notes were made to be able to retrieve relevant information back later on. The references of the relevant articles were scanned for further relevant publications.

7.2.2. Desk research

Information that was needed to provide the context of the research in Chapter 9 was collected by applying the second method of data acquisition: a desk research. This research focused on the following three main topics and the sub–topics:

1. The energy transition in the Netherlands:
    - the main drivers of the energy transition;
    - the currently ongoing energy transition in comparison to earlier energy transitions;
    - the technical aspects of the gas production in the Netherlands;
    - the (inter)national climate agreements and goals in the energy transition;
    - objectives for the implementation of geothermal energy at both national and local level;
    - the technical aspects of geothermal energy production in the Netherlands.
2. Social acceptance as factor for success in a transition process: the case of the loss of social acceptance for gas production in Groningen;
3. Communication towards the local public during a gas production project
    - the communication towards the local public by the government and the operator;

- lessons from 'Groningen' for the communication in the implementation of geothermal energy.

This desk research was conducted by the analysis of available (inter)national governmental documentation and references that were available in these documents (Table 7.2). Scientific papers that were used to describe the goals as set at the climate summit in Paris in 2015 were found using Google Scholar. The main search terms were 'climate goals Paris', 'IPCC report' and 'Dutch climate goals after Paris 2015'. Especially the goals set for geothermal implementations in the Netherlands have not been used extensively in scientific literature yet. Therefore, and to prevent confusion about the goals for geothermal applications, specific governmental websites (Ministry of Economic Affairs and Climate Policy **(EZK)**, States Supervision of Mines **(SodM)**) were used in the desk research to always have the most recent data. Governmental reports that were used during desk research, were mostly scanned for particular pieces of information or new insights that were used to describe the context of the research in detail. In Table 7.2, the search terms that were used as a starting point for the desk research are listed. For the governmental documentation, mostly the regular website of Google was used. However, it is stressed that where possible, the official websites and documentations of reliable institutions were used in this phase of the research. This desk research took place before the interviews were organised, so that the objectives for geothermal engineering in the Netherlands were clearly defined before data about the policy–making and communication were collected during the interviews.

Table 7.2: Search terms used in Google Scholar and the regular Google website during the desk search.

Energy transition in the Netherlands	**Social acceptance as factor for success**	**Communication during gas production**
Drivers of the Dutch energy transition	Social acceptance gas production Groningen	Initiators and local public in gas production Groningen
Energy transition from coal to gas	Earthquakes in gas production region Groningen	Communication to local public during gas production Groningen
Gas production techniques in the Netherlands	Social impact of earthquakes Groningen	Uncertainty communication during gas production Groningen
Techniques for geothermal energy production in the Netherlands	Resistance to changes in subsurface: CCS Barendrecht	Lessons from uncertainty communication Groningen for geothermal energy
Ultra–Deep geothermal energy in the Netherlands	Shale gas production in the Netherlands	Communication to local public in link with social acceptance gas production
Goals for the Dutch energy transition		
Goals for geothermal energy in the Netherlands		
'Transitievisie Warmte'		

7.2.3. Semi–structured expert–interviews

Based on the context description as it was constructed by conducting desk research, the step was taken towards the third method of data collection that is applied in this study: the semi–structured expert–interviews. As a first step, the different stakeholders in the research spectrum were identified (Figure 7.1). Since the implementation of geothermal energy in residential areas is a new technique of energy production, not many literary sources provide information on the technical uncertainties that are present in the implementation of this technique [Gross, 2013]. Therefore, this gap in literature needed to be filled. To do so, experts in the field of geothermal energy were selected based on their expected knowledge based on the information that was collected during the desk research. The choice for semi–structured interviews came from the desire to organise a structured interview in which the needed information was collected on the one hand, but on the other hand room for additional information was appreciated as well.

Based on the context description, the following stakeholder groups were chosen for an interview about the technical uncertainties that are present in geothermal energy implementation:

1. States Supervision of Mines, as SodM is the controlling agency for mining operations in the Netherlands. Based on the review of documentation that was provided by SodM, it was expected that the interviewee would have an extended knowledge base about the technical uncertainties in geothermal energy implementation.
2. A scientist in the field of geothermal engineering to identify the different technical uncertainties that are present in geothermal energy implementation. At Delft University of Technology, there is a department dedicated to geothermal engineering. Based on the attention for this research field at the university, the assumption was made that a scientist from this department would be able to identify the different technical uncertainties that are present in geothermal energy implementation.
3. A policy–maker from the Dutch national government (the Ministry of Economic Affairs and Climate Policy). Since the Dutch government becomes more aware of the role that geothermal energy will play in the Dutch energy transition, policy–makers are developing strategies for the implementation of this technique. From the point of the different steps that are involved in the process of permit authorisation and the communication of technical uncertainties towards a local public, a policy–expert of the government was chosen as interviewee.
4. A communication–expert from the Dutch national government was expected to have ideas about how the technical uncertainties can be communicated to a large public, in the social perspective of the gas production in the Netherlands.

Once the first four interviews were planned, the work paths and experiences of the interviewees that were relevant for the research were reviewed. Moreover, background information about their work related to geothermal energy was investigated to determine the positions of interviewees in the research spectrum. This background search was done by searching the interviewees on the internet, read relevant documents that were found as results in this search and scan their working history on LinkedIn.

During these four interviews, new stakeholder groups that might be interesting to interview, were mentioned by the interviewees. Based on their knowledge and the context description of this research, the relevant stakeholder groups were identified after these first four interviews (Figure 7.2). By the end of the interview–phase of the research, which took about three months in which the appointments were made, the interviews were conducted and the relevant data was collected, nine interviews had been conducted with ten interviewees; for logistic reasons, the interviews with P7 and P8 were combined into one meeting.

In total, the following ten representatives have been interviewed for this study:

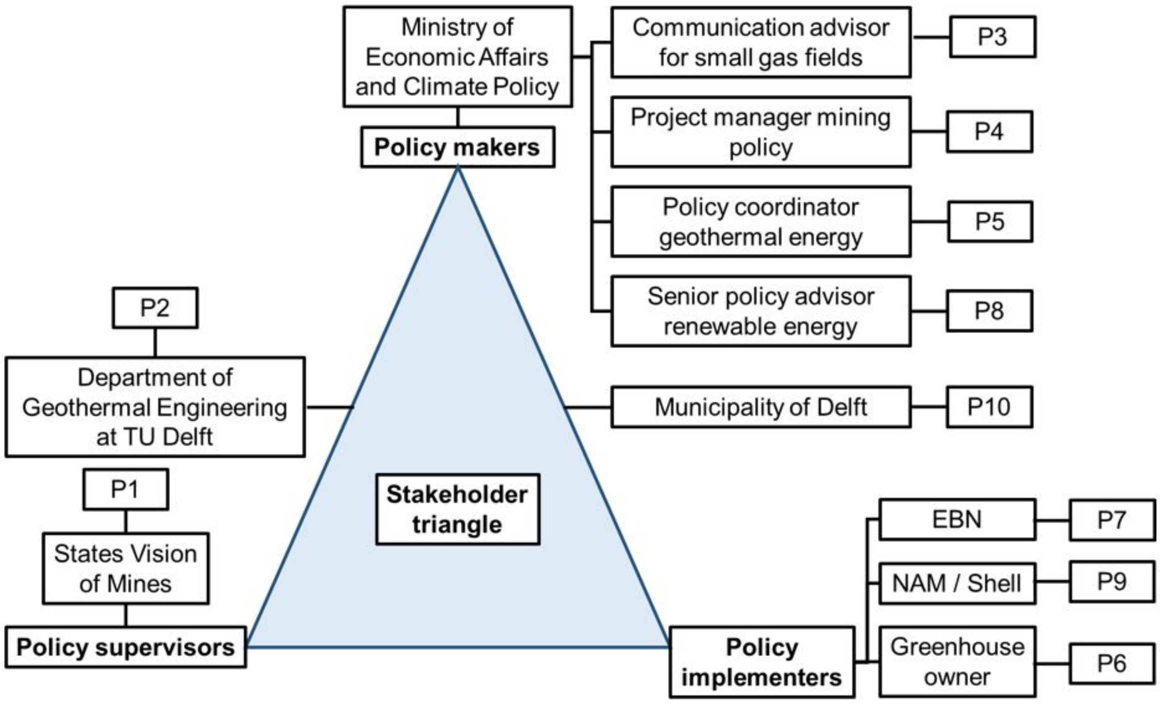


Figure 7.2: The main stakeholder groups in this study visualised in the stakeholder triangle.

1. A policy officer from the Geothermal Sector of States Supervision of Mines on the role of SodM as controlling agency in a rapidly transforming energy system, and about the risks and uncertainties that are present in geothermal energy implementation **(P1)**. The interview took place on December 18th, 2019 at the main office of States Supervision of Mines in The Hague.

2. A scientist in the field of geothermal engineering, on the technical uncertainties present in this type of energy production **(P2)**. The interview took place on December 19th, 2019 at the Faculty of Civil Engineering and Geosciences at Delft University of Technology.

3. The Communication Advisor for small gas fields on his expertise in the production of onshore gas and the interaction with the local public **(P3)**. The interview took place on December 23rd, 2019 at the Ministry of Economic Affairs and Climate Policy in The Hague.

4. The Project Manager Mining Policy on the processes of policy–making for both gas and geothermal energy production **(P4)**. The interview took place on January 9th, 2020 at the Ministry of Economic Affairs and Climate Policy in The Hague.

5. The Policy Coordinator Geothermal Energy on the policy–making process for geothermal energy production **(P5)**. The interview took place on January 14th, 2020 at the Ministry of Economic Affairs and Climate Policy in The Hague.

6. The owner of Ammerlaan The Green Innovator on the experiences as a pioneer in the production of geothermal energy, and the existence of uncertainties in this technique **(P6)**. The interview took place on January 14th, 2020 at the main office of Ammerlaan – The Green Innovator in Pijnacker.

7. The Communication Advisor for the SCAN–project at Energiebeheer Nederland (**EBN**) on the role of EBN in the implementation of geothermal energy in the Netherlands and the potential for deep geothermal energy production **(P7)**. The SCAN–project

focuses on the identification of locations in the Dutch subsurface that is suitable for geothermal energy production. The interview took place on January 16th, 2020 at the main office of EBN in Utrecht.

8. The Senior Policy Advisor Renewable Energy on the communication around the implementation of geothermal energy production in the Netherlands **(P8)**. The interview took place on January 16th, 2020 at the main office of EBN in Utrecht.

9. The Development Manager of Shell Geothermal on the implementation methods of geothermal energy and the possible technical uncertainties in these techniques **(P9)**. The interview took place on February 4th, 2020 via Skype.

10. The Senior Advisor Energy Transition of the municipality of Delft on the specific developments and policy–making practices regarding geothermal energy implementation in Delft **(P10)**. The interview took place on February 5th, 2020 at the city hall of the municipality of Delft.

The design of the interview protocols
Based on the context of the research and the goal of each interview, a specified interview protocol was designed prior to each interview (see Appendix G for an interview protocol and transcript). Not every interview protocol was the same; depending on the expertise of the interviewee, the focus was more towards the technical uncertainties in geothermal energy implementation, the communication of technical uncertainties or the impact of these uncertainties on the level of social acceptance of geothermal energy.

Before every interview, the interviewee was told that the interview served the purpose of data–collection for this research. The research question, the relevant sub–questions and additional information was sent beforehand. At the beginning of every interview, the project was briefly explained again to the interviewee. Orally, permission was asked to record the interview with a mobile phone, so that the interview could be transcribed or summarised later on.

Participants approved of the use of quotations from the interviews in the report, which were translated from Dutch to English if necessary. Participants were offered the opportunity to review the interview transcript, along with any possible translated sections. Similarly, participants were offered a final pre-print version of this report, in order to check they use of their quotations.

Although not all questions in the interview protocols were the same for each interviewee, in every interview, whether it was with a scientist or a policy–maker, questions were asked about the ideas the interviewee had on the communication of the technical uncertainties. This was interesting to do because it did not matter what a person's role was; every interviewee had ideas about the technical uncertainties in geothermal energy implementation should be communicated, or how the rise of negative social sentiments around this technique of energy production can be prevented and reduced.

Interview transcripts
In the process of transcribing the interviews, two methods have been applied: a) the method of verbatim transcription (P2 (English) and P3 (Dutch)) and b) summarising transcription [Kawahara, 2007; Stuckey, 2014]. To provide insight in how the interviews were conducted, two interviews were transcribed using the method of verbatim transcription. The remainder of the interviews were summarised using the method of summarising transcription. In the transcripts of P2 and P3, filled and unfilled pauses have been left out of the transcript [Indian Scribes, 2018; Skukauskaite, 2012]. Interruptions are shown as three dots in the transcript. Despite the use of a recording device, face expressions, intonations and body

language [Kawahara, 2007] were not transcribed after the interviews. In the summarised interviews, segmented sentences or sentences that were not finished by the interviewee were constructed into regular sentences to form paragraphs. The use of 'I' was limited in the transcripts [Skukauskaite, 2012]; instead, the interviewees were de–identified [Stuckey, 2014] by 'P(number)', and the researcher as 'the researcher' for the cause of objectivity in the interview transcript.

Coding the interview transcripts and summaries
For this report, one example of a transcribed interview is included in Appendix G. The interview was held in English, so the transcript is in English as well. The interview transcripts were coded using Atlas.Ti software using the method of semi–open coding [Burnard, 1991]. After every interview, notes were made about the topics that had been discussed during the interview, and the transcript for each interview was worked out. When the transcripts for all the interviews had been worked out, each transcript was read carefully and notes were made on the topics that were discussed in more than one interview. In this phase of the research, the focus was on the technical uncertainties that are present in geothermal energy implementation and the ways how these uncertainties can or should be communicated to a local public. Based on these notes, the first code tree of the research was compiled (Appendix H, Figure H.1). Since the method of semi–open coding was applied, the code tree was expanded and supplemented each time an interview was coded. Each time the codes changes, the previously coded interview transcripts were re–coded. The choices of the to–be–used codes were made by the researcher, and these choices were based on the relevance of codes within the two main categories: technical uncertainties and the communication of these uncertainties. Over the coding process, the researcher followed these two categories (H.2).

Based on the results that were collected by the three aforementioned methods of data acquisition, first the draft and later the final version of the communication approach was designed. In the next section, the design and verification process that lead to the final communication approach will be described.

7.3. Design and verification process

THE three research methods resulted in a data base that included the ingredients for the communication approach: from the theoretical framework, an existing communication model served as the starting point. The different steps of this model were filled in based on the context description and the results from the interviews. After a draft approach for communicating technical uncertainties to a local public was created, five verification discussions were organised with policy–makers and communication–experts to discuss the results. In between these discussions, new insights were processed, thereby updating the approach in different feedback loops.

The goal of the verification discussions was to improve the communication approach with the help of people that are part of the initiator–group or people that have experience with the communication process to a local public and who had, preferably, experience with communication about geothermal energy. This way, the verification discussion could be specified on the case of uncertainty communication in geothermal energy implementation.

The verification discussions focused specifically on the communication of technical uncertainties to increase the level of social acceptance for the implementation of geothermal energy. To mark the boundaries of the scope in which the opinion of the interviewees was asked, the following limits were set:

- The type of uncertainties that is communicated, is limited to the *technical* uncertainties that are present in the *implementation phase* of a geothermal project.
- The communication process held between the initiators of a geothermal project and the local public that lives within a radius of 5 km.
- The communicators possess a sufficient amount of knowledge about the geothermal project and the technical uncertainties to contribute in a meaningful way to the conversation.

The interviewees that were selected for the semi–structured expert–interviews were contacted and asked for their views and ideas on the results. Some of the interviewees were available themselves for the discussion, some asked a communication–expert to join the discussion. Participants that had been interviewed before were send no information in advance, to guarantee a fresh view on the results so far. The participants that had not been spoken with before, received a summary of the research process and the relevant results in advance. This way, time was saved during the interview itself. The discussions were summarised and relevant data was processed from these summaries into this report.

To verify the draft version of the communication approach, the following people have been asked for a critical view:

1. The Senior Advisor Energy Transition of the municipality of Delft **(P10)**. The discussion took place on April 3rd, 2020 via Zoom. P10 had been interviewed before to identify the technical uncertainties that are present in the implementation process of a geothermal well at the campus of the TU Delft. During the discussion, P10 was specifically asked for feedback on the technical uncertainties that had been identified, and how these technical uncertainties can be communicated from the perspective of increasing social acceptance of geothermal energy implementation.
2. The Sector Leader Geothermal **(P1)** and the communication–expert for the Sector Geothermal **(V1)** of States Supervision of Mines. The discussion took place on April 3rd, 2020 via Skype. Where P1 was asked for feedback on the identification of the technical uncertainties and the links with social acceptance of geothermal energy implementation, V1 was asked about the ways of how these technical uncertainties could be communicated to a local public.
3. The communication advisor at the Ministry of General Affairs in The Hague **(V2)**. The discussion took place via Skype on April 6th, 2020. Due to the experience that V2 has in the field of resistance to policies and communication to a local public, the discussion with V2 focused on the reference frames of the communicating parties in a communication process.
4. Two communication–experts that work for the Dutch Association Geothermal Operators (DAGO) **(V3 and V4)**, the organisation that represents the operators that are active in geothermal energy production in the Netherlands. The discussion was held via Microsoft Teams on April 8th, 2020. Due to their link with the practice of geothermal energy production, these communication–experts were asked for their views on the communication of technical uncertainties that is adjusted to the different levels of social acceptance.
5. Three people living on the TU Delft campus who functioned as a focus group in a discussion about the reference frame of the public in the implementation of a geothermal well on the campus of the TU Delft **(F1)**. In this discussion, different methods

and channels of communications were discussed based on the constructed approach. This discussion took place Friday May 1st, 2020.

Each verification discussion took place via video–calling since the discussions took place during the lockdown because of the Coronavirus. To create an informal setting and open discussions during the meeting, no interview protocols were designed. This way, the participants were encouraged to think out loud about the direction of the design. Each discussion was recorded using a mobile phone so that the information could be extracted from the recording by the researcher. Orally, permission was asked to record the discussion to each of the participants and the question for permission can be heard on the recording.

7.4. Chapter summary

In this qualitative and exploratory research, the three main methods used for data collection were desk research, semi–structured expert–interviews and literature research. The desk research focused on the context of the study; the ongoing energy transition in the Netherlands, the need of social acceptance for a technique to be successful in the energy transition and the lessons that can be learned from how the communication towards the local public during the gas production in Groningen was organised.

Based on this context, semi–structured interviews with ten experts were organised to collect data about the technical uncertainties that are present in geothermal energy implementation in the Netherlands. Moreover, these interviews were used to collect information on how the communication process of technical uncertainties to a local public can be designed in a structured way. The interviews were coded in Atlas.Ti software and used extract relevant information from the interviews.

The third method of data collection, literature research, focused on a) the shared concepts of a transition process and the phases of these transition processes; b) the role of (technical) uncertainties in transition processes; c) the need of social acceptance in transitions and the impact of technical uncertainties on the level of social acceptance; and d) a communication approach which is based on a communication model.

The results of this study have been verified in discussion with a policy–maker, a supervisor and communication–experts that work in the geothermal sector in the Netherlands. After each verification discussion, the communication approach was adjusted and updated. In the next chapter, the theoretical framework of this research is provided (Figure 7.3).

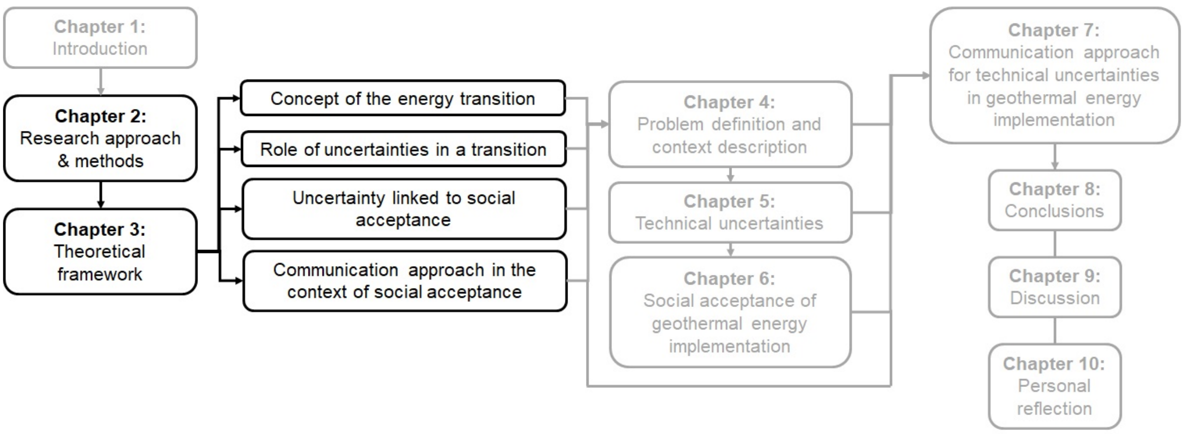


Figure 7.3: From approach and method description to theoretical framework.

8

Theoretical framework towards a model for communication of technical uncertainties

WORKING towards a communication model means unravelling the context first. As described in Chapter 6, the context of this research is the level of social acceptance towards the implementation of geothermal energy in the Dutch energy transition. A first step is to analyse the concept of 'energy transition' from a theoretical point of view (Figure 8.1). In this chapter, this will be done by the transition model presented by Loorbach and Rotmans [Loorbach and Rotmans, 2006], in which the energy transition is linked to three shared concepts: a) the transition itself; b) a transition framework; and c) transition management (Section 8.1).

Following to this model on the different phases of a transition and the role of uncertainty in a transition process, Section 8.2 describes the sources of uncertainty and the different types of uncertainty resulting from these sources. In Section 8.3, the importance of social acceptance for the success of a transition is described. The importance of the level of knowledge of the public in the context of the level of social acceptance of a transition process. Based on literature, a link is recognised between the level of knowledge of the public, the uncertainties that are present in the transition process and the level of social acceptance of the local public towards this transition process. In the light of the scope of this research, the role of technical uncertainties in uncertainty analyses is described.

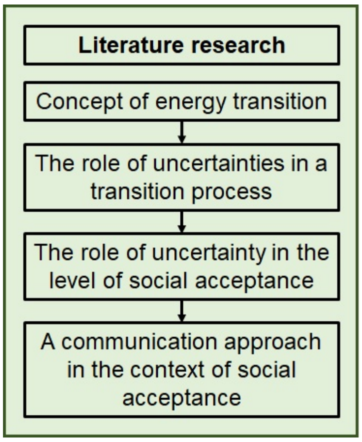


Figure 8.1: The different steps of the theoretical framework visualised in the green colour of the literature search (Chapter 7).

Finally, Section 8.4 discusses a communication model to serve as a base for the communication approach that will be designed in this study. This model will be applied on the case by introducing the different elements of the approach.

8.1. Theoretical approach of the energy transition

TRANSITIONS can be of great help in solving persistent societal problems [Loorbach and Rotmans, 2006]. In the light of this study, the transition that forms the reference frame is the energy transition: a transition is defined as *'the shift from an initial dynamic equilibrium to a new dynamic equilibrium'* [Rotmans *et al.*, 2001]. For the energy transition, this means the transition from a fossil fuel–based energy consumption to an energy system based on sustainable and renewable energy. This shift is characterised by fast and slow developments [Rotmans *et al.*, 2001]; it is a long–term process of change during which a society or sub–system of society fundamentally changes [Loorbach and Rotmans, 2006]. In the energy transition, a variety of participants is involved and both the structure of the system and the relation among the participants is significantly changed during the innovation process [Loorbach and Rotmans, 2006]; a transition can be described as a set of connected changes that take place in different areas, such as technology, economy, culture, belief systems, etc. and reinforce each other [Rotmans *et al.*, 2001].

In line with the definition of a transition as provided above, the energy transition can be described as a set of shared concepts. This way, the concept of the energy transition itself, the transition framework and the concept of transition management contribute to an understanding of the different aspects of the energy transition that will need to be defined in the context description of this study.

8.1.1. The energy transition as set of shared concepts

Previous research places the energy transition in a science perspective that is based on a set of three shared concepts [Loorbach and Rotmans, 2006].

1. The first shared concept is the energy transition itself. The concept of a transition is defined as a shift in a system from one dynamic equilibrium to another equilibrium. This process of change is highly non–linear: when things reinforce each other, slow change is followed by rapid change. This rapid change is followed by slow change again in the new equilibrium. The underlying mechanism is that of co–evolution, as different subsystems co–evolve with each other during the process of change. A transition can be accelerated by one–time events or a crisis, but can not be caused by such events. This is because co–evolution of a set of slow changes determine the undercurrent for a larger, fundamental change. In terms of content and context, two main types of transitions are distinguished:

    - Evolutionary transitions, in which the outcome is not planned or pre–defined.
    - Goal–oriented transitions, in which goals or visions of the end state guide public actors and orient the strategic decisions of private actors.

2. The second shared concept concerns a transition framework in which two concepts can be distinguished:

    - The multi–phase concept, which indicates that transition paths are highly non–linear with different phases, as the path from one dynamic to another is taken. During a multi–phase transition, the following stages are recognised [Loorbach and Rotmans, 2006; Rotmans *et al.*, 2001; Wiek *et al.*, 2006] (Figure 8.2):

        (a) The *pre–development phase*, where there is a very little visible change at the systems level, but a lot of experimentation at the individual level.

        (b) The *take–off phase*, where the process of change starts to build up and different reinforcing innovations cause a start in the shift of the state of the system.

        (c) The *acceleration phase*, in which accumulation and implementation of socio–cultural, economic, ecological and institutional changes cause visible structural changes.

(d) During the *stabilisation phase*, the speed of societal change decreases and a new equilibrium is found.

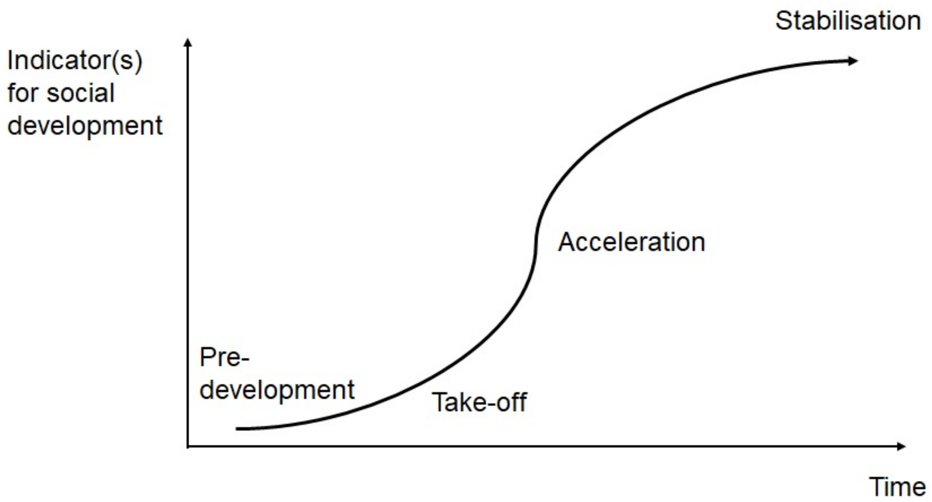


Figure 8.2: The four phases of transition. Image modified from Rotmans et al. [Rotmans et al., 2001].

- The multi–level concept, which describes a transition process in terms of different, interlinked scale dynamics. In the multi–level concept, a distinction is made between niches, regimes and the socio–technical landscape at three interacting scale levels: the micro–, meso–, and macro–level [Loorbach and Rotmans, 2006].

  (a) At the macro–level, the socio–technical landscape is determined by slow changes in material and immaterial elements: political culture and coalitions, material infrastructure, social values, worldviews and paradigms, demography and the natural environment [Rotmans *et al.*, 2001]. This level comprises conglomerates of institutions and organisations [Rotmans *et al.*, 2001].

  (b) At the meso–level, the social norms, interests, rules and belief systems that underlie companies', organisations' and institutions' strategies and political institutions' policies are found. This level comprises networks, communities and organisations [Rotmans *et al.*, 2001].

  (c) On the micro–level, there are individual actors, technologies and local practices (companies, environmental movements [Rotmans *et al.*, 2001]); at this level, deviations from and variations to the status quo can occur, such as alternative technologies and social practices [Rotmans *et al.*, 2001].

  Across the different levels that have been described above, individual actors (micro–level) may act as a catalyst in the transition process.

3. The third shared concept is the concept of transition management, which indicates that transitions can be managed: adjusted, influenced and steered. Transition management aims to better organise and coordinate transition processes at a societal level.

Now that the energy transition has been described as a set of shared knowledge, the four main activities in transition processes will be described. These four activities are relevant on the multiple levels of the transition process and allow to identify the different phases of a transition process.

8.1.2. Four activities in transitions

Across the macro–, meso– and micro–level, transition management is a cyclical and iterative process; one round of the cycle consists of four main activities [Loorbach and Rotmans, 2006; Loorbach, 2009]:

1. **Strategic: problem structuring and the establishment of the transition arena.** The first activity is to identify the participants of the transition process. Participants need to be open–minded and able to look beyond their own domain. Participants in the transition arena need a constant feed of background information and detailed knowledge on specific topics, to support the process of co–production of knowledge among the participants. During this process, the transition issue is framed in time and space and in relation to other issues in relevant fields. The transition manager has an important role in this process; as he or she brings together the different participants, is responsible for the overall communication in the transition arena and overviews the different activities that take place within the arena.

2. **Tactical: development of a long–term vision and a common transition agenda.** The organisation of an envisioning process requires that one questions one's own paradigm and it requires the ability insight to look ahead one or two generations. All participants in a transition process take their agenda into the arena; therefore it is important to design one common problem perception and shared vision. This is called the transition agenda. In the transition agenda, it is important to decide which participant is responsible for which type of activity or project [Dirven *et al.*, 2002].

3. **Operational: initiation and execution of the transition process.** This step is about the exploration of the uncertainties that play a role in transition processes. These uncertainties can be the result of a lack of knowledge and can be reduced, but they can also be caused by the variability of the system and so be structural and irreducible by nature. In the transition management cycle, these uncertainties need to be explored and mapped systematically. Learning more about the uncertainties in the process may lead to an adjustment of the transition images, visions and goals. In this process, the development of different scenarios plays an important role.

4. **Reflexive: monitoring and evaluation of the transition process.** Two monitoring processes are distinguished: a) the monitoring of the transition itself, and b) the monitoring of the transition management. The monitoring of the transition management asks for monitoring of the actors within the transition arena first regarding their behaviour, alliance forming, networking activities, and responsibilities. Secondly, the transition agenda needs to be monitored concerning the actions, goals, projects and instruments that have been set previously. Lastly, the transition process itself needs to be monitored in terms of progress, barriers and improvements.

The essence of transition management can be summarised by *learning–by–doing* and *doing–by–learning*. Learning–by–doing concerns the development of theoretical knowledge from practice, whereas doing–by–learning is the development of practical knowledge from theory [Loorbach and Rotmans, 2006; Wiek *et al.*, 2006]. Learning–by–doing is realised by monitoring, evaluating and adjusting the strategy and its outcomes as it is being executed [Wiek *et al.*, 2006].

In the third activity described above, the role of uncertainties in the initiation and the execution of the transition process is mentioned. In the next section, the sources of uncertainty in a transition process will be described, resulting in an overview of the role of uncertainty in transition processes.

8.2. Uncertainty in transition processes

COMPLEX societal problems, such as the energy transition, do not arise simple, one–dimensional questions that can be answered unambiguously by science [Van Asselt, 2000], leading to the situation that these issues inherently involve uncertainty. The spectrum of different levels of knowledge shows a strong variation, from complete ignorance to the unachievable ideal of complete understanding [Walker *et al.*, 2003]. To increase the level of knowledge of the public, uncertainties will partly or completely need to be communicated to the public [Kramer, 2014]. Therefore, this section provides an overview of the sources of uncertainties and their role in a transition process. All combined, uncertainty can be defined as *'the entire sets of beliefs and doubts that stems from our limited knowledge of the past and the present and our inability to predict future events, outcomes and consequences'* [Van Asselt, 2000].

The sources of uncertainty can be classified into two categories [Van Asselt, 2000]:

1. **Variability**, when the system can behave in different ways or if the system is valued differently. Variability leads to variability uncertainty, which is defined as *'the randomness induced by variation associated with external input data, functions, parameters and certain model structures' [Walker et al., 2003]*. Sources for variability uncertainty are social, economic and cultural dynamics, human behaviour and value diversity [Van Asselt, 2000; Walker *et al.*, 2003].

2. **Lack of knowledge**, which is a property of the analyst performing the study. Lack of knowledge is partly a result of variability, but other sources are inexactness (measurement errors or metrical uncertainty), a lack of observations or measurements, practically immeasurable, conflicting evidence, reducible ignorance, indeterminacy and irreducible ignorance. The first three sources of a lack of knowledge (inexactness, lack of observations and practically immeasurable) are also known as unreliability, whereas the last four sources are referred to as structural uncertainty or systematic uncertainty [Van Asselt, 2000; Walker *et al.*, 2003]. A lack of knowledge leads to epistemic uncertainty.

'Uncertainty' versus 'risk'

In literature, various definitions are provided of the terms 'risk' and 'uncertainty'. Some define 'risk' as '*the product of the probability of a consequence and its magnitude. Therefore, risk considers the frequency or likelihood of occurrence of certain states or events (often termed 'hazards') and the magnitude of the likely consequences associated with those exposed to these hazardous states or events*' [Young *et al.*, 2003]. The term 'uncertainty' is defined in the same report as follows: '*Uncertainty exists where there is a lack of knowledge concerning outcomes. Uncertainty may result from an imprecise knowledge of the risk, i.e. where the probabilities and magnitude of either the hazards and/or their associated consequences are uncertain. Even when there is a precise knowledge of these components, there is still uncertainty because the outcomes are determined probabilistically*'. In other words, uncertainty describes the '*quality of the knowledge concerning risk*' [Young *et al.*, 2003]; uncertainty is defined as a characteristic of the environment or a psychological state [Bordia *et al.*, 2007]. Research aims to reduce uncertainties in an innovation process, but the primary purpose of adopting a risk–based approach to decision–making is to ensure that uncertainty is acknowledged and treated accurately in decision–making [Young *et al.*, 2003]. Since the probability and frequency of negative events are hard to qualify for geothermal energy, the term 'risk' is left outside the scope of this research in the remaining part of this report.

Both sources of uncertainty ask for different strategies of uncertainty reduction: *'epistemic uncertainty can be reduced but is difficult to quantify; variability uncertainty is easier to quantify, but hard to reduce'* [Peerlings, 2019]. Both epistemic and variability uncertainty are linked to different types of uncertainty. A type of epistemic uncertainty are *technical uncertainties*, which are a result of the quality or appropriateness of the data used to describe the system [Walker *et al.*, 2003]. In other words, technical uncertainty is a primary result of uncertainty due to unreliability.

The generation, integration and sharing of knowledge is of vital importance to a transition process. System changes and transition processes are often surrounded with great uncertainty [Kemp and Loorbach, 2005; Loorbach and Rotmans, 2006; Morgan, 2003], and since the importance of knowledge, a lack of knowledge might act as a barrier in the energy transition [Jauch and Kraft, 1986; Loorbach and Rotmans, 2006]. In the next section, this link between a lack of knowledge as a barrier in the energy transition will be analysed from the perspective of social acceptance.

8.3. The context of the communication approach: social acceptance as a factor for success in the energy transition

TRANSITION processes are often accompanied by (technical) uncertainties that result from the state of development [Huijts *et al.*, 2007]. People that are confronted with these technologies will try to form their own perceptions; a lack of knowledge or uncertainty might form a barrier in the process of forming a perception. On the opposite, pre–existing knowledge about a transition or technique can also form a barrier if this knowledge limits the acceptation or consideration of new knowledge. For these people, it is difficult to balance risks and benefits against each other since information in these situations is limited. In situations like this, intuitive feelings based on life experiences can start to play a more important role and form a negative sentiment around the transition process [Huijts *et al.*, 2007]; concerns can turn into beliefs that are so persistent, while not necessarily related to risk.

Due to the persistent character of the energy transition, the transition is likely to lead to permanent alterations in the organisation of society and the patterns of resource use [Scheidel and Sorman, 2015]. For the (successful) implementation of renewable energy sources, public acceptance is of vital importance [Wurstenhagen *et al.*, 2007; Yazdanpanah *et al.*, 2012]; public acceptance also establishes the degree to which the public is willing to support the development, use and implementation of these renewable energy sources [Yazdanpanah *et al.*, 2012]. In other words, these people play an important role in the energy transition; nowadays no technical choice on any energy model or source can be adequately implemented without social acceptance [Yazdanpanah *et al.*, 2012].

In transition processes, there are several ways in which the social acceptance by the public can be increased, under the assumption that social acceptance of the transition is in favour of the final state of the transition process. Social acceptance is, in general, a social process, with actors influencing each other through different types of interaction [Huijts *et al.*, 2007]; the level of social acceptance often depends on the views of different stakeholders, from professionally involved actors such as the government and NGO's, which is often channelled by the media, to the view of the local public. Since it may be difficult for the public to understand, select and process this information, these people rely on others to form balanced personal views on the technologies [Huijts *et al.*, 2007]. In this process, trust is important; that is *the extent to which one expects the other to act in line with the needs and interests of oneself* and *the willingness to be vulnerable under conditions of risk and interdependence* [Huijts *et al.*, 2007; Rousseau *et al.*, 1998]. People's acceptance of a transition process might be troubled by a lack of trust in the leading actors regarding a supposed neglect of the public interests, hesitations about the fair allocations of benefits and risks and the safety of the public [Huijts *et al.*, 2007; Liu *et al.*, 2019]. On the contrary, trust may increase the tolerance of uncertainties, the willingness of the public to explore possibilities and open the public to new information [Huijts *et al.*, 2007]. Assuming that trust consists of two main components, i.e. a) the perceived good intentions of a trustee, and b) the perceived competence of the trustee [Johnson, 2011], the trustee should be able the handle these two components in a transition process to lead the process towards the desired end state. Trust between two communicating parties depends to a certain extent on the level of shared values between the two communicators [Gillespie and Mann, 2004]; the more people identify with each other's values, the higher the expected level of trust in each other. Suspicion towards investors, mistrust, the level of awareness and the level of knowledge of the public [Dowd *et al.*, 2011; Rosso-Ceron and Kafarov, 2015; Stigka *et al.*, 2014] have a negative effect on the level of social acceptance of a transition.

Other factors that influence the social acceptance of a transition are economic and institutional factors, such as the economic conditions in a region, complex licensing or bureaucratic problems; and, technical or planning factors, such as issues with the previous use of a location.

Altogether, public awareness, perceptions and social acceptance of renewable energy sources are elements that should be taken into account in the governance of the energy transition. Implementation of renewable energy sources, such as geothermal energy, can be effective and sustainable only if the public is aware of the benefits and the need for implementation [Yazdanpanah *et al.*, 2012]; the public needs to support the energy transition for it to be successful. Studies from various fields [Byrnes *et al.*, 2013; Ndamani and Watanabe, 2015; Upham *et al.*, 2015; Wheeler, 2008] explain that a lack of public support due to benefit perceptions, the level of awareness, risks and a lack of knowledge can lead to a rejection of scientific innovation and the development of new technologies [Yazdanpanah *et al.*, 2012].

Three dimensions of social acceptance are distinguished [Wurstenhagen *et al.*, 2007] (Figure 8.3):

1. The *socio–political dimension* refers to the acceptance of a technology by politics, policy makers, key stakeholders and the public [Rosso-Ceron and Kafarov, 2015].
2. The second dimension is *market acceptance*, which refers to the process of market adoption of an innovation or acceptance of a technology by consumers, investors and intra–firm.

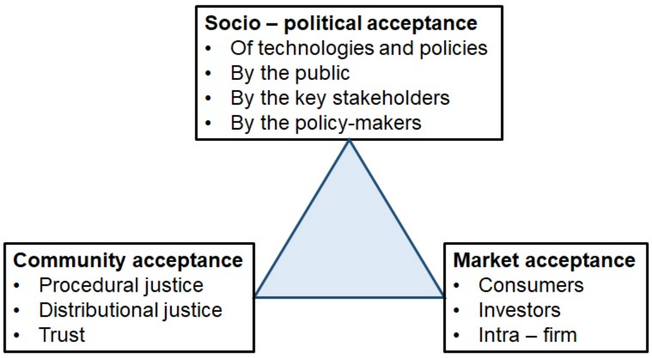


Figure 8.3: The triangle of social acceptance. Image modified from [Wurstenhagen et al., 2007].

3. The third level is the *community level*, which refers to the specific acceptance of local stakeholders, such as residents and local authorities. This is the level on which the debate around the idea of 'Not In My Backyard' **(NIMBY)** unfolds, which holds the idea that people support renewable energy implementation as long as it is not in their backyards; this phenomenon might lead to social conflict and economic losses [Rosso-Ceron and Kafarov, 2015]. The opposite is the PIMBY (Please In My Backyard) phenomenon, which is considered to occur when a process is considered favourable

and reviewed positively by local communities [Rosso-Ceron and Kafarov, 2015]. One feature of community acceptance, is that is has a time dimension [Wolsink, 2007]; the local acceptance shows a U–curve, wherein one goes from a relatively high acceptance to a low acceptance during the implementation phase and back up to a higher acceptance once the project is running.

This study focuses on the level of the community, as the local public of a geothermal energy project has been included as one of the main communicating parties. The three main concepts influencing the level of acceptance are procedural and distributional justice, and trust. Procedural justice deals concerns the *'timely access to decision-making processes and fair and transparent procedures that engage all stakeholders in a non-discriminatory way'* [Jenkins *et al.*, 2016]. Main elements of procedural justice are a) the access to relevant information for all stakeholders, b) the access to and a meaningful participation in the communication process, and c) a lack of bias by the stakeholders that have a decision–making role in the communication process [Sovacool and Dworkin, 2015]. Distributional justice deals with the *'distribution of material outcomes, or public goods such as resources or wealth and public bads such as pollution or poverty'* [Sovacool and Dworkin, 2015]. The meaning of trust in the context of this research has been described earlier in this section [Huijts *et al.*, 2007].

In previous sections, the role of uncertainty in the level of social acceptance has been identified. In this study, a communication approach for the communication technical uncertainties to a local public is proposed. In literature, links between the increase of information and a decrease in uncertainty have been found [Kramer, 2014]. In the light of this communication approach, a communication model that will serve as a basis for the communication approach will be provided in the next section.

8.4. Working towards a communication approach: starting from a communication model

COMMUNICATION is a relevant dimension in the success of a change process and is considered important in the reduction of uncertainties [Simoes and Esposito, 2014]. The term 'communication' is defined as '*a social process where people, immersed in a particular culture, create and exchange meanings*' [Simoes and Esposito, 2014]; communication is not limited to verbal products or written expressions but includes gestures, actions and behaviours.

Communication models come in all sorts and sizes. Basic communication models focus on unilateral communication; one–way communication from a sender to a receiver [Trench, 2008]. In these linear models, the receiver needs to consider the sender as being credible, the message as being suitable and the receiver needs to be receptive to the message to obtain the desired effect [Oomkes, 2013]. Since the communication of uncertainty in the perspective of increasing social acceptance is merely a bilateral and interactive process, the communication model proposed by Oomkes [Oomkes, 2013] was chosen as a starting point in this study (Figure 8.4).

Due to the interactive aspects of this communication model, being open to each other is one of the key factors of a successful communication process. From Figure 8.4 one can interpret the importance of both communicators having equal opportunity to participate in the conversation and to determine the content of it. Both participants must be willing and able to listen to each other and take suggestions that are put forward by the other party into consideration. Lastly, mutual respect and empathy are important factors in this model,

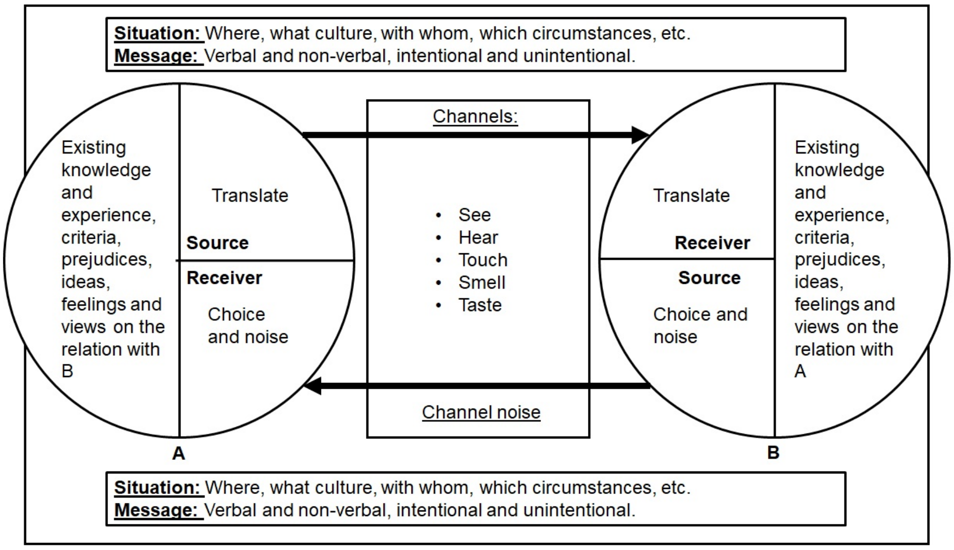


Figure 8.4: The bilateral communication model proposed by Oomkes [Oomkes, 2013].

combined with the fact that both participants need to take each other seriously. The topic of the communication process must be able to change and develop during the conversation, and people need to feel free to change their opinions while knowing their views are taken into consideration.

In the next sections, the different steps in the communication model of Figure 8.4 will be discussed.

8.4.1. Context, goal and situation description

The communication model in Figure 8.4 starts with a description of the **situation** in which the communication process takes place [Oomkes, 2013]; at this stage of the communication process, questions of where, under which circumstances, when, by whom, etc. the communication process takes place, are asked. The location of a communication process partly defines what is discussed; specific locations contribute to a specific way of conversation – a church or a library is not the right location for a conversation that is full of jokes. Other factors that play a role in the situation of a communication process are the level of privacy, the spatial organisation of the conversation location and the time duration of a conversation.

Context, goal and situation in the communication approach

For the communication approach that will be designed in this study, two steps before the situation description are implemented in the model. The first step is a description of the **context** in which the communication process takes place (Figure 8.5, in blue). The context of the communication approach in this study is defined by the level of social acceptance for geothermal energy implementation and how this level can be increased by the communication of technical uncertainties.

Determined by the scope of this research, 'technical uncertainty' is the main type of uncertainty in the communication approach. However, communicating technical uncertainties does not automatically lead to an increase in social acceptance. For the topic of this study, multiple aspects affect the level of social acceptance in a transition process will be discussed in Chapter 9. The communication of uncertainty to increase the level of knowledge is one method that influences the level of social acceptance, and a subset of uncertainty communication is formed by the communication of technical uncertainties. In Chapter

14, an analysis of the other types of uncertainties as posed above in uncertainty communication will be provided.

The second step is to define the **goal** of the communication process [Kloprogge *et al.*, 2007] (Figure 8.5, in blue). There are multiple types of goals that can be addressed by uncertainty communication; for example *creating awareness about the existence of important uncertainties, developing agreement about the different project option, if possible* or *enhance understanding of specific ideas* [Rowan, 1991]. The goal of the communication process can be to *inform* or to *persuade* the other communicator [Rowan, 1991]. Each type of goal implies a different communication strategy and a different relationship between the communicators. The goal of the communication process therefore determines to a large extent the outline of the process and should therefore be determined at the start of the communication process. The goal for the communication in this study is to communicate the different technical uncertainties that are present in the geothermal project in order to increase the level of social acceptance of geothermal energy implementation. This goal is defined to reduce the impact of undesired surprises, rather than hoping to eliminate these surprises [Walker *et al.*, 2003].

The context and the goal of the communication process that will be addressed in this study, are equal in each communication process. This means that it is within the scope of this study to design a communication approach that focuses specifically on the communication of technical uncertainties to increase the level of social acceptance. Within the context of the approach and the main goal that has been defined previously, the **situation** in which the communication process takes place is specific for each case. The situation in which the communication process takes place, can be expressed in terms of which stakeholders are involved, in which setting the communication process takes place, and where in along the technical timeline of a geothermal project the communication process can be initiated. In Figure 8.5, this is visualised by the context and goal not having a direct link with the communication process, whereas the situation description is linked to the communication process.

Concerning the involvement of the stakeholders, in both the sender and receiver groups, the stakeholder group that has the ultimate responsibility in the communication process needs to be determined to organise the communication process in a structured way. The stakeholder group that is appointed to have the ultimate responsibility, takes the lead in the communication process and draws the general outline of the communication process. Other aspects of the role of the responsible stakeholder, are, for example: who will be the communicator towards external parties, such as the media, or if the communication experts will be involved in the communication process, and what the role is of policy or technical experts in the communication process. Moreover, ideas need to be shared about if and how all senders tell the same story during the process, or that differences might be highlighted in the communication process. Lastly, the influence of one shared message is on the success of the conversation needs to be determined.

Regarding the location, the decision for organising the communication process at different locations have consequences for the content of the conversation(s), since different locations at suitable for different communication processes [Oomkes, 2013]; organising an information evening in the local library, or visiting people at home in house–to–house visits leads to a completely different setting. Secondly, the spatially distribution of the communicating actors over the available location needs to be considered in advance. Considering the last step of the situation description the timeline of the project needs to be identified and linked to the different steps in the communication process. By doing so, the technical planning of the project will be visualised and ideas about when the external communication needs to take place can be shared amongst the stakeholder groups. This way, the technical and social timeline of the project are integrated.

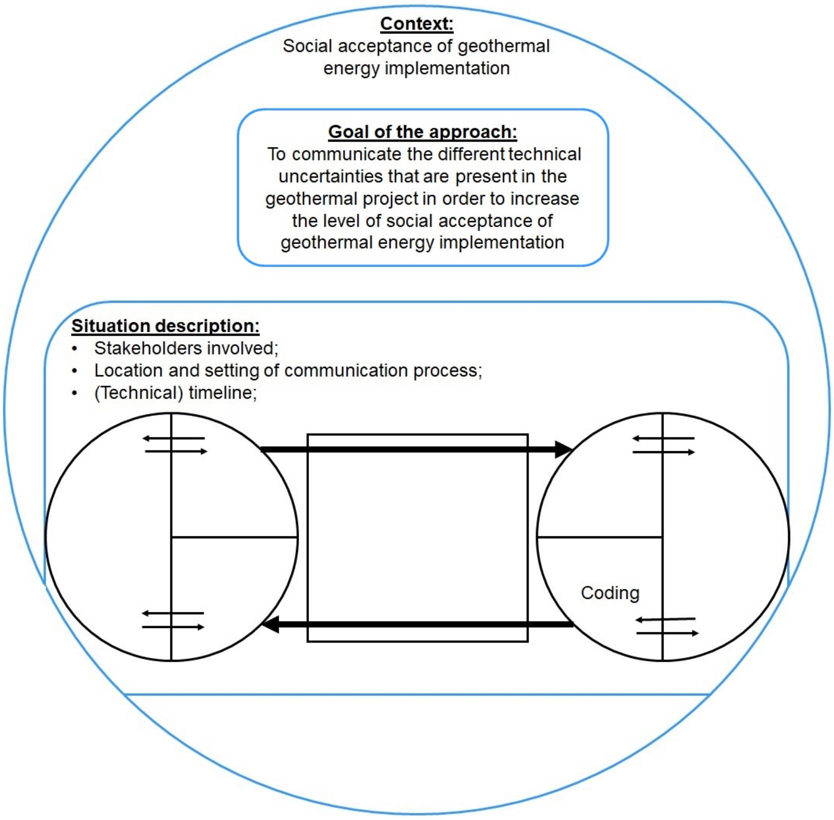


Figure 8.5: The communication model [Oomkes, 2013] adjusted for the context, goal and situation description for this study.

8.4.2. The communicators in the communication approach

Figure 8.4 shows a model of **two communicators**; a sender and a receiver. The sender, or source, communicates the message from one's own experience, perspective, standards, knowledge preconceptions. However, in real life, also the relationship with the receiver and the assessment of the situation play, consciously or subconsciously, a role in the communication process [Wehrmann and Dijkstra, 2018]. The same holds for the receiver: the message is being interpreted based on the receivers' knowledge, perspective, standards, experience and preconceptions. These pre–existing knowledge, experiences, standards, etc. of the sender and the receiver can be the same, but they can also be completely different from each other. Moreover, the situation in which the communication process takes place might also have an impact on how the sender and receiver interpret the messages that are transferred.

In uncertainty communication, a distinction is made between primary target audiences (the receiver, for which the report or communication matter is specifically intended) and secondary target audiences, who may be described as 'others who are interested in the matter' [Kloprogge *et al.*, 2007; Wardekker *et al.*, 2008].

In the perspective of the design of a communication approach for the communication of technical uncertainties to a local public, amongst multiple stakeholder groups, the 'initiators of a geothermal project' are chosen to be the senders (group A) and the 'local public' is chosen as receiver (group B) (Figure 8.6, in pink).

The initiators of the geothermal project have been assigned as senders based on the social perspective that resulted from the gas production in Groningen; there, the national government and the operator failed to communicate uncertainties in a transparent way to the local people for more than thirty years. To draw a parallel for the case of geothermal energy implementation, the national government and the operator are, together with the regional government and SodM, appointed as senders in this communication process. Due to the local scale on which the geothermal energy projects will take place, the role of regional governments is bigger than in the old situation, where the gas came from in Groningen. Therefore, the municipalities have a role in the communication process with their local public. SodM was appointed as one of the initiators based on its supervising role and independent review of the feasibility of geothermal projects. Also in line with the parallel to 'Groningen', the local public was determined to be the other communicating party. In this study, the communication of technical uncertainties towards the public has been studied. Although being categorised under the term 'local' – meaning living within a radius of 5 km from the location of the geothermal project – the public is a varied group of people; it is assumed that people from different ages, different levels of education and working in various sectors are represented in the public.

A stakeholder group that plays an important role in uncertainty communication, but is not directly taken into account as sender or receiver in the communication process, are news media journalists. In some cases, the stories of journalists will celebrate a new scientific finding and thereby, downgrade uncertainties, whereas in other cases, journalists will emphasise the difference of opinions among scientists, and thereby highlight uncertainties [Friedman *et al.*, 1991]. When a new piece of scientific knowledge or information needs to shared with the public, it becomes difficult for scientists to speak with one voice. Journalists play an important role in determining which voices are heard in a transition process. Since journalistic practice recognises the attractiveness of controversy as news, it plays a role in the framing of uncertainties towards the public [Friedman *et al.*, 1991].

In the design of the communication approach, the choice is made that the communication of technical uncertainties to the local public takes place between the public and the initiators. This choice was made to limit the complexity of the communication approach, in order to make it applicable in different communication settings. In reality, however, the communication process can take place between the local public and more than one of the initiators at the same time.

The relationship between different communicators in the communication approach

The organisation of a communication process between two parties that do not share any type of relationship is difficult; in conversations, the participants build towards a relationship [Littlejohn and Foss, 2008]. For the communication process of technical uncertainties, these relationship is between the initiators of a geothermal project and the local public. Over time, the ways how people communicate influence their relationship; different communication patterns define who is in control over the relationship, who is included and what direction the relationship takes [Littlejohn and Foss, 2008].

8.4.3. Coding and decoding from a reference frame

Once the focus and the target groups for the uncertainty communication process have been determined, the reference frames from which the communicating parties act in the communication process are identified (Figure 8.7, in green). In a communication process, the sender goes through the process of implementing thoughts and feelings into words, body language or images [Oomkes, 2013]. On the other side of the model, the receiver goes through the reversed process of interpreting the message based on thoughts, feelings and ideas. For an effective communication process, this means that the message is adjusted to

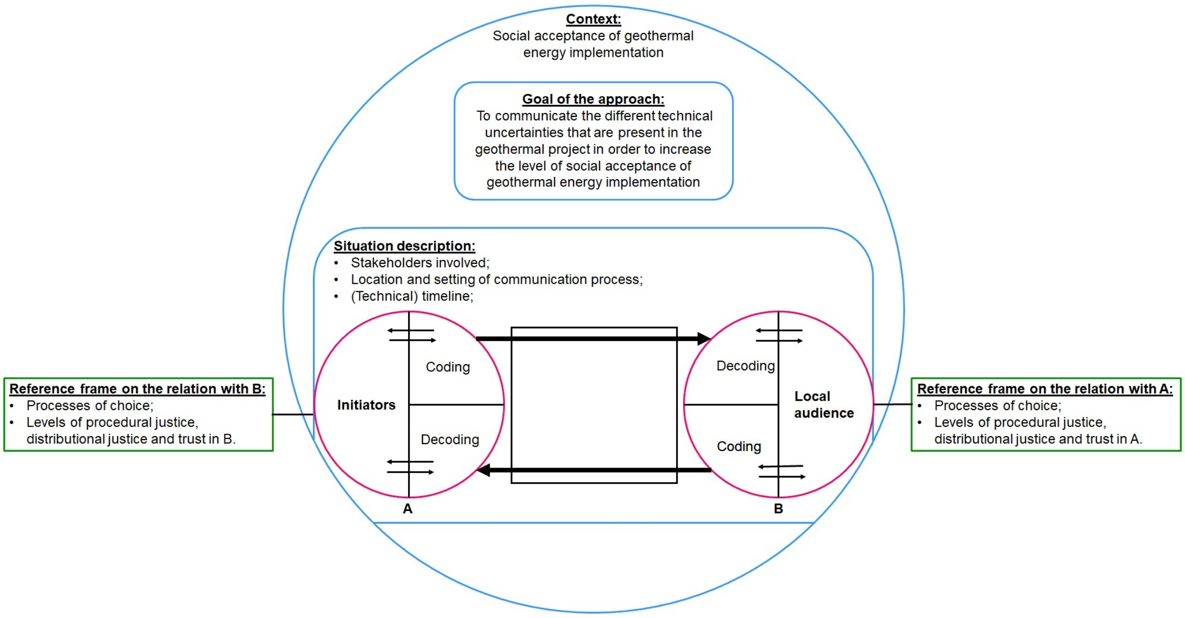


Figure 8.6: The communication model [Oomkes, 2013] adjusted for the communicating actors and the reference frames they apply in a communication process.

the receiver because the receiver needs to understand the message of the communication. Adjusting the message to the receiver can be done by choosing words that are understood by the receiver, considering its level of understanding, preconceptions and vocabulary, and to project the message in the experiences of the receiver.

In other words, the message is coded by the sender and decoded by the receiver based on an existing set of knowledge, prejudices, opinions, feelings, ideas, etc. In total, there are seven selection mechanisms or **processes of choice** that might play a role in the definition of this reference frame of the communication process:

1. Selective sending: the sender only sends the messages of which he/she thinks they will be appreciated by the receiver.
2. Selective receiving: selective receiving is a necessity since it is impossible to read, watch and listen to all messages that are being communicated by news media, radio, tv, books, etc. And so one has to choose for certain communication channels and messages. From all available information, people choose to receive the messages that suit their ideas and opinions [Lakoff, 2004].
3. Selective attention: in a communication process, it is physically impossible to process all incoming impressions. Therefore, people choose what is processed and what is left out of scope for the communication. Overall, more time is spent on reading the primary layer of the report, where the summary, introduction, conclusions, recommendations, and chapter that contain relevant information to the reader are found [Kloprogge *et al.*, 2007].
4. Selective observation: based on observation, people choose what is desired, expected or what seems logical to fill existing gaps in their knowledge.
5. Selective remembering: people tend to forget the things that do not match their opinions, values or does not support their visions. Typically, readers with a negative attitude towards the conclusions of a report tend to spend little time reading the document or specifically search for uncertainty information that supports their ideas [Kloprogge *et al.*, 2007]. Receivers that have a positive attitude towards the conclusions of

the report, show the exact opposite behaviour; since information about uncertainties is not in line with their views, they tend to skip the uncertainty information or process it in a fast and frugal way.

6. Selective acceptance: in a communication process, people are more willing to accept the things that are beneficial for them.
7. Selective talking to others: people can not discuss everything that is heard, seen or thought. Therefore, people choose what they discuss with friends and colleagues.

After the uncertain information has been read and processed, there are multiple options of what is done with the information [Kloprogge *et al.*, 2007]. Information can be simply forgotten, or be dismissed by the reader if it is not concerned to be relevant or important.

8.4.4. Theories supporting the definition of a reference frame

The different aspects of the reference frame link to different theories in communication theory. In this section, three of these theories will be described and their link to the reference frame of the communicating actors will be provided. These three factors of the reference frame of the communicators can be linked to the *social–judgement theory*, which is part of the socio-psychological tradition in communication theory [Granberg, 1982; Littlejohn and Foss, 2008]. The socio-psychological tradition focuses on the communicators as individuals; the social–judgement theory describes how statements are judged by the communicators in a conversation, and impact the belief systems of the communicators. Each communicator comes with an own set of social perceptions, which are centred around reference points that are (unconsciously) chosen by the communicating actors. Each communication process takes place within these social perspective of the different participants. Social–judgement theory also implies that a message that is in line with the social perspective facilitates attitude change. Specific to the case, this means that people that are positive towards geothermal implementation are more willing to be open to technical uncertainty.

The *elaboration–likelihood theory* continues on the social–judgement theory by discussing the probability that a communicating party will evaluate the incoming and outgoing information critically [Littlejohn and Foss, 2008; Petty and Cacioppo, 1986]. Therefore, this theory strongly links to the seven processes of choice described previously. There are two ways of processing information: *the central route* and the *peripheral route*. When using the central route, arguments are weighed carefully; the communicator thinks actively about the information and weighs it to what is already known. When one chooses the peripheral route, the information is much less critically reviewed. Attitude changes will therefore be more temporally. The level to which information is overthought critically depends on the motivation and the ability of the communicator; a high motivation is often channelled into the central route, whereas a low motivation often leads to the application of the peripheral route. This reflects back to the processes of selective attention and selective acceptance, since people that have a higher motivation and interest in the topic of the conversation, it is likely that they pay more attention to it. ‘Motivation’ can be split up into three factors: a) involvement, or the personal relevance of the communicated topic, b) the diversity of the arguments, and c) the personal predisposition towards critical thinking [Littlejohn and Foss, 2008; Petty and Cacioppo, 1986]. A last factor of motivation comes from the wish to disprove information that is not in line with someone’s expectations [Heneman and Schwab, 1972].

In the cybernetic tradition of communication theory, the connections of different parts of a system are emphasised [Littlejohn and Foss, 2008]. The *information–integration theory* focuses on the way people collect information about other persons, objects, and situations to form attitudes or predispositions towards a certain topic [Anderson, 1971]. For the communication of technical uncertainties towards a local public, it might be useful to identify the sources of information on which the attitudes and ideas of the public have been based, to be able to place the reference frame of the public in a larger context. In this study, the social perspective developed during the gas production in Groningen forms, for example, one of the sources of information for the attitudes and ideas of the public towards the implementation of geothermal energy. Two factors play a key role in the information–integration theory: valence and weight. Valence indicates if information supports one's beliefs, or refutes them; if information has positive valence, it means the information supports one's beliefs. The second factor, weight, is linked to the credibility of the information; if someone values information to be true, this information probably plays a larger role in the belief of that person [Kaplan and Anderson, 1973]. In addition to the information–integration theory, the *theory of expectancy–value* explain the changes in attitude due to three different sources [Littlejohn and Foss, 2008; Smetana and Adler, 1980; Wilson *et al.*, 1975]. The first source is information that can change the weight of specific personal beliefs. Secondly, information can change the valence of a belief. Lastly, information can add new beliefs to an existing set of beliefs.

These theories all contribute to how the reference frames of the main communicators are constructed, because these theories indicate how people value, weigh or collect available information. In Section 8.3, three concepts that impact the level of community acceptance (Figure 8.3) have been mentioned:

1. procedural justice;
2. distributional justice;
3. trust.

In the communication of technical uncertainties, these three concepts (partly) determine the reference frames of the main communicators: in a communication process that takes place in the context of social acceptance, the factors that form the level of social acceptance determine how the communicators interpret and translate the messages.

1. In the definition of a reference frame of the communicators, the concept of *procedural justice* [Jenkins *et al.*, 2016] identifies a) the extent to which the communicators have the access to relevant information, b) the extent to which the communicators have access to a meaningful participation in the communication process, and c) a lack of bias by the stakeholders that have a decision–making role in the communication process [Sovacool and Dworkin, 2015]. The concept of procedural justice is based on two models: the control theory and the group–value model [Erdogan *et al.*, 2001]. The control theory states that individual communicators desire to control what happens to them and what their role in the process is; when the communication process is important to them, the individuals prefer to be part of the process than wait passively and be controlled by other parties [Erdogan *et al.*, 2001]. The group–value model states that individuals want to be considered as valuable members of the groups they participate in [Erdogan *et al.*, 2001]. The communicators perceive higher procedural justice when they believe that they are respected in their groups [Erdogan *et al.*, 2001]. For a higher level of procedural justice, the communicators each have control over the communication process according to the control theory. If people feel that they are in control of the direction and the discussed topics in the conversation process, they are

more willing to invest and cooperate in the conversation [Baronas and Louis, 1988]. In other words, if the people feel that their level of control in affected in a negative way, a more negative attitude towards the transition process is developed. Conditions that determine the level of procedural justice in a communication process are, amongst others, a) being trustful in communication, b) treating the other communicators with respect, and c) suppressing biases [Folger and Bies, 1989]. Being truthful in communication includes fairness and transparency and main values in the communication. For a meaningful participation of all communicators in the communication process, the communicators have a certain level of existing knowledge about the other communicator(s), the goal of the communication process or procedure of the communication process [Kemp and Loorbach, 2006; Kloprogge *et al.*, 2007; Rotmans and Kemp, 2003]. Procedural justice implies access to information for all participants in the communication process, thereby referring to which sources of information are used in the communication process and to the level of trust of the communicator in these information sources.

Level of openness and transparency in the communication process

Procedural justice as factor of influence in the level of social acceptance implies trustful communication by the communicators [Folger and Bies, 1989]. For the communication of technical uncertainties in geothermal energy implementation to a local public, choices about the level of transparency and openness in the communication will need to be made by the communicators. Transparency can be defined as that *'the methodology is easily reproducible and understood by the public opinion'* [Domenech and Melguizo, 2008]. For a two–way symmetrical approach in communication processes, openness between the communicating actors is a prerequisite [Heath *et al.*, 1998]. The level of openness in a communication process balances between full closure and complete openness of both the procedure of communication as the contents of the communication process. If the level of openness is considered to be too low, the public may think they are denied access to sources of information and they are fed half–truths [Heath *et al.*, 1998; Visser *et al.*, 2005]. On the other hand, it is assumed that full disclosure about the uncertainties in the communication process can lead to criticism, be interpreted as incompetence or even decrease public trust [Van der Bles *et al.*, 2020]. The communication of uncertainties might disturb the public as it might create changes in the perception of safety [Johnson and Slovic, 1995]. Confusion amongst the public can both be created and removed by uncertainty communication. In reality, the effects of the communication need to be weighed in the context of the communication process.

The importance of being open and transparent about uncertainties as emphasised in literature [Domenech and Melguizo, 2008; Heath *et al.*, 1998; Kloprogge *et al.*, 2007] raises questions about *when* the technical uncertainties can be best communicated to the local public [Johnson and Slovic, 1995; Van der Bles *et al.*, 2020]. Considering the timing of the communication of uncertainties along the technical process of geothermal energy implementation, the initiators should be aware that 'no communication' is no option: not communicating is also communicating [Visser *et al.*, 2005]. If new information is not communicated in the technical process, the public might interpret this as bad news, or as if the communication is not the priority of the initiators [Visser *et al.*, 2005]. There are multiple option considering the timing in the communication process: one possibility is to communicate the technical uncertainty to the public as soon as it is identified in the the technical process. Another option is to wait until more information has been collected on the implications of the specific uncertainty. The initiators will have to make a choice about the timing of their communicating actions.

2. Distributional justice deals with the *'distribution of material outcomes, or public goods such as resources or wealth and public bads such as pollution or poverty'* [Sovacool and Dworkin, 2015]. For the reference frame of the communicators in a communication process centred around the technical uncertainties, distributional justice refers to the level of self–efficacy of the communicator [Kemp and Loorbach, 2006]. Distributional justice links to the extent to which advantages and disadvantages of the outcome of the communication process can be controlled by the different communicators. In other words: ideally, if the communicating actors have a certain level of control, they are able to distribute the outcomes of the communication process in a just way [Jenkins *et al.*, 2016] – depending on the desired outcome of the communication process – thereby influencing the level of social acceptance in a positive way.

3. *Trust* forms the third factor of influence in the reference frame of the communicators within the scope of this research. The level of trust – *the extent to which one expects the other to act in line with the needs and interests of oneself* and *the willingness to be vulnerable under conditions of risk and interdependence* [Huijts *et al.*, 2007; Rousseau *et al.*, 1998] (Section 8.3) – depends on the experience that different communicators have with each other. The level of trust is partly determined by the extent to which communicating parties share the same values [Gillespie and Mann, 2004] and trust shares a close link with openness in a communication process [Heath *et al.*, 1998]. The same holds for the internal trust of communicating groups. The influence of trust amongst communicators on the level of social acceptance emphasises the importance of shared values amongst the communicating parties [Rosso-Ceron and Kafarov, 2015]. Trust within a communicating group can be expressed in the feeling of forming a community, and the extent to which people support each other within the community [Wiener, 1988].

8.4.5. Communication channels

The communicators in the model communicate through **channels**, which carry the message that is being transported [Oomkes, 2013]. In total, five communication channels are distinguished: see, hear, touch, smell and taste. In the majority of the communication processes, three channels are used at the same time: the vocal/aural channel (to speak and listen), the visual channel (to watch) and the tactile channel (to touch). The channel that is chosen in the communication varies per stakeholder group [Wardekker *et al.*, 2008] and is important to the message that is communicated: good news is often communicated in person, while bad news is often communicated indirectly. Overall, transparency in uncertainty information is deemed highly important [Wardekker *et al.*, 2008].

Uncertainty information can be expressed in a linguistic, numerical or graphical way [Kloprogge *et al.*, 2007]:

- **Verbal expressions of uncertainty information** have the advantage that most readers are better in hearing and remembering uncertainty information in words than in numbers since words can be better adapted to the level of understanding of the readers [Kloprogge *et al.*, 2007]. A risk in this is an oversimplification of the information, or if information gets lost in nuances. Also, different people in different settings might have different interpretations of qualitative expressions. Another pitfall is the use of ambiguous language or the situation where information becomes vague if many people have to agree on the final text of the document.

- **Numeric expressions of uncertainty information** have the general advantages that numbers are more specific than words: if the readers understand the presentation of numeric uncertainties, the difference in interpretation between different readers will be smaller compared to verbal expressions [Kloprogge *et al.*, 2007]. However, it is possible that readers still (try to) make the translation to words for themselves. If this is done wrong, the interpretation of the uncertainty by the reader may be wrong as well. Especially when ranges of uncertainty are used, one needs to emphasise to what the ranges refer to and what aspects of uncertainty are used in a certain uncertainty range.
- **Graphical expressions of uncertainty** allow a lot of information to be summarised [Kloprogge *et al.*, 2007]. A pitfall is that not all graphical expressions of uncertainty are straightforward to understand [Grainger *et al.*, 2016]. Figures or diagrams 'seduce' the reader to draw conclusions based on what they see [Oomkes, 2013]; if they do not study the figure correctly, or misinterpret displayed information, they may draw the wrong conclusions. Rather than only explaining what is displayed in a certain figure, it might be useful to explain what is *not* shown as well. This might prevent readers from drawing their own conclusions about what is displayed in a figure. Scale bars, magnitudes or other elements of a figure may be suggestive to the reader [Kloprogge *et al.*, 2007].

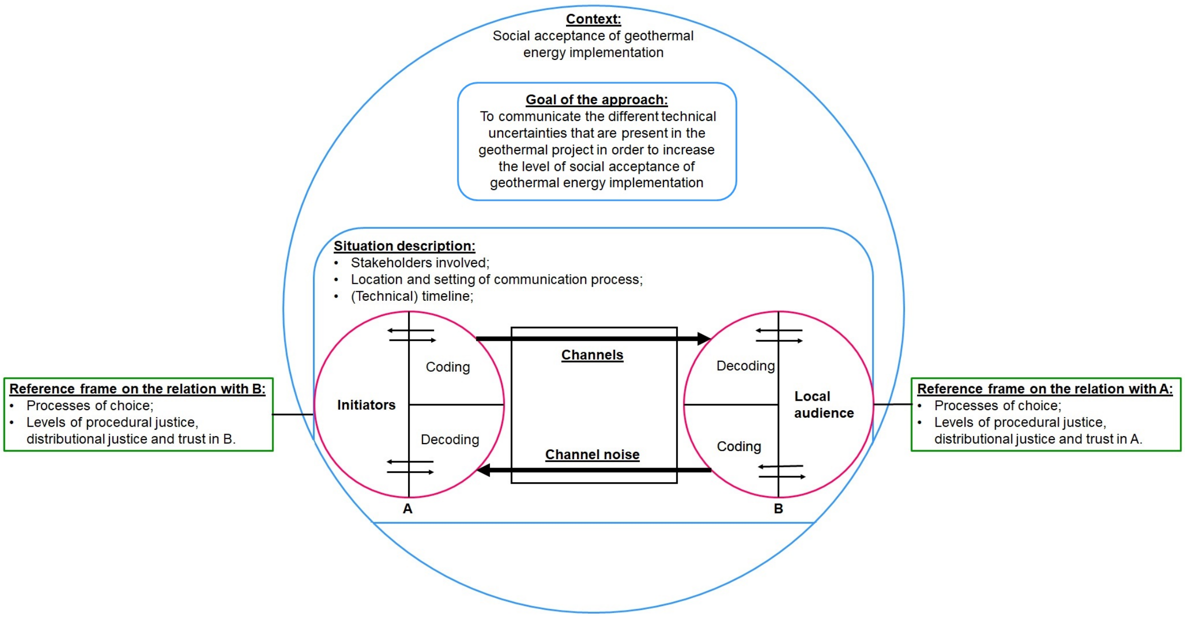


Figure 8.7: The communication channels and noise added to the communication model [Oomkes, 2013].

8.4.6. Noise in the communication process

In the communication channel, there is a possible interference or **noise** that influences the communication process. Oomkes distinguishes three types of noise: physical, psychological and semantic noise [Oomkes, 2013]. Physical noise consists of all external signals that hinder speaking, listening, watching or feeling in the communication process. Psychological noise comprises prejudices and stereotypes that hinder the communication process. Semantic noise lastly, is developed when the communicators use different codes, such as language or jargon.

During the process of uncertainty interpretation, certain misunderstandings or biases may be present [Kloprogge *et al.*, 2007] and cause noise in the communication process by influencing the reference frame of (one of) the communicating actor(s). Typical types of biases are the availability heuristic (people are likely to judge an event as frequent or likely if it is easily brought to mind, such as disasters and accidents), the confirmation bias (resulting in a situation that once a view has been formed, new evidence is generally made to fit this view [Sheth, 1981]) and the overconfidence effect/bias (which implies that people generally have too much confidence in their own judgements) [Kloprogge *et al.*, 2007]. Another important issue of uncertainty interpretation is that risk–experts almost automatically separate the two components of risk (magnitude and probability), whereas the most local publics do not. This might lead to an under–appreciation of low–probability high–impact risks, or an overestimation of high–probability low–impact risks [Kloprogge *et al.*, 2007].

In the communication approach that is designed in this study, noise can come from different sources. There is a potential for semantic noise, if, for example, the sender and the receiver different interpretations of what is 'safe'. Also, the use of jargon might cause noise between the public and the initiators. Physical noise can consist of not being able to information evenings, and psychological noise can be caused by prejudices by the public about certain stakeholder groups that are initiators in the project.

8.4.7. The message in the communication approach

Within the socio–psychological tradition, the *action–assembly theory* links to they way information is organised in the mind and used to construct messages [Littlejohn and Foss, 2008]. In this theory, two types of knowledge play a key role: content knowledge and procedural knowledge. In other words, each message is about something and about how to do something. The content of the messages in the current study are the technical uncertainties that influence the level of social acceptance in a specific area where a geothermal project will be implemented. In the procedural knowledge of the communication of technical uncertainties, procedural records will need to be created. These procedural records are sets of associations and actions that structure the communication process. For the communication of technical uncertainties, these procedural records did not have the time yet to be constructed, but the communication approach that will be designed in this study forms a start.

According to the action–assembly theory [Greene, 1984], different messages ask for the selection of different procedures. When a communicator acts in the communication process, the appropriate behaviour is selected from known procedural records. In this study, examples of this behaviour will be presented: in the communication of the technical uncertainties, the pillar of social acceptance that the uncertainty is linked to partly defines the communication method and channel that is used [Walker *et al.*, 2003].

8.5. Chapter summary

THE theoretical framework described in this chapter provides a base for the design of an approach for the communication of technical uncertainties between the initiator of a geothermal project and the local public. To be able to place this communication approach in the context, an analysis of the concepts of an energy transition have been identified. These shared concepts are complemented by the four different activities in a transition process: the strategic, tactical, operational and reflexive activities. The operational phase of a transition focuses on the identification of uncertainties. Therefore different types of uncertainties that can play a role in a transition process have been identified. In theory, a link is made between the level of knowledge of the local public in a transition process (or, in other words, the level of uncertainty) and the level of social acceptance of this transition.

This level of social acceptance forms the final context for the communication approach that is designed in this study. Based on the communication model proposed by Oomkes, each step of the model has been explained and relevant theories were selected to address the different steps in the communication approach. In the next chapter, the context of this study will be explained (Figure 8.8).

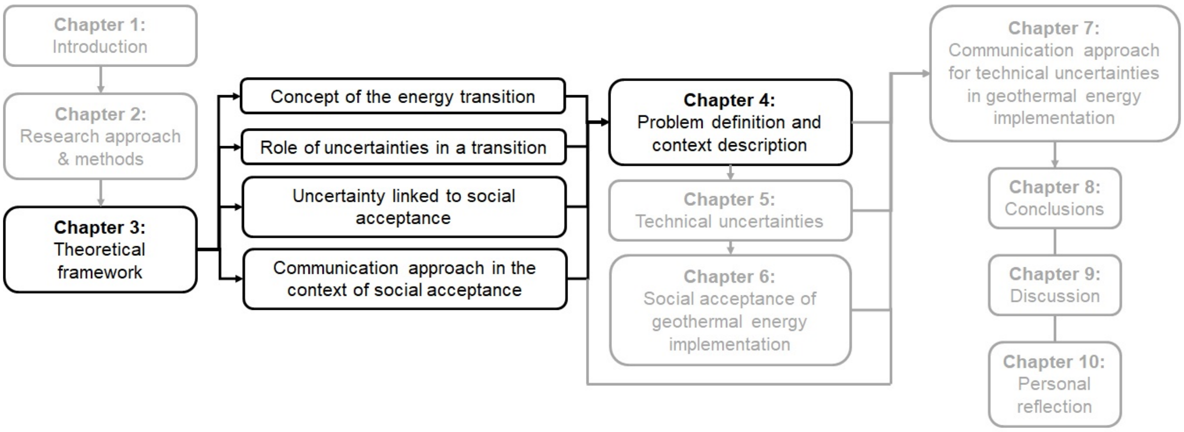


Figure 8.8: From the theoretical framework of the study towards the problem definition and the context description.

9

Context description

The Netherlands has played a key role in the gas production in Europe for more than 60 years, mainly thanks to the gas production from the gas reservoir in Groningen, which was discovered in 1959 [Van Meurs, 2006] and still is the largest onshore gas reservoir in Western Europe [Van Thienen-Visser and Breunese, 2015]. Now, the ongoing energy transition towards a more sustainable society implies the need for energy sources that do not add to the emission of greenhouse gases to the atmosphere [Demirbas, 2009; Hoel and Kverndokk, 1996; Hook and Tang, 2013; IPCC, 2018].

Geothermal energy implementation is one of the promising techniques to produce energy in a sustainable way. In this chapter, the role of geothermal energy in the total energy transition in the Netherlands will be discussed. In addition, the development of a social perspective concerning mining operations in the Netherlands due to the gas production in the Dutch province of Groningen will be analysed in the light of the scope of this research: if geothermal energy implementation needs to be a success in the Dutch energy transition, the level of social acceptance for geothermal energy should not go the same path as the social acceptance of gas production in Groningen went.

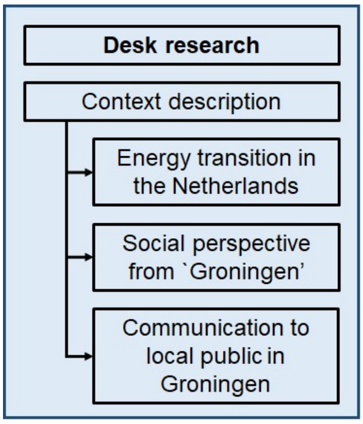


Figure 9.1: The steps of the desk research visualised in the blue colour of this research method (Chapter 7).

The theoretical framework that has been developed in the previous chapter will serve as a basis for a structural description of the context of this research. The results of the desk research (Figure 9.1) will provide answers to the first two sub–questions of this research as defined in Chapter 6:

- Which objectives for geothermal energy implementation in the Netherlands have been set by the Dutch government?
- How similar are the techniques for geothermal energy and gas production in the Netherlands?

In Section 9.1, the drivers behind energy transitions in the past and the current energy transition will be compared. This section results in a reasoning why the current energy transition is different compared to previous energy transitions. Then in Section 9.2, the history of the gas industry will be described with a main focus on the gas production in the province of Groningen. Different techniques to produce gas will be described and the need for gas in the Dutch energy transition will be analysed. The third section (Section 9.3) describes the (inter)national goals for the reduction of CO_2 emissions. Following on the international goals for CO_2 reduction, a description of the production techniques for geothermal energy and a comparison to the techniques for gas production is provided in resp. Sections 9.4 and 9.5. This section is followed by an overview of the goals for geothermal energy implementation in the Netherlands (Section 9.6). Finally, section 9.7 describes the development of public resistance to gas production in Groningen, and which lessons can be learned from this case for the communication of technical uncertainties in the implementation of geothermal energy in the Netherlands.

9.1. Drivers of the energy transition

THE current energy system in the Netherlands still merely relies on fossil fuels. However, from the perspective of the growing social need for renewable energy sources the share of sustainable energy in the Dutch energy mix needs to increase in the coming decades [Asif and Muneer, 2007; Demirbas, 2009]. To do so, the Dutch energy system must adopt new technologies that either do not burn fossil fuels to produce energy or do use fossil fuels but capture and store the emission of greenhouse gas emissions [Fri and Savitz, 2014].

Changing an energy system is challenging. Nevertheless, it is a challenge that has taken place several times in the past couple of centuries: the energy supply in the Netherlands changed from wood to coal to oil and gas over roughly sixty–year time intervals [Fri and Savitz, 2014]. An important factor in these transition processes was technological evolution. However, the energy transition that is currently going on, is different than previous energy transitions. The main reason for this is that in previous energy transitions, the main driver has been the creation of consumer value that the market could easily embrace [Fri and Savitz, 2014]. Think for example of the steam engine and coal, which made the industrial revolution and the innovation of water and railroad infrastructure possible. The development of the internal combustion engine contributed to innovations in the field of mobility. The evolution of the electricity network increased comfort and economic efficiency. These values were appreciated by individual and organisational consumers, and therefore they willingly paid to adopt these new technologies in a changing energy system. One shared factor in these energy transitions was that sustained innovation required the energy system to change; the energy demand over energy supply formed another driver of these transitions [Grubler, 2012].

Different energy transitions have different drivers. In 1959, the discovery of gas in Groningen induced a transition from coal to gas as main energy source [Correljé and Verbong, 2004]. Currently, the transition from gas to geothermal energy is at its starting point [Laes *et al.*, 2014]. By the time that the natural gas resources were found in Groningen, a significant shift in the Dutch energy system was already taking place. Until World War II, coal had been the main energy source in the Dutch economy. From that time onward, coal was confronted by low–priced oil. Newspapers dated from around the time that the gas was found [De Telegraaf, 1959] showed increasing optimism about the contents of the gas field, and described the first steps that were taken to build a gas network in the Netherlands [Trouw, 1959] from Groningen to the rest of the country. Between 1952 and 1962, the share of coal in the total energy consumption fell from 80% to 50% [Correljé and Verbong, 2004; Trouw, 1955]. After 1962, the exponential growth of energy use was completely covered by natural gas [Correljé and Verbong, 2004]. In comparison, 26% of the total amount of used energy in the Netherlands was produced from gas, 25% from oil, 16% from electricity and 2% from renewable energy, of which 8% from geothermal energy in 2019 [Energie Beheer Nederland, 2019].

The gas from Groningen offered opportunities in heating, mobility, electricity and other applications that improved the comfort of the Dutch population. The gas from Groningen was distributed in a market that easily embraced this new product. Currently, a new energy transition is about to take place. Over the last 10 years, pioneers –mainly in greenhouses and residential areas – experimented with the implementation of geothermal energy. There is one big difference between the ongoing energy transition and previous transitions: in the current energy transition, innovation is not the main driver, but merely a consequence or result of the transition. The current main driver is the global warming and the goals to reduce the rise of the global temperature in different agreements.

Whereas the comfort of the Dutch population increased over the previous energy transition, this is not the case at the same timescale now: eating less meat, taking shorter showers, not travelling by plane and buying a more expensive electric car are not considered as improvements. However, measures like these are necessary to prevent global warming in the future. Contrary to the previous energy transition, people have trouble overseeing the advantages of the energy transition, as these advantages are long–term advantages – whereas the costs of taking actions are short–term, and the costs of in–action is long–term. Therefore, it is still a question whether the current energy transition will be as automatic as the previous transitions went, for two main reasons [Fri and Savitz, 2014]:

1. The currently ongoing energy transition will need more than market forces to encourage individuals and organisations to adopt and use new technologies: people are not automatically 'willing' to adopt new technologies and more sustainable products.

2. Existing governance institutions and policy frameworks will have to adapt to the unique characteristics of climate–induced technological innovation.

As the main drivers for innovation and change are lacking, good governance is needed to overcome this barrier. This makes the energy transition that is going on a complex exception compared to previous transition processes.

In the next section, an overview of the history of gas production in the Netherlands will be provided and different techniques of gas production will be described.

9.2. Gas in the Dutch energy consumption

SINCE the Dutch natural gas field in Groningen was found in 1959 [TNO, Geologische Dienst Nederland, 2019], the economy of the Netherlands relied heavily on gas as the energy source for a long time. Up to 2050, fossil fuels will probably make up most of the Dutch energy use, as there is not enough energy available yet from sustainable energy sources [Ministerie van Infrastructuur en Waterstaat, Ministerie van Economische Zaken en Klimaat, 2018]. However, the role of gas will change due to a decrease in a) the need for gas in the Netherlands; b) the supply of gas, especially since the gas field of Groningen will be closing from October 2022 onward; and c) the dependence on gas from the Russian Federation [Rijksoverheid, 2018]. The need for gas will be changed mainly under the influence of energy reduction in different sectors – namely, i) buildings and residential areas (around 50% of the total gas use in the Netherlands); ii) the industry (ca 33% of the total gas use); iii) the transport sector; and iv) the agricultural sector (ca. 8%) [Schoof *et al.*, 2018] – and the growing influence of renewable energy in the electricity network. These two trends will be the results of (inter)national climate goals (Section 9.3) [De Joode, 2015].

In the Netherlands, gas is currently produced from two main sources:

1. The gas field in Groningen. The start of the production was in 1963 and since then, ca. 75% of the gas initially in place (**GIIP**) has been produced [Van Thienen-Visser and Breunese, 2015].

2. Besides 'big parent' Groningen, there are gas fields that are marked as 'small gas fields': this category comprises all gas fields that are smaller than the field in Groningen [Breunese *et al.*, 2005]. Around 50% of these fields is located offshore in the North Sea (Figure 9.2). The production from the other 50% will be reduced in the coming decades to pave the way for sustainable energy sources [Rijksoverheid, 2019a; Wiebes, 2018].

The next subsection provides clarity about the differences between 'conventional' and 'unconventional' gas. Chemically, both conventional and unconventional gas reservoirs contain the same substance, but the difference is in the way the gas is stored in the rocks and produced from it.

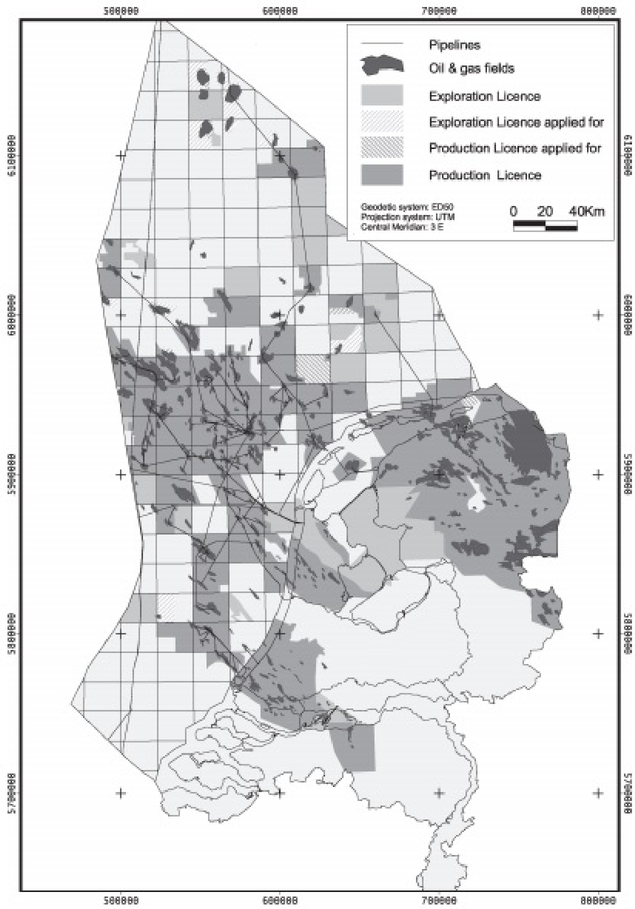


Figure 9.2: Location of the onshore gas reservoirs in the Netherlands [Breunese et al., 2005]. Except for the Groningen field (northeastern part of the Netherlands), all gas fields are marked as 'small gas field'. The small gas fields that are located offshore have been left out of scope for this research.

9.2.1. Conventional gas production in the Netherlands

If organic material in the subsurface is buried under high temperatures and pressures, fluid hydrocarbons are developed: oil and gas. Due to density differences between the gas and the surrounding rock, the developed hydrocarbons migrate from its source rock to a porous reservoir rock. In this reservoir, the gas is stored under a seal (a salt layer, for example). Ideally, these conventional gas reservoirs are made up by rocks that have a porosity which is high enough to make fluid flow possible (sandstone, for example) so that no artificial methods of increasing the fluid flow are necessary. Before the gas–bearing layer can be drilled, the subsurface is mapped by sending sound waves into the subsurface. Each layer responds to this wave by reflecting it. If these reflections are detected, the position of different layers in the subsurface can be visualised. This is called mapping the subsurface by collecting seismic data. In the Geology–part of this report (Chapter 3), examples of these data and the interpretation of the layers is provided for the gas–bearing area in Australia.

Once the presence of gas in the subsurface is proven, an exploration well is drilled to determine the amounts of gas present in the reservoir. If the amount of gas is proven to be substantial for production (rule of thumb: onshore, a gas field is economically suitable for production if it contains more than 500,000 m^3 of gas; offshore, more than 1,500,000 m^3 of gas needs to be present [TNO]), an infrastructure for production and transport is developed. The production facilities are vertical or horizontal production wells. Usually, more than one well is drilled into a reservoir [Staatstoezicht op de Mijnen]. Facilities to treat the gas after production to make it suitable for transport, are located at the surface. Transport usually happens via pipelines, both onshore and offshore [TNO]. At the moment, the infrastructure for the Dutch gas supply is not suitable for the gas that is produced from fields other than the Groningen field Wiebes [2018], making it more difficult to shut down the production from Groningen immediately.

Conventional gas production is not the only technique to produce gas from the subsurface: in the next section the method of unconventional gas production will be explained. Due to public resistance towards unconventional gas production in the Netherlands, this technique is not applied in the Netherlands (Appendix I). However, in the light of the identification of the technical uncertainties in geothermal energy implementation, some background of these techniques will be relevant.

9.2.2. Unconventional gas production

Unconventional gas stays trapped in its source rock, which usually has a lower permeability than the porous conventional gas reservoir rocks. Examples of unconventional reservoir rocks are shale rocks. One of the most common and debated ways of unconventional production is 'hydraulic fracturing' or fracking when an unconventional gas reservoir is turned into a 'conventional' one by breaking the source rock, and so increasing the permeability of the rock. This way, the gas can be produced more easily from the source rock. There are three methods of breaking the rocks:

- Hydraulic fracturing: this process of fracking is done by pumping fluids that contain mostly water and sand (99.5%) and chemicals (approximately 0.5%) [Northern Territory Government, 2019] into the subsurface, creating an over–pressure that breaks the rock. In case no chemical additives are necessary to create the over–pressure, the term *water fracturing* is used [Van der Hoorn and De Pater, 2016]. In most industrial cases, the technique of hydraulic fracturing is applied.
- Thermal fracturing: in this case, the temperature difference between the cold injection fluid and the hot reservoir rock creates a shrinking in the rock, and thereby inducing fractures in the rock [Van der Hoorn and De Pater, 2016].
- Acid fracturing: acids are pumped into the rock to dissolve the rock around the well, creating fractures in the rock [Van der Hoorn and De Pater, 2016].

In the perspective of the ongoing energy transition, the gas production in the Netherlands can not immediately be stopped due to multiple reasons. The next section provides an overview of the need for the gas produced from the small gas fields after the production in Groningen is brought to a full stop.

9.2.3. The need for gas from small gas fields in the Netherlands

Besides the gas field in the Dutch province of Groningen that will be closing from 2022 onward (Section 9.7), there are about 240 small gas fields located in the Netherlands [Rijksoverheid, 2019a]. Despite their size, the small gas fields in the Netherlands (of which 50% are located in the North Sea) are responsible for around 50% of the total gas production in the Netherlands. Since 'Groningen' will be closed, but the Netherlands do need gas in the energy mix in the coming years, and since – under the condition that gas production takes place under safe circumstances – gas production is preferred over gas import, these small gas fields will become more important in the gas supply. The main differences between the Groningen field and smaller gas fields are, a) that the Groningen field is much larger than the small gas fields (Groningen field contained ca. 2,800 billion Nm^3 of gas, the largest small field contains ca. 73 billion Nm^3 of gas), b) that there is less subsidence of the surface in smaller gas fields, since the reservoir layers of these fields are thinner than Groningen, and therefore less compacted than Groningen, and c), there are fewer earthquakes recorded at smaller gas fields. The small gas fields will be able to fill the need for gas when the Groningen field is closed [Ministerie van Infrastructuur en Waterstaat, Ministerie van Economische Zaken en Klimaat, 2018]. However, also the production in the small fields will be reduced in the coming decades up to 2060 [Rijksoverheid, 2019a].

As described in Section 8.1.1, the energy transition towards a more sustainable energy system can be classified as a goal–oriented transition. The goals that have been set for this transition will be discussed in the coming section.

9.3. (Inter)national climate agreements and goals in the energy transition

In 2013, the Netherlands was one of the countries in Europe that were in major arrears in terms of the use of renewable energy compared to other European countries. Only the United Kingdom, Luxembourg and Malta had a lower share of renewable energy in the total gross energy use [Centraal Bureau voor de Statistiek, 2014]. In September 2013, the Dutch 'Energieakkoord' (Agreement on Energy for Sustainable Growth) was signed by 47 parties: local and national governments, parties from the environmental sector, financial organisations, etc. The goal of the agreement was to make the energy supply of the Netherlands more sustainable by setting goals for energy reduction and the share of renewable energy in the total energy production in the Netherlands [SER, 2013]; the main objectives of this agreement is that the Netherlands reach a 14% share of renewable energy in the total energy consumption in 2020 and 16% in 2023 [Provoost *et al.*, 2019].

At the international climate conference in December 2015 in Paris (referred to as 'Paris 2015'), 195 countries [Europa Decentraal, 2016], amongst which all countries of the European Union, signed a contract that aimed to reduce the rise of the global temperature to a maximum of 2° Celsius, but preferably to keep the global temperature rise below 1.5° Celsius compared to the pre–industrial time (1850 – 1900 [IPCC, 2018]) [European Commission, 2019]. This means that in the case of a global temperature rise of 1.5°, a net–zero CO_2 emission – which is achieved if anthropogenic CO_2 emissions are balanced globally by the anthropogenic CO_2 removal over a specific time [IPCC, 2018] – will be reached around 2050, and in the case of 2.0° global temperature rise, the net–zero CO_2 emission will be reached around 2070 [IPCC, 2018]. For the Netherlands, the following goals were set for the reduction of greenhouse gas **(GHG)** emissions [Rijksoverheid, 2019b]:

1. In 2020, the emissions of GHG in Europe should be reduced with 20% with respect to 1990, 20% of the energy mix should be made up of renewable energy and 20% of the energy use should be saved.
2. In 2030, the emissions of GHG should be reduced with at least 49% with respect to 1990 and 27% of the energy mix should be made up of renewable energy.
3. In 2050, at least 95% less GHG should be emitted compared to 1990.

The international goals of 'Paris 2015' correspond well with the national goals of energy reduction and increase of renewable energy as set in the Dutch Energy Agreement (2013). In June 2019, the Energy Agreement was followed by the national 'Klimaatakkoord', or National Climate Agreement. Whereas the Energy Agreement had a strong focus on energy policy only, the Climate Agreement has only one goal: to reduce the emission of greenhouse gases. Therefore, not only the production and use of energy is taken into account, but also the emission of greenhouse gases by different sectors – like the agricultural or the industrial sectors [Klimaatakkoord, 2019b]. In the agreement, parties from the electricity, agricultural, residential, industrial and mobility sectors cooperate to reach the goals for 2030 (49% GHG reduction in comparison to 1990). For the residential sector, for example, the Climate Agreement means that 7 million houses and 1 million buildings need to be excluded from the use of gas. This means that the use of renewable energy and isolation of the buildings need to be increased in the coming years [Klimaatakkoord, 2019a]. For the industrial sector, one of the goals from the Climate Agreement is that the Dutch industrial sector is a circular system by 2050 so that no GHG are emitted anymore. Therefore, the industry needs to work on the implementation of sustainable energy from solar or wind energy production, or geothermal energy.

In the light of the important role for geothermal energy as renewable energy source in the Dutch energy transition, the next section explains different techniques for geothermal energy production in the Netherlands.

9.4. Geothermal energy production in the Netherlands

HEAT that is produced deep inside the earth's interior is radiated towards the outer layers of the earth. In the Netherlands, the most outward layer of the earth is several kilometers thick and contains porous sandstone and limestone layers. Especially in the sandstones from the Permian, Lower Triassic and Lower Cretaceous the hot water is accumulated in geothermal reservoirs. These layers are target formations for geothermal energy [Van Heekeren and Koenders, 2010]. In these layers, the water that is present in so–called aquifers is heated by the warmth of the Earth's core. In the Netherlands, the geothermal gradient is about 30 degrees Celsius per 1,000 meters – meaning that with each kilometre in–depth, the temperature increases with 30 degrees Celsius. From the Earth's surface, production wells can penetrate the water–bearing layers and extract the water. For every location where geothermal energy is produced, at least two wells are needed: an injection well and a production well. Warm water is produced from the subsurface by the production well, while used, colder water is pumped back into the subsurface via the injection well. Ideally, this system is a closed system, so that the cold water is pumped back into the reservoir, so the pressure in the reservoir remains the same and no water or other fluids are lost.

In the geothermal engineering, two types of production are distinguished. For shallow depths, a closed–loop system where the injection well and production well are connected, can be applied. In this system, the water that is pumped into the ground from the surface remains in the pipe but is heated by the surrounding rocks in the subsurface. Once the water is heated, the production well pumps it up towards the surface again, where it can be used as a heat source. In an open–loop system, the injection and production wells are not connected. The colder water from the surface is injected into the reservoir. By pressure differences, warm water flows through the reservoir to the production well, which pumps it up towards the surface.

In geothermal energy production, different techniques can be grouped based on their technical aspects [Provoost *et al.*, 2019] and the depth at which the warm water is produced [Schoof *et al.*, 2018] (Figure 9.3):

1. Heat and cold storage, up to 500 meters depth. Heat and cold storage can be divided into the following categories:

- Ground source heat pumps (**GSHP**). These systems are focused on heat or cold abstraction from the soil and the supply of this energy to buildings.

- Underground thermal energy storage (**UTES**). These systems are designed for seasonal heat and cold storage and work like a battery. If the UTES is an open system, groundwater wells are used to store the heat and cold (aquifer thermal energy storage, **ATES**). If the system is closed (borehole thermal energy storage, **BTES**), borehole loops are used to exchange heat and cold from the soil. The typical temperature range for energy storage lies between 7 and 17 degrees Celsius. Due to the reduction of gas production in Groningen, UTES systems are regarded as a suitable alternative for gas–using boilers in houses and other buildings.

- High temperature storage (**HTS**). For this technique, the storage temperature ranges between 30 and 90 degrees Celsius. HTS is suitable for locations that have a high demand for heat, such as residential and agricultural areas. The legal framework of this technique is not fully defined (yet).

- Hydro–thermal energy (**HTE**). HTE uses the capacity of surface water in rivers and lakes to store energy. Without dropping the surface temperature of the water body too much, enormous amounts of heat can be extracted from large water bodies. Due to the location of many Dutch cities close to surface water collections, this technique is considered to be of high potential for the Netherlands.

2. Shallow geothermal energy (**SGE**), between 500 and 4,000 meters depth. Per 100 meters depth, the temperature rises with 3 degrees Celsius. Depending on the surface temperature, a water temperature between 30–40 degrees Celsius can be produced from a depth of 1000 meters. At 2000 meters depth, the temperature increases to 70–100 degrees Celsius. This warm water can be used to heat buildings or greenhouses or be applied in industrial facilities.

3. Deep geothermal energy (**DGE**) or Ultra Deep Geothermal (**UDG**), at more than 4,000 meters depth. The temperature of the water at these depths is higher than 130 degrees Celsius. Water (steam) at this temperature can be used in industrial processes or the production of electricity. However, there is still a large gap in knowledge around DGE. In the subsurface of the Netherlands, more than 3,000 wells have been drilled onshore for the oil and gas industry, but these wells do not go deeper than 4,000 meters. Only ca. seven drilling projects to a depth of more than 4,000 meters have been executed, leaving a lot of uncertainties around the production of DGE.

After the warm water is produced from the subsurface, it needs to be processed so that the heat can be extracted from the water. In a discussion with **P2** (Appendix G), the steps of this process were explained: *'The water is pumped up by a pump which is located at a depth of several hundred's of meters in the injection well. Above the ground, there are some pipes and a typical Christmas tree–looking facility, comparable to what can be seen at a gas production location. At the surface, the warm water will flow through pipes to a filter, where solid components that are present in the water will be separated – including sand and various suspended solids, some of which may be radioactive.*

Then the water continues probably through a gas separator, then through a heat–ex–changer, then another filter, and then it goes back into the ground. At this stage, you will need a buffer tank to keep injection and production constant and supply heat at the correct demand level. Heat–exchangers are four to five meters big, and that is the biggest structure you need. So nothing you can not hide in a building.'

Now that both the gas and geothermal techniques have been described in previous sections, the two techniques for energy production can be compared in the next section.

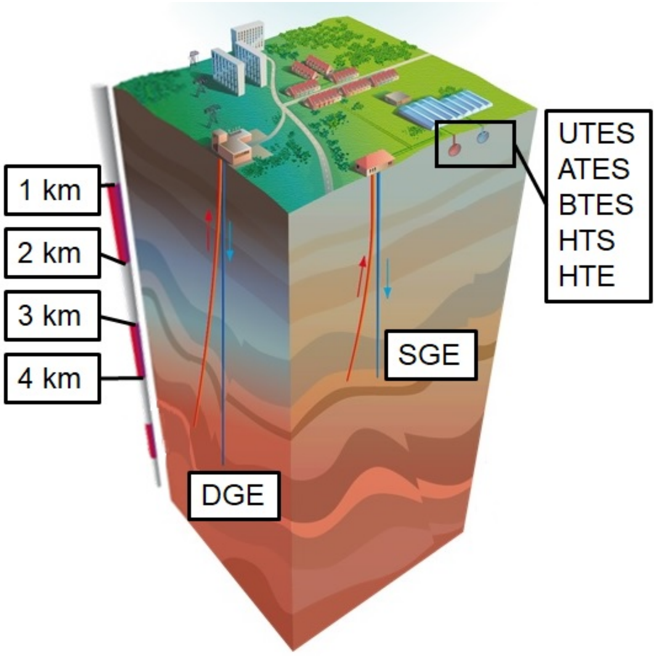


Figure 9.3: Techniques in geothermal energy applications, characterised by depth. Up to 500 meters depth: UTES = Underground Thermal Energy Storage, ATES = Aquifer Thermal Energy Storage, BTES = Borehole Thermal Energy Storage, HTS = High Temperature Storage, HTE = Hydro Thermal Energy. 500 – 4,000 meters depth: SGE = Shallow Geothermal Energy. More than 4,000 meters depth: DGE = Deep Geothermal Energy. Image modified from [ThermoGIS, 2019].

9.5. Comparing conventional gas and geothermal energy production

To be able to draw the parallel between the level of social acceptance of gas and geothermal energy production, the two techniques will be compared. Based on the technical aspects, gas and geothermal energy can be compared to the extent that both operations are classified as 'mining operations'. In both operations, wells are drilled into the Earth's subsurface. During the implementation phase, heavy equipment is needed at the plant for both gas and geothermal energy production. The most significant difference is that in geothermal energy production, both an injection and a production well are needed, while gas production only knows a production well. This is because the water needs to be pumped to the surface where gas flows to the surface due to density differences, and the cooled water is injected back into the reservoir. This way, the pressure in a geothermal reservoir is more likely to remain the same during production, compared to a gas reservoir.

From the goals for the energy transition as described in Section 9.3, the goals for geothermal energy implementation in the Netherlands will be described in the next section.

9.6. Objectives for geothermal energy in Dutch energy transition

On a national level, the Masterplan Geothermal Energy ('Masterplan Aardwarmte') was presented in May 2018 by four organisations – Stichting Platform Geothermie, the Dutch Association of Geothermal Operators, Stichting Warmtenet and EBN – that are working on the implementation on the development of a geothermal network in the Netherlands [Schoof *et al.*, 2018]. By the time of the introduction of this report, ca. 40% of the total energy need in the Netherlands is used for heat production. In the future, around 50 PJ (Peta joule, or 10^{15} joule; one PJ per year can produce heat for ca. 20.000 households, the total amount of heat needed in residential areas is ca. 400 PJ per year) can be produced using geothermal energy in 2030 and more than 200 PJ can be produced in 2050. This will lead to a CO_2–equivalent reduction of resp. 3 and 12 mton [Schoof *et al.*, 2018]. To reach these goals, different measures will be needed to reduce the dependency of the energy sector in the Netherlands on fossil fuels and to increase the use of renewable energy. One of these measures is the reduction of the heat demand from the current 960 PJ to 930 PJ in 2030 and 870 PJ in 2050 [Schoof *et al.*, 2018]. Different sources of energy can be linked to new individual (heat pumps) or collective (heat networks) heat infrastructures in the future: energy from biomass, hydrogen or geothermal sources.

In the Masterplan, the following national goals for the implementation for geothermal energy in the Netherlands are set [Schoof *et al.*, 2018]:

- In 2018, the share of geothermal energy in the total energy use of the Netherlands was 3.6 PJ GE out of 3147 PJ of total energy and ca. 0.29% of the total need for heat. This share of geothermal energy is produced in 20 doublets and covered 4.5% of the total heat needed for greenhouses.
- In 2030, the share of geothermal energy in the total heat production needs to be at least 5% of the ca. 930 PJ total heat. This heat needs to be produced from ca. 175 doublets. Until 2020, ca. 3 doublets per year needed to be opened and between 2025 and 2030, around 20 doublets per year need to be opened. In comparison, in 2018 five new doublets were opened.
- In 2050, at least 23% of the total amount of heat needed, needs to be produced from ca. 700 geothermal energy doublets. From 2030 onward, ca. 26 doublets need to be opened per year to achieve this goal. For this goal, the assumption is made that a heat network can be installed in 50% of the residential areas.

In line with the climate agreement of 'Paris 2015', each municipality in the Netherlands needs to have a 'Transitievisie Warmte' (heat transition policy) finished by 2021. In this plan, the municipality describes the methods that will need to be implemented to transform specific neighbourhoods into energy–neutral areas [Rijksdienst voor Ondernemend Nederland, 2019].

In the transition model proposed in Chapter 8, the municipalities form the meso–level: in between the macro–level (the national strategy to implement geothermal energy) and the micro–level (a project of geothermal energy implementation) (Table 9.1).

Table 9.1: The goals for geothermal energy implementation at the different levels of the transition model (Section 8.1).

Level	Translation to energy transition
Macro	National goals for geothermal energy implementation (Section 9.6)
Meso	Regional energy strategies and heat transition policies
Micro	A specific case of geothermal energy implementation

On the meso–level, the regional energy strategies have a focus on clusters of areas for example 'Metropoolregio Den Haag – Rotterdam'), which build towards the implementation of sustainable technologies. The municipalities design a heat transition policy for the residential areas. In these policy documents, municipalities describe how they will work towards a fossil–free and sustainable future and the policies need to be finished by the end of 2021. In these sustainable future visions, there is room for the implementation of geothermal energy, but also the use of solar and wind energy to replace gas and oil in the energy infrastructure.

By approaching the implementation of geothermal energy on the three different levels, the central (national) goals in the energy transition can be transferred into de–central (regional or local) implementation strategies. For the energy transition, this approach suggests that a de–central strategy is needed to reach the desired result of the energy transition. In other words, the implementation of geothermal energy needs to be successful at different locations at different moments in order for the whole energy transition to become a success. In this perspective, the problem is the social acceptance that is needed for the implementation of geothermal energy and the problem owner is the ultimate responsible minister of the Dutch climate policy: the minister that represents the Ministry of Economic Affairs and Climate Policy.

However, the past tells that social acceptance for mining operations is not easily gained and maintained. Section 9.7 describes an example of a mining operation that lost its social license to operate, partly due to a lack of social acceptance. This loss of social acceptance impacted the continuity of the project to the extent that the gas production will be closed earlier than was planned and led to a total loss of the social license to operate for the gas production in Groningen. In the Section 9.7, lessons that can be learned for the communication of technical uncertainties in the implementation of geothermal energy will be provided.

9.7. The loss of the social acceptance for gas production from the Groningen field

THE energy transition in the Netherlands will take place in the social perspective towards mining operations that developed over the past 15 years of gas production in Groningen. In this section, this perspective will be explained as context for this research, followed by an analysis of the communication towards the local public in Groningen. Then, an analysis of lessons that can be learned from Groningen for the implementation of geothermal energy will be provided.

Up till the late 1960s, the Dutch energy networks relied heavily on coal production in the Dutch province of Limburg [Voncken, 2009]. In 1955, the very first gas shows of gas in the Netherlands were discovered in the Lower Permian Rotliegendes Formation in the Dutch province of Groningen [Algemeen Handelsblad, 1955; Gereformeerd Gezinsblad, 1959; Van der Voort and Vanclay, 2015].

The Royal Dutch Shell and ExxonMobil (on behalf of *"Maatschap Groningen"*, which is a partnership of the Nederlandse Aardolie Maatschappij and Energie Beheer Nederland [Bal *et al.*, 2019]) formed 50:50 joint venture called the NAM, the Dutch Gas and Oil Company (‘Nederlandse Aardolie Maatschappij, **NAM**) to extract the gas from the subsurface (Figure 9.4). EBN is owned by the Dutch state, whereas managing personnel of the NAM is executed by Shell [Bal *et al.*, 2019].

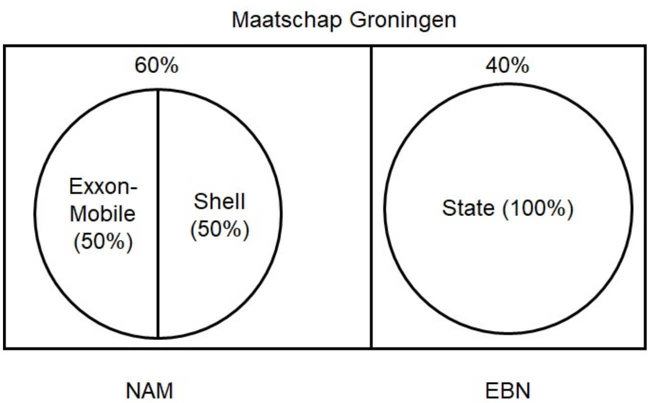


Figure 9.4: Main stakeholders of the gas production in Groningen. Image modified from [Van der Voort and Vanclay, 2015].

From the year of 1986, earthquakes have been measured in the Dutch province of Groningen – a region that is assumed otherwise to be tectonically inactive [Bal *et al.*, 2019; De Telegraaf, 1986; Mulder and Perey, 2018; Van Bruggen, 2015; Van der Voort and Vanclay, 2015; Van Thienen-Visser and Breunese, 2015]. Since 2003, the magnitude and frequency of seismic events had been increasing, and over the years it became clear that induced seismicity in Groningen is non-stationary and increases with time [Van Thienen-Visser and Breunese, 2015]; in 2006, the Royal Dutch Meteorological Institute increased the expected maximum magnitude to 3.9 on the Richter scale. The largest seismic event took place on 16 August 2012 and had a magnitude of 3.6 on Richter scale [Bakema *et al.*; Bal *et al.*, 2019; Van der Voort and Vanclay, 2015]. Compaction of the (partly) depleted reservoir is now assumed to be the main cause of the seismic events [Van Bruggen, 2015; Van Thienen-Visser and Breunese, 2015]. Examples of social impacts in the area are [Mulder and Perey, 2018; Van der Voort and Vanclay, 2015]:

- damage to property;
- decline in house prices;
- concerns about the chance of dyke breaking;
- feelings of a lack of safety;
- health issues, including stress, anxiety, insomnia and depression;
- increased distrust and anger.

In 2012 an earthquake with a magnitude of 3.6 on the Richter scale brought back the feeling of a lack of safety. Immediately, the Ministry of Economic Affairs and Climate Policy ordered a further decrease of gas production, which finally led to the decision to stop production from the Groningen gas field by 2030, and if possible already in 2025 [Bakema *et al.*; Bal *et al.*, 2019]. Until 2012, neither NAM nor supervisory authority SodM conducted further research to understand the possible problems, uncertainties and risks associated with the production rates from the gas field [Bal *et al.*, 2019]. Until 1993, the NAM refused to see the seismic events as a result of the gas production, and the underestimation of the situation in Groningen slowly decreased the trust amongst locals. Traditionally, the local population of Groningen had already felt neglected by the Dutch government residing in the western part of the Netherlands, in The Hague [Bal *et al.*, 2019]. By the time the NAM conducted research on finally determining the risks in all different areas, it was too late for social acceptance [Bal *et al.*, 2019]. An important factor in this research was the lack of local technical organisations that were able to focus on seismic risks and structural damages, to produce counter–arguments to those stated by the NAM [Bal *et al.*, 2019].

Since 2015, decisions have been made to reduce the production from Groningen, since the safety and security for inhabitants of the region could not be guaranteed if the production would be continued [Bal *et al.*, 2019; Rijksoverheid, 2018]. Multiple steps preceded this decision. Firstly, in 2015, a norm defining a risk of death for an individual from external causes, such as earthquakes, was expanded to Groningen by the Dutch government; practically, this meant that the risk of dying from an earthquake in Groningen was limited to 1 in 100,000 annually [Bal *et al.*, 2019]. Secondly, the "burden of proof" was shifted from the claiming body to the licensee for the Groningen gas field in the Dutch Mining Law [Bal *et al.*, 2019]. Thirdly, in 2018, a court case confirmed that the exploiter of the field should pay for the losses in the house real estate value, at the time which the house owner will decide – so not necessarily the time of selling the house [Bal *et al.*, 2019].

All combined, distrust, lack of technical expertise of earthquake engineering, contradicting decisions, changing hazard maps and the struggle for compensation that affected people living in damaged houses led to a loss of social acceptance for the companies that are exploiting the Groningen gas field [Bal *et al.*, 2019]. People that live in the affected areas feel fearful, angry, disappointed, uneasy and terrible, but overall powerless [Mulder and Perey, 2018]. Mitigation measures by the NAM, such as an overall campaign to improve trust or repairing damages and compensating for damages [Mulder and Perey, 2018], are largely inadequate [Van der Voort and Vanclay, 2015]. The damage compensation mechanism needs more speed and service, procedures to mitigate the physical health issues need to be developed and procedures for compensating for declining house prices need to be implemented. One of the fundamental problems is distrust, which is at the root of other social impacts or amplifies them. NAM should engage with the community more [Van der Voort and Vanclay, 2015] and the value of gas extraction to the local people needs to be established. These are examples of how the NAM tries to regain its social license to operate in the area.

9.7.1. Communicating to the residents of the earthquake area in Groningen: a reference frame for uncertainty communication

In Section 9.7, the process of how the gas production in the province of Groningen lost its social license for the local residents, has been described. A study from 2015 evaluates the communication by the NAM, the involved municipalities, the province of Groningen and the Ministry of Economic Affairs to the residents of the earthquake region from the moment of the 3.6 magnitude earthquake of 2012 and the moment of the study [Van Bruggen, 2015]. This study was used to reconstruct the communication process of uncertainties towards the local residents, and then extract the do's and don'ts of this communication process. In this study, amongst other things, the following aspects of the communication process were analysed:

- The stakeholder group that the residents held responsible for the earthquake, which turned out to be the operator (NAM), the national government or a combination of these stakeholders.
- The stakeholder group that the residents held responsible for the consequences of the earthquakes, where the operator (NAM), the national government or a combination of these two were mentioned.
- The remembrance of all communication activities: letters, media attention, meetings and information points. Here, the respondents answered that media attention (the local news station RTV Noord and the local newspaper Dagblad van het Noorden) was the main information medium and that the residents would have liked to be informed by the NAM or the government personally instead of by the media. The second most remembered medium were information meetings, followed by information letters. In the respondents' views, the information meetings were a bad example of effective communication, just like the letters that were not rewarded with much enthusiasm. The information meetings and the letters did not address the feeling of a lack of safety of the respondents. Lastly, the information desks were mentioned as a good form of communication by the respondents.
- The influence of undertaken communication activities on the feelings and thoughts towards the NAM, the national government, the involved municipalities and the province of Groningen, most residents declared that the communication process negatively affected the feelings, leading to mistrust; participants felt that they were not taken seriously and some of them lost all faith in the Dutch political system.
- The national government and the municipalities (the mayor) were held responsible for the communication process towards the residents. Operators were not held responsible for the communication process towards the residents.

- In this phase of the process, most of the residents felt informed insufficiently, but only approximately half of the respondents undertook action themselves to get more information (via the internet).

The study showed that the residents of Groningen did not feel personally informed and that the information that they did receive was biased to place the NAM and the national government in good daylight for the rest of the Netherlands. This resulted in feelings of a lack of safety about the value and safety of their houses. Consequently, the people felt sceptical about the mitigation measures that the NAM and the government are taking – that the focus is too much on money rather than on increasing the feeling of safety and understanding the local people.

In the study, the residents were able to express the need for alternative communication strategies by the NAM, the government, the province or the municipalities. Here, the respondents indicated the need for a written journal or an online blog, consistent updates by an objective and independent party, preventive door–to–door visits to notice damage, or asking the residents what their needs and questions are. Communication needs to be transparent, open and honest, according to the respondents; a relationship with the public should be constructed and maintained. This means that there should be a role for emotions and messages should be consistent to create an effective communication strategy. To increase the credibility of the communicating parties, cooperation is necessary – both between the operator, the national and regional governments, as well with the media.

In the Netherlands, there are more examples than the gas production in Groningen where public resistance influenced the continuity of the operation. Another example is the production of shale gas, on which a moratorium was placed by the Dutch government. A description of this situation where public resistance led to a production stop is provided in Appendix I.

9.7.2. Conclusions from Groningen: lessons for communication in the perspective of social acceptance

The communication process going on at this moment in Groningen and the communication processes around geothermal energy implementation that are being organised, can not directly be compared to each other. As described in previously, the gas production in Groningen lost its social license over the past thirty years, Therefore, the current communication process between the government, the NAM and the local people focuses on the compensation of damage and not so much on the implementation of gas production on itself.

Nevertheless, lessons can be learned from the communication process to the local people in Groningen. The primary lesson from Groningen is that communication to the local public does not only have to be transparent, but the initiators of the project also need to be open about where people can go to in case they experience disadvantages of the project **(P1, P3 and P4)**. Therefore in future mining activities, such as geothermal energy implementation, the settlement of damage claims due to mining activities needs to be regulated before the actual damage takes place. One way to do this, is to communicate present uncertainties, risks and certainties transparently and fairly to the local public. For geothermal energy implementation, a fresh start can be made in communicating what is (un)known, albeit from the social perspective that results from ‘Groningen’.

In the process of policy–making for geothermal energy implementation, people are already thinking about how things can be communicated to prevent public resistance **(P3, P4)**. Keywords in this communication process gathered from the interviews are ‘transparent’

(P1, P3, P4, P5 and P10) and 'fair' **(P3, P4, P5, P6 and P10)**. For geothermal energy implementation, the government will look more into the themes that are important to the local public, instead of communicating during the permit request period only **(P3)**. It is important to communicate what is unknown or uncertain, and how one will increase the knowledge about this topic **(P3, P4 and P10)**. However, in all cases, it is important to make sure that there is a balance between the safety and feasibility of a project, such that the emphasis on safety does not overpower the level to which a project can be executed **(P4)**. **P6** adds that including the local public in the procedure and planning of a project is one of the key factors to prevent or decrease public resistance. Furthermore, **P6** mentions that while a project is running, it is important to provide information to and answer questions of people that have concerns or questions.

9.7.3. Current communication approach in uncertainty communication in geothermal energy implementation

Since the first geothermal projects that are located in residential areas have been realised, policy makers and geothermal experts already have experience with the communication to the local public; albeit not with a specific focus on the communication of technical uncertainties, and no strategy is used for the communication. While keeping the loss of public acceptance for gas production in Groningen in mind [Bal *et al.*, 2019] (Section 9.7), the communication process around the implementation of geothermal energy as to how it is applied at this moment can be reviewed. The results are clustered according to the different elements of the theoretical framework developed in Section 8.4. The different elements will be filled in based on the interviews that were held during the study.

1. **The main communicators**
   The overall goal of the current communication process focuses on the safety perception of the public and to bring this perception to a realistic level **(P3)**. Currently, the main communicators in the implementation of geothermal energy are the Ministry of EZK, the municipality, the operator, SodM and the part of the public that has a clear opinion about the implementation of geothermal energy in their neighbourhoods; this opinion can be both positive or negative.

   - **Responsibility in the communication process**
     To the question who has the ultimate responsibility in the communication process, different interviewees appointed different stakeholder groups that should be responsible:

     – At Delft University of Technology, a specialised communication employee will be appointed from February 2020 **(P2)** for the geothermal project that will take place on the campus of the university. There, a geothermal well will be drilled that will produce heat for the campus and the city centre of Delft.

     – The Ministry of Economic Affairs and Climate Policy will appoint an employee specifically for geothermal projects in 2020 **(P3)**.

     – **P8:** *'The ministry does not communicate proactively, except for the communication concerning permit requests.* **P8** furthermore mentions that *'the government is not involved in the communication process – the executing parties are responsible for that process. The government does communicate about the role of geothermal energy in the energy mix and the policies that are developed. The communication process is organised by involved parties, such* *as municipalities and provinces, which are informed by the national government. The roles have been divided such that EZK develops the policies, EBN executes them and Stichting Platform Geothermie is the communicator.'*

– **P9** explained that the communication process about a project from the operator's point of view first focuses on the direct neighbours of the project location, *'since these are the people that see the increase of traffic or the build–up of a drilling rig.'* Concerning the external communication about geothermal implementation, **P9** discusses the policy that *'we prefer to be invited to share knowledge or information.'*

– **P10:** *'The communication process around geothermal energy to the local public will be organised by multiple parties together. Each communication process will be organised by the municipality who requests for a permit, and the Ministry of EZK, who authorises the request. (...) In this process, EZK has the ultimate responsibility; they organise the information markets, collect the outcomes, etc.'*

2. **Reference frame of main communicators**
Currently, no systematic and centrally organised research about the reference frame of the communicators is conducted, although the interviewees seemed to be aware of the impact of current knowledge and opinions on the communication process **(P1, P4 and P5)**.

3. **Communication channels, noise and the messages**
In the communication between the initiators and the local public, the following channels and messages are distinguished:

(a) Local news media, such as newspapers, and websites are used as tools to inform local people on the stage of a geothermal project **(P2, P6 and P10)**, although it occurs that a newspaper article only covers the opinion or concerns are shared by a small part of the society **(P3, P9 and P10)**.

(b) SodM informs the public by documents like the Staat van de Sector [Staatstoezicht op de Mijnen, 2017], and currently works on a document to inform the public on how the supervision on the risks that are analysed in the Staat van de Sector, will be organised **(P1)**.

(c) Door–to–door visits are also an opportunity to inform and include the public in a project and currently, this form of communication is executed by the heat distribution companies **(P10)**.

(d) For geothermal projects, damage protocols and mitigation measures in case damage to properties occurs, are already in development; since the gas production in Groningen, the public wants to know what the potential and the impacts of (negative) consequences of the project are **(P1, P3 and P5)**. Recently, pilot projects in which local people shared the ownership of the project have been released in Ternaard (gas production); this way, people have insight in the consequences of the projects that are located close to their properties and they can have a supervising role. For all mining operations, including geothermal projects, a central counter that handles the reports of damage due to geothermal projects will be installed **(P3 and P4)**. For this process, the communication around the damage claims in Groningen will form an example **(P3)** in how important transparency is. Overall, this will be a process of learning–by–doing **(P3)** [Loorbach and Rotmans, 2006; Wiek *et al.*, 2006].

(e) The Ministry of Economic Affairs and Climate Policy released a web page that described the frequently asked questions and the most mentioned subjects concerning geothermal energy **(P3)**. This page is also used by journalists and other interested audiences. Furthermore, ready–made info-graphics that discuss the concerns of the public about geothermal energy are under construction **(P3)**.

(f) When a municipality or company applies for a permit at the Dutch Ministry of Economic Affairs and Climate Policy, this permit request is always open for inspection for a certain amount of time **(P3)**. In this period, everyone who has an opinion about the permit request is allowed to react on the request and commonly, information evenings are organised **(P1, P3 and P6)**. During such an evening, which is preferably organised in the people's neighbourhoods, the stakeholders in the process of the permit request are present to explain the project plans and discuss the concerns, ideas, fears, etc. with the local people that attend these information markets. This way, the ministry or other involved parties do not only provide information during these evenings but also collect relevant information. Also, the utility and necessity of a project, the procedure of the project, how the occurrence of damage will be treated and the technical factors of a project will be explained **(P4)**. Each stakeholder is invited to explain its share of the permit request **(P1)**. Usually, representatives of the following stakeholder groups attend these information markets **(P1, P3 and P5)**:

- States Supervision of Mines;
- Ministry of Economic Affairs and Climate Policy;
- the municipality;
- TNO (the Dutch Geological Survey);
- EBN;
- the Dutch Platform Geothermal Energy;
- the operator.

The attendance of the evening depends on multiple factors, such as the location of the market and the experience the public has with these information evenings **(P4)**. One of the main goals of this evening, besides sharing information, is to show that there are actual people involved in the organisations **(P1 and P4)**, to minimise the feeling of the public that there is a big distance between the public and the policy makers, the companies, etc. During the information evenings, ready–made information posters and sheets, or some stones that will be drilled through in the subsurface, are shown so that people can see, touch and feel them **(P4)**.

With every information evening, the organising party has the choice between a walk–in setting or a presentation **(P9 and P10)**. The outcome of this choice depends on the public; in a presentation, there is the risk of people disturbing the presentation, whereas in small–setting walk–in evenings, the atmosphere is more friendly **(P10)**. One–to—one discussions offer more opportunities to discuss specific situations or concerns. In plenary presentations, one person can dominate the discussion, while the rest of the audience remains quiet. This is not the case in one—to-–one discussions **(P9)**. According to **P10**, it might be useful to include the public in the development phase of a project already, to show them they are involved in this phase of the project as well.

9.8. Chapter summary

In this chapter, the importance and role of the energy transition in the Dutch energy consumption for the coming decades have been provided. Due to its crucial role in the Dutch energy transition, and to prevent public resistance towards geothermal energy having an impact on the implementation, social acceptance of geothermal energy implementation is a vital factor to make the energy transition a success in the coming decades.

Based on a) the analysis of the energy transition in the Netherlands, b) the goals that have been set for the implementation of geothermal energy, and c) the need for social acceptance for this transition to be successful, a structured approach for the communication of technical uncertainties in the implementation of geothermal energy towards the local public is needed.

In the next chapters, this approach will be constructed. In Chapter 10, the technical uncertainties that are present in the implementation of geothermal energy will be identified (Figure 9.5). In Chapter 11, these uncertainties will be linked to the level of social acceptance of geothermal energy implementation. Then in Chapter 12, the final communication approach will be presented.

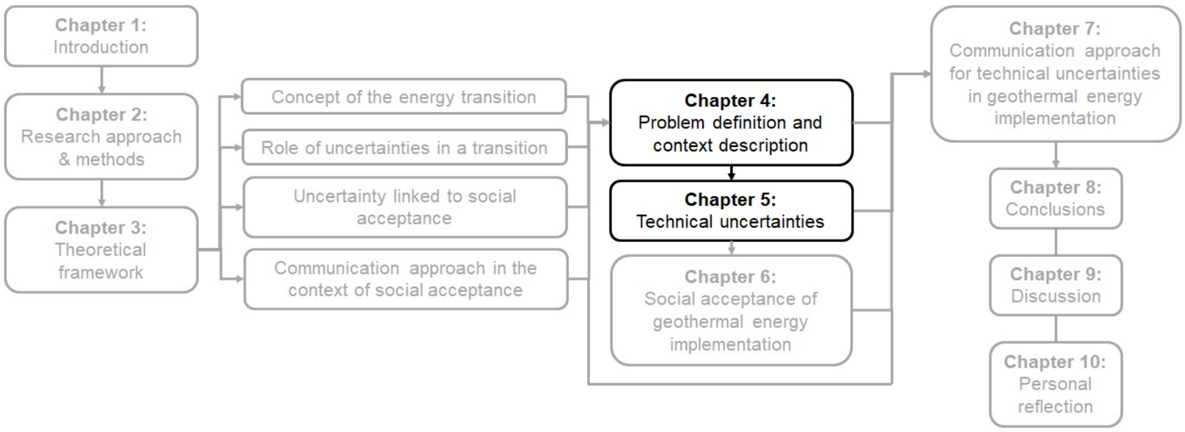


Figure 9.5: From the context description of the study towards the first results: the identification of the technical uncertainties in geothermal energy implementation.

10

Technical uncertainties in geothermal energy production in the Netherlands

THE theoretical framework as described in Chapter 8 will be used as a basis in the remaining part of the report; as described in the theoretical framework, uncertainties in a transition process can have an impact on the level of public acceptance of the transition. This results in sub–question 3 as defined in Chapter 6 of this research:

- What are the similarities and differences between the technical uncertainties that are recognised in geothermal energy implementation, and the technical aspects of gas production in The Netherlands?

Figure 10.1 visualises how the different methods applied in Chapter 8 and 9 contributed to the results that will be presented in this chapter. The context description that was obtained by doing a desk research provided an overview of the different stakeholders that are present in the area of geothermal energy implementation in the Netherlands. Different aspects of the context descriptions were used in the interview protocols to ask the experts in the interviews about their expertise and experience with specific parts of the research context. At the same time, different subjects that are represented in the theoretical framework formed a guideline for the design of the interview protocol.

The main method that is used to obtain the results that are provided in this chapter, is the collection of data from the interviews by transcription and coding. In the chapter, the relevant information is linked to the interviewees by indicating the interviewee in bold. Quoted text is displayed in cursive style, and are literal representations of what was said during the interview, whereas the non–cursive information is interpreted to fit fluently in the text of this chapter. Nevertheless, it was attempted to stay as close as possible to the literally spoken text.

To answer sub–question three, a comparison between hydrocarbon and water production methods will be provided first. Then, 10 clustered technical uncertainties, obtained from nine expert–interviews, will be clustered and described in the order of how often they were mentioned during the interviews.

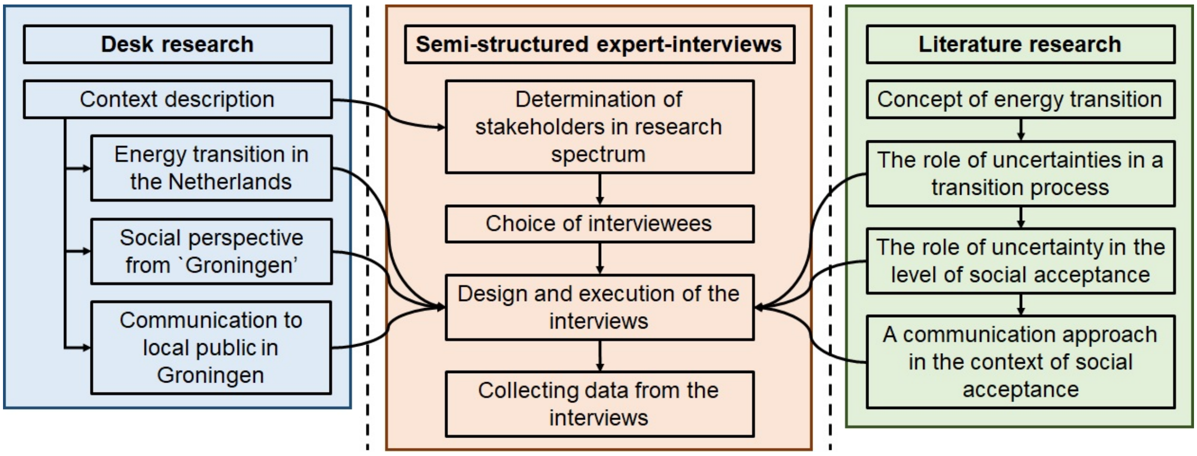


Figure 10.1: Overview of the desk and literature research contributing to the semi–structured expert–interviews (Chapter 7).

Figure 10.2 displays the location of the interviewees in the stakeholder triangle that was constructed during this study. This figure aims to indicate where in the stakeholder triangle the interviewees are located that were able to discuss the technical uncertainties in geothermal energy implementation.

In Section 10.1, similarities and differences between gas and geothermal energy production will be described, followed by a description of the technical uncertainties that are present in geothermal energy implementation in the Netherlands (Section 10.2).

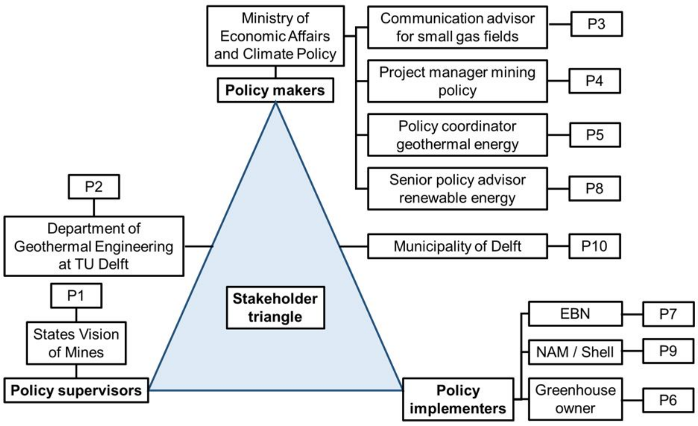


Figure 10.2: The main stakeholder groups in this study visualised in the stakeholder triangle.

10.1. Comparing water and hydrocarbon implementation: technical aspects and uncertainties

IN the interviews, differences and similarities of the techniques to produce geothermal energy and hydrocarbons from the subsurface have been discussed. In Tables 10.1 and 10.2, the main differences and similarities are listed:

Table 10.1: Similarities between gas and geothermal energy implementation in the Netherlands.

Similarities gas and geothermal energy implementation
The techniques to produce hydrocarbons or water are comparable, since both are mining operations **(P1, P2, P3, P7 and P9)**.
In both gas and geothermal energy implementation, heavy equipment is needed at the plant; the activities of the employees working at the plant are comparable **(P9)**.

Table 10.2: Differences between gas and geothermal energy implementation in the Netherlands.

Differences gas and geothermal energy implementation
In gas production, the gas comes to the surface due to density differences whereas in water production, pumps are needed to produce the water **(P2 and P6)**.
In geothermal energy production, the water is pumped back into the subsurface, whereas in gas production, the gas is produced but nothing is pumped back into the reservoir **(P2 and P9)**. Therefore, the potential for earthquakes is lower for geothermal than for gas production.
Geothermal energy implementation needs to take place closer to the area where the heat is used; compared to gas implementation, the implementation of geothermal energy can not take place in remote and rural areas **(P9)**.
The knowledge about geothermal energy is still at a lower level than the level of knowledge of gas production in the Netherlands **(P1, P2, P4 and P5)**; until recently, geothermal energy was mainly produced by greenhouse owners, whereas now the step to industrial applications needs to be taken. Therefore, parties that have the knowledge, for example operators from the gas industry, need to join.
The way(s) how damage is monitored and settled is/are not defined yet for geothermal energy production, whereas this is for gas production **(P1)**.
If fracking would have to be applied to stimulate the fluid flow in the water reservoir, this would be at a much smaller scale than in gas production **(P1)**.
Since hydrocarbons and water are different fluids, the design of the wells needs to be different **(P1)**.
Economically, gas is a more profitable fluid than water **(P2, P4 and P5)**.

10.2. Technical uncertainties in geothermal energy implementation

FROM nine expert–interviews (Figure 10.2), the technical uncertainties listed in Table 10.3 have been clustered. In the next subsections, these uncertainties will be described.

Table 10.3: Technical uncertainties in geothermal energy implementation in the Netherlands.

	Technical uncertainties in geothermal energy implementation
1	(Induced) seismicity
2	Location of a geothermal well
3	The use of hydraulic fracturing
4	Well design, well integrity and corrosion
5	The distribution and storage of the produced heat
6	Unfamiliarity with the subsurface: temperatures, injection pressures and reservoir integrity
7	Co–production of chemicals, radioactive material, oil and/or gas
8	Noise, traffic and heavy equipment during drilling process
9	Cooling of the water
10	The potential for ultra–deep geothermal energy in the Netherlands

10.2.1. (Induced) seismicity

The most–mentioned technical uncertainty of geothermal energy activities is the occurrence of induced seismicity – defined as *measurable movement of the Earth, caused by activities taking place in the subsurface* in areas that were stable in the subsurface before the geothermal energy activities took place. The word *induced* is placed between brackets because with **P1**, it was discussed that the local public is not always aware of the difference between natural seismicity and induced seismicity; natural seismicity is the result of the movement of the Earth by natural processes, while induced seismicity means that humans are responsible for the movement of a subsurface that is naturally stable. For all cases of geothermal energy activities, seismicity can occur once one starts to drill in the Earth's surface **(P1, P2, P4, P5, P7, P8, P9)**. Especially in places where the subsurface is faulted, such as the province of Limburg, or (induced) seismicity has taken place in the past, such as the province of Groningen, the occurrence of induced seismic activity due to geothermal activities is uncertain **(P1, P4, P5, P7, P8, P9)**.

However, **P2** mentions that since the same amount of water is pumped into the reservoir as is taken out of the reservoir, the magnitudes of seismic events caused by geothermal activities will be several magnitudes lower than the earthquakes as a result of gas production in Groningen: *'The biggest one [earthquake, SS.] in Groningen was 3.6, I believe. And I don't think almost any have been measured in geothermal projects in the Netherlands. It depends a bit on where you are. So the West Netherlands Basin ones, which have flow through the rock matrix and not fractured flow, it more or less means that the magnitudes will be below 1 or something. So with the instruments that the Royal Dutch Meteorological Institute **(KNMI)** has, they are not even noticeable.'*

Currently, data about seismicity in the Dutch subsurface is collected and visualised by the KNMI in De Bilt (Utrecht). Due to the oil and gas activities in the Netherlands, knowledge has been collected about seismic activity up to 3 kilometers depth, since this was the maximum depth of the hydrocarbon explorations. The KNMI is not able to provide reliable data about the exact depth of seismic activity deeper than 3 km **(P9)**; therefore, the depth of seismic events deeper than 3 km is always set at 3 km, which was roughly the depth of the oil and gas fields in hydrocarbon production in the Netherlands.

P1 discussed the steps that companies need to take before the actual drilling process can start: *'Before the actual drilling process can commence, companies need to perform an analysis on the seismic risks. In this analysis, the type of rock that will be drilled, the seismic data that is available about the subsurface and the knowledge of faults in the subsurface, etc. needs to be included. Since 3D seismic data is still very expensive, companies mainly use the data by TNO (NLOG).'*

10.2.2. Location of geothermal well

The second–most mentioned technical uncertainty in geothermal energy applications is the location where the geothermal well(s) are drilled **(P1, P2, P3, P4, P5, P6, P7, P8 and P9)**. One of the main issues here is that to prevent heat losses during the transportation of the hot water, geothermal wells need to be located as close to the users as possible; meaning that geothermal wells probably need to be drilled close to or in residential areas, whereas this is not necessarily the case for gas or oil production **(P1, P2, P3, P4, P6, P9 and P10)**. **P1** therefore mentions, that when new neighbourhoods are designed in the coming decades, the production of geothermal energy in a neighbourhood will need to be taken into account in the neighbourhood design.

The location of a geothermal well is closely related to other technical uncertainties, such as the potential for induced seismicity and damage related to this seismicity **(P3)**; if more people live close to the location of the geothermal well, more people are facing the disadvantages of the project, for example, noise disturbances or damage to the houses **(P2, P3)**. Also, the distance to areas that are used for drinking water production **(P5)** are important uncertainties in relation to the location of a geothermal well. Moreover, there is still only a small amount of knowledge about what the (long–term) effects are if geothermal wells are placed relatively close to each other **(P5)**. Considering the goals for geothermal energy production that have been set by the Dutch government for the near future, hundreds of geothermal doublets need to be built in the coming decades. **P5**: *'At a certain point, the plots will be located so close to each other, that one geothermal well will influence the water flow and temperature of the other well. Do the plots need more space than currently is calculated? That is still uncertain for now.'* Furthermore, **P2** mentions that since the technology allows drilling the geothermal wells under a certain angle, *'the effects of the wells is under lots of peoples property – by the flow of water in the subsurface. This area is quite large.'*

However, **P10** mentions that before drilling for geothermal energy in builded areas can be applied, more knowledge about the subsurface at these locations needs to be collected. The SCAN–project by EBN focuses on the subsurface that was not further investigated if no oil or gas was found in the past. For the implementation of geothermal energy, these 'white spots' fill be filled in **(P7)**. Since the production of hydrocarbons in the past mostly did not take place in the residential areas, some of these white spots are located close to the residential areas where geothermal energy might be produced in the future.

10.2.3. The use of hydraulic fracturing

The third technical uncertainty that is been discussed during the interviews, is the use of hydraulic stimulation or fracking during the drilling process **(P2, P3, P7, P8 and P10)**. **P2**: *'Fracking is a whole range of different techniques, and there are also other options. People talk about putting acids in the wells, to clean them. But if you put acids in in a certain way or even put them in under pressure and frack the rock a little bit, then you actually destroy some of the rock, without big pressure changes. Moreover, there is this drilling technique that is called laterals; that means drilling outwards to the rock, to also increase the permeability. There are lots of different ways. If you think about a well and the typical type of pressure distribution towards the well, it is a logarithmic curve. So if you damage a bit of rock close to the well, the production is increased a lot.'* The last technique that P2 mentions is to use temperature changes to damage the rock slightly which increases permeability: if temporally hot water is pumped into the reservoir, followed by very cold water, the rock is cracked and shifted. **P7 and P8** indicate that fracking will probably be applied in ultra–deep geothermal reservoirs only, because due to the depth of these reservoirs, the permeability of the reservoir is lower than the permeability of shallower located reservoirs. **P2** indicates that currently, in general, reservoirs that do not need hydraulic stimulation are targeted: *'once one starts to stimulate reservoirs that do not have such a good permeability, one has to take the public relations into account.'* Currently, stimulation is applied in the Netherlands to drill for drinking water **(P2)** or gas from small gas fields **(P4)**. However, the scale on which fracking is applied in these projects is much smaller than the scale on which fracking is applied in shale gas projects that have taken place in the United States, for example **(P3 and P4)**. Furthermore, fracking applied in drinking water production is more gentle **(P2)**. Nevertheless, the rock is damaged to increase the flow of water **(P2)**. Lastly, **P2** expects that fracking in urban areas might be a bigger issue, but if fracking will be needed as a production technique is still uncertain **(P10)**.

10.2.4. Well design, well integrity and corrosion

This technical uncertainty was discussed in the interviews with **P1, P2, P4, P5, P6 and P10**. **P6** had experience with a well that started leaking after seven years of production and therefore, **P6** currently works with an inhibiter to prevent corrosion processes to take place within the wells. However, this is still a process of trial–and–error. **P6** considers the potential of well leakage in the subsurface as one of the main technical uncertainties in geothermal energy production. **P1** confirms that the first generation of the geothermal wells did not meet the standards that were applicable for the oil and gas industry: *'Those first generation geothermal wells have been built single–walled. Combined with the saline fluids in the subsurface, this leads to corrosion of the wells. This is the reason that currently, the expected life duration of the wells is not met. Furthermore, the first generation geothermal wells did not have the space to place instruments in the well to monitor the production process. Therefore, pressure differences that were caused by leakage of the well were not noticed at first. (...) Once double–walled wells are, just like in gas production, applied in geothermal energy production, corrosion of the well can be prevented since the second wall of the well forms another barrier to prevent flow out of the well.'* Currently, the life expectancy of a geothermal well is thirty years **(P2 and P5)**; on the other hand, **P6** was convinced that the water that is pumped back into the reservoir is almost the same temperature as the water present in the reservoir. Therefore, he expects the reservoir to have an almost unlimited life span, as the temperature of the water in the reservoir does not drop over time. However, according to **P5**, one should already consider how the wells and corrosion of the wells can be monitored during production, or how leakage of the wells can be monitored. This monitoring process becomes more important once a geothermal well is located close to a drinking water production area so that potential pollution of drinking water storage is prevented **(P5)**.

The well design depends on different criteria, such as the amount of pressure and the temperature that the well experiences in the subsurface **P1 and P2**. Currently, most geothermal wells are produced vertically, which is partly due to the value of the product; the amount of value one gets from geothermal energy is much lower than from gas **(P2)**. Currently, more criteria to the well design are being set by the government to prevent leakage of materials from the wells **(P4)**.

Lastly, **P10** mentions that the potential of a blow–out is also a technical uncertainty in geothermal energy implementation. During a blow–out, the produced fluid (hot water, in this case) comes out of the well in an uncontrolled way. This might create an unsafe situation at the production site.

10.2.5. The distribution and storage of the produced heat

Once the hot water is produced from the subsurface, there is the challenge of transporting this water to the customers **(P2, P5, P7, P8, P9 and P10)**. Currently, heat networks are only applied at a very local scale (e.g. building blocks, as discussed with **P10**). **P2** expects that the distribution of warm water will be a big challenge compared to producing it since a hot water network is needed that might leak hot water instead of cold water occasionally. **P8** confirms this uncertainty, supplemented with the scenario that the heat networks will be developed in cooperation with provinces and municipalities. For geothermal energy as a sustainable energy resource to work in the future, people need to willing to adapt to this new technique; the measure to which people will be willing to adapt is an uncertainty according to **P8**. **P7** agreed that *'the subsurface will not be the main challenge, but it will be for people to switch to geothermal energy'.*

More practically, **P2** suggests that the heat network might be replacing the gas network in the future, or be placed next to the gas network as long as gas is still used in the Netherlands. According to **P2**, the biggest uncertainty in the transportation of the heat is the length over which it can be transported without losing too much heat: *'It all depends on the size of the pipe that is used. Most of the losses are really getting it from where the heat network finishes to the individual houses because your pipes become much smaller. For the bigger pipes, it is not so much of an issue.'* In geothermal energy production, one sometimes has to deal with peak loads that need to be distributed in a good manner **(P5)**; the distribution of these peak loads will have to be regulated for geothermal energy production.

P9 mentioned that the construction of the heat network is a complex process that needs to be regulated on a large scale (municipalities or neighbourhoods). Therefore, good agreements between the different stakeholders are necessary. By doing so, **P6** expects that companies or operators can even benefit from each other production wells.

10.2.6. Unfamiliarity with the subsurface: temperatures, injection pressures and reservoir integrity

P1 mentioned that currently, it is uncertain what the impact of geothermal activity will be on areas where natural fractures occur since the flow of water through broken rocks will be different compared to less permeable rocks. This uncertainty was illustrated by P10 for the situation of Delft: *'The biggest uncertainty is in the drilling process, for example if you drill in a layer of which you did not know it was there, or if a certain layer is under pressure and you were not aware of that.'* **P6** confirmed this during the interview, when it was discussed that you never know what you will find in the subsurface, until you do. The exact circumstances in the subsurface vary per location, and so ask for specific equipment **(P1 and P2)**. Also, the amount of pressure that is needed to obtain the water flow in the reservoir depends on the specific configuration of the subsurface **(P2 and P9)**. The injection of water changes the pressure and chemical balance in the subsurface, which might influence the drilling process **(P2)**. Lastly, one of the main objectives for geothermal energy production is that the same amount of water is pumped back into the subsurface as was taken out of it **(P1, P2, P5, P9 and P10)** to prevent pressure differences in the subsurface or subsidence of the surface. Currently, the prognosis for subsidence of the surface is approximately 2 millimetres over thirty years **(P5)**.

10.2.7. Co–production of chemicals, radioactive material, oil and/or gas

How much chemicals and radioactive materials will be co–produced during geothermal energy production is uncertain **(P2, P7, P8, P9 and P10)** and depends on the reservoir rock **(P2)**. **P6** described that the amount of radioactive material that is pumped up by the well is barely measurable. **P2 and P5** compare the amounts of radioactive materials in geothermal energy production to the radioactive materials doctors work with in hospitals; **P5**: *'Radioactive materials become a risk if they accumulate in filters. People can be trained in how to deal with these materials, comparable to how radioactive waste is handled in hospitals.'*

One of the main challenges in geothermal energy production will be the co–production of oil and/or gas, since the production of hydrocarbons falls under a different financial regime and different permits than the production of renewable geothermal energy **(P4, P5 and P10)**. The co–production of oil and gas can be up to *'several ten's of percents of the energy of the total production'* **(P2)** of the geothermal well. Therefore, P2 was not even sure if geothermal energy can always be marked as 'sustainable'. Once oil or gas is co–produced in geothermal energy production, a separator can be installed to separate the hydrocarbons from the water **(P6)**. P6 uses the gas to generate electricity, whereas other greenhouse owners burn the gas and use the CO_2 to help their crops grow faster **(P2)**. A last possibility is to add the gas to the gas network, as long as that is still in function **(P2)**.

10.2.8. Noise, traffic and heavy equipment during drilling process

During the 24/7 drilling process, which takes up to five months **(P1, P2, P6, P9 and P10)**, there will be noise coming from the drilling rig. Also in this phase of the process, traffic and heavy equipment will be transported to the drilling site **(P2, P6, P9 and P10)**. Furthermore, **P1 and P10** mentioned that falling objects and the working procedures that involve working with chemicals at the plant might lead to working hazards.

10.2.9. Cooling of the water

Most of the interviewees expect the water that is used for geothermal energy application to slowly cool over the years, until the temperature of the reservoir drops so much that the reservoir should be abandoned **(P2, P5)**; this is hopefully after thirty years of production. Re–heating the water in the reservoir takes a much longer time that the operational period of the project; several hundreds of years, probably **(P2)**. However, for some applications that have a lower heat demand, it is fine to produce water that has a lower temperature. On contrast, **P6** is convinced that the water is used in the greenhouse cools about 1 degree Celsius over thirty years of production. Therefore, **P6** expects that the heat–producing power of the Earth is so powerful that the water does not cool at all. This would make the production a process that could go on forever, theoretically. Other interviewees, expects that at some point in time, a breakthrough of cooled water into the reservoir will occur and the reservoir will have to be abandoned **P1 and P2**.

10.2.10. Ultra–deep geothermal energy in the Netherlands

Ultra–deep geothermal (UDG, where the heat is produced from more than 3 km depth) applications have been discussed in the interviews with **P1, P2, P4, P5, P7, P8, P9 and P10**. Interviewees **P2, P4, P5, P9 and P10** confirmed that more research about geothermal energy production from these depths is necessary before the techniques can be applied in residential or industrial areas. Since the drilling experience in the Netherlands from the oil and gas industry did not exceed depths deeper than 4 km, only a little knowledge is available about the circumstances that are present in terms of pressure, temperatures and reservoir integrity at 4 km depth **(P2)**. In ultra–deep geothermal applications, induced seismicity is a technical uncertainty **(P7 and P8)**, as well as the permeability of the rock in the subsurface, the amount of radioactive material that is being pumped up from the deep subsurface the possible leakage of wells **(P7)**, the use of hydraulic stimulation of the reservoir **(P7 and P8)** and the high expected costs of the projects **(P2, P5 and P7)**. In the words of **P2**: *'The deeper you get, the hotter you get, the more equipment you need'.*

Currently, six consortia are being funded by the government to start looking at the potential for UDG in the Netherlands **(P2)**. In 2016, the Green–Deal Ultra–Deep Geothermal has been developed by EBN, TNO, the ministries of Economic Affairs and Climate Policy and Infrastructure and Water Management and seven consortia [EBN, 2019]. The goal of this Green–Deal is to find an answer to the question if UDG in limestones in the Dutch subsurface at 4 km depth can be produced safely and responsibly, and if this heat will contribute to a sustainable heat supply to fulfil industrial purposes [EBN, 2019]. One of the projects that is concerned with the mapping of these 'white spots in the maps of the Dutch subsurface' is the SCAN project by EBN. In this project, the limestone layers of the Dinantien [Boxem *et al.*, 2016] (Lower Carboniferous, 358–330 million years old) is studied on its potential for UDG. Once the subsurface is mapped properly, strategies for the production of UDG can be developed. In the words of **(P2)**: *'In the Green–Deal in Ultra–Deep geothermal, they want to develop projects that specify what they know and what they don't know, what information they need, how to work out the different well designs, etc. I think, in the end, two or three of the most promising projects will be heavily subsidised by the government or paid for by the government to go ahead.'* **P5** confirms that the policies to contribute financially to the development of UDG have already been worked out, but that there is still a lot uncertain in terms of how profitable UDG will or can be in the Netherlands. **P5** suggests that it might be more profitable to investigate other forms of geothermal energy production first. **P7** shares this attitude towards UDG applications in the Netherlands: *'Currently, five consortia investigate the potential of UDG, but the percentage of projects that succeed is still only around 10%. Much more research is needed.'*

P9 mentioned that Shell Geothermal is involved in a consortium to investigate the potential for UDG in the area of the Port of Rotterdam. However, **P9** confirmed the statement above that UDG is a technical challenge: *'The goal of UDG applications is to generate sustainable steam for the use in the industrial sector; however, considering the challenges of UDG in the Netherlands, there might be more possibilities to reach this goal than UDG only. These possibilities need to be investigated in the future.'*

10.3. Chapter summary

IN this chapter, 10 clustered technical uncertainties that have been extracted from coded expert–interviews have been described. This description aims to provide an overview of the technical uncertainties that might play a role in geothermal energy implementation in the Netherlands, but also to indicate that there is a great variety of technical uncertainties.

Considering this, the technical uncertainties that are important in a specific geothermal energy implementation project might vary over different projects.

In the next chapter, the concept of public acceptance as discussed in the theoretical framework of this study (Chapter 8) will be linked to aspects of public acceptance that were discussed in the interviews (Figure 10.3). Moreover, the technical uncertainties are linked to the three different pillars of public acceptance, leading to indications of which technical uncertainties have an impact on the level of public acceptance of geothermal energy implementation.

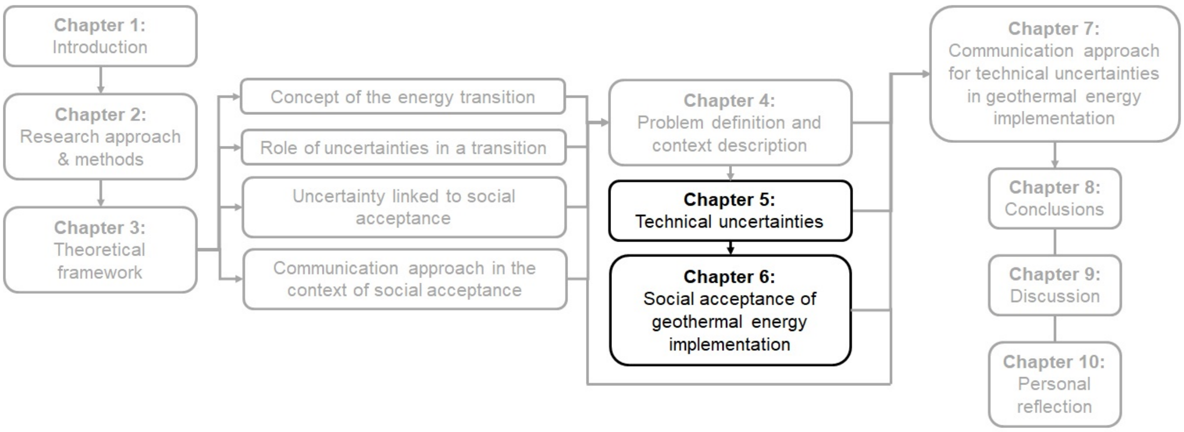


Figure 10.3: In the next chapter, the pillars of public acceptance of a transition will be discussed and linked to the technical uncertainties of this chapter.

11

Social acceptance of geothermal energy implementation

BASED on Section 8.3 of the theoretical framework, it is of vital importance for the success of a transition process that the public is aware of a) the benefits, b) the need of implementation of the new technique, and c) the certainties, uncertainties and risks. In the light of this, an analysis will be provided of how and when the public lost its support for the production of gas from the field in the Dutch province of Groningen. Then, the factors that influence the creation of a public support base for geothermal energy implementation will be described using the results of the interviews. These analyses will provide answers to sub–question 4 of the research as defined in Chapter 6:

- How do technical uncertainties influence the level of social acceptance of geothermal energy implementation?

The results in this chapter are based on a combination of desk research, literature study and the interviews that have been conducted in this research (Figure 11.1).

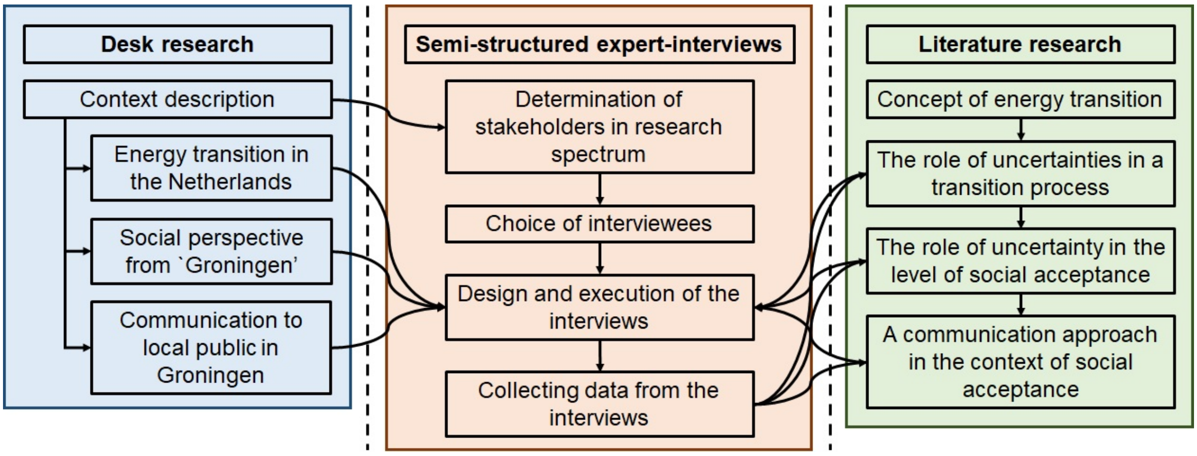


Figure 11.1: The methods used to obtain the results that are presented in this chapter. The link with the theoretical framework is stronger than in the previous chapter.

Figure 11.1 is comparable to Figure 10.1, but the main difference lies in the connection between the results from the interviews and the theoretical framework. The link between the technical uncertainties and social acceptance was established by making links with relevant communication and uncertainty theory. Therefore, the link between the interviews and the theoretical framework is stronger in this chapter than in the previous one: in literature, not so many technical uncertainties of geothermal energy have been defined yet, but existing literature on the link between uncertainty and the level of social acceptance is available.

11.1. The development of a perspective in Groningen

As described in Section 9.7, gas production from the Groningen field lost its social license over the past decade [Van Thienen-Visser and Breunese, 2015]. Over the years, 'Groningen' became the national reference frame for safety and environment risks **(P5)** [Van Bruggen, 2015], although the gas production forms a very specific case for energy production due to the size of the gas field **(P3, P4 and P5)** (Figure 11.2 indicates the stakeholder triangle of this research).

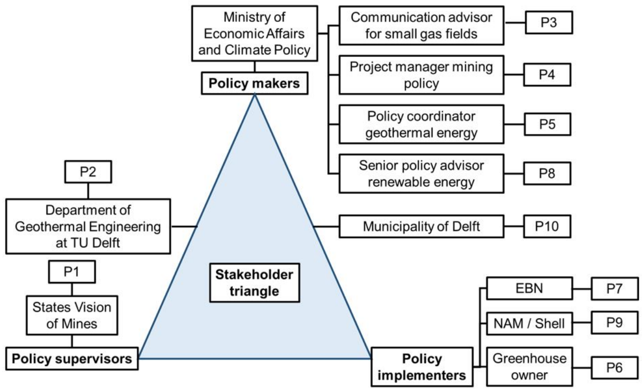


Figure 11.2: The main stakeholder groups in this study visualised in the stakeholder triangle.

At least three factors played a vital role in the loss of the social acceptance for gas production in Groningen. Firstly, the safety perception of the people living close to the gas production area has been affected negatively **(P3)** [Bal *et al.*, 2019; Mulder and Perey, 2018]. Secondly, the extent to which the local people in Groningen benefited from the gas production in their neighbourhoods was not defined [Van der Voort and Vanclay, 2015]. This led to the feeling that the value of the gas extraction was not returned to the people who suffered from the gas production because their houses were damaged. The people in Groningen experience merely the negative effects of the gas production, while they were not rewarded with the benefits: the gas 'disappeared' into the gas distribution network to other parts of the country **(P3, P4 and P5)** [Leeuwarder Courant, 1953; Trouw, 1955]. This distribution of advantages and disadvantages of energy production in the area is the second pillar for social acceptance. Thirdly, from the perspective of the energy transition towards renewable energy production that is going on in the Netherlands, an increasing amount of people is aware that gas will be replaced by sustainable energy source in the near future (see Section 9.3) **(P3, P4 and P5)** [Rijksoverheid, 2018]. Therefore, the extent to which the utility and necessity of gas production are understood by the local public forms the third pillar of social acceptance. Based on the expert–interviews that were conducted during this study (Figure 11.2), these three pillars (safety perception, the distribution of advantages and disadvantages and the utility/necessity of a project) indicate the extent to which geothermal energy implementation is socially accepted in a certain area. In the next section, the three pillars for the social acceptance of geothermal energy implementation will be described.

11.2. Social acceptance of the implementation of geothermal energy

Over the past three decades, the NAM lost its social license to operate in the province of Groningen; the trust issue today is much a result of the denial of the problem that was there already decades ago [Van der Voort and Vanclay, 2015]. The implementation of geothermal energy applications is still in the take–off phase and therefore, in this section three values that influence public acceptance of this technique will be analysed. Then, an analysis will be provided about which technical uncertainty as discussed in Chapter 10 will have the most impact on these three values, and so has a role in the establishment of a public acceptance base for geothermal energy implementation.

In this section, the foundation values for public acceptance for geothermal energy implementation will be discussed based on the interviews.

11.2.1. Safety perception

The first pillar value of public acceptance is the 'safety perception' of the stakeholders involved in a geothermal project. In the current phase of the energy transition that is going on in the Netherlands, people have high expectancy's from the production of geothermal energy according to **P1, P2, P3, P6 and P9**: due to its sustainable character, most people seem to embrace this relatively new technique for energy production. However, States Supervision of Mines warns in its document 'Status of the Sector' that '*there are concerns about the extent to which risks are recognised and controlled. Although there are some good examples, the environmental and safety risks are not recognised well, law and legislation are not being adhered and the culture of safety is poorly developed by many of the permit holders and their advisers. The sector is barely experienced, small in size and the sharing process of knowledge is not sufficient*' [Staatstoezicht op de Mijnen, 2017].

In the interviews, it was discussed that there is a difference between something that is safe and something that is perceived as safe **(P1, P3, P4, P5, P7 and P8)**. **P3** described that, during the discussions that were held in the preparation phase of shale gas production in the Netherlands, the public had questions about the safety of this technique. People said things like: *'In Groningen you [the government, SS.] said that it [the mining operation, SS.] was safe as well.'* This quote shows how the gas production is leading in the public's idea and questions concerning mining operations in the Netherlands. Furthermore, **P3** adds that when a new technique is implemented, the risks and uncertainties that come with this technique are adopted differently by the public than the risks and uncertainties of an already existing technology.

P2 discussed that induced seismicity will occur when geothermal energy is implemented since geothermal is a mining operation just like gas production. In the interview with **P7**, it was discussed that if earthquakes happen, it is important to study the magnitude of the earthquakes and the possible effect; if small vibrations take place in an area where even low magnitudes have an impact on the safety perception of the public, it is a different story compared to if a heavier earthquake happens in an area where it is not noticed.

Over the past decades, people learned how the operators and the government handled the damage that happened in Groningen; the government and the operators reacted too late on the impacts of the seismic events **(P3 and P5)**. This experience might influence the implementation of geothermal energy in the sense of public communication; since the stakeholders communicated in Groningen too long that everything was safe and under control, for geothermal energy implementation, the initiators need to be open and transparent about what is known and what is uncertain, and that if damage or unsafe situations occur, there are mitigation measures ready **(P3)**.

11.2.2. Distribution of advantages and disadvantages

The second key value in public acceptance in the distribution of the advantages and disadvantages of the drilling for geothermal energy in a certain area **(P1, P3, P4, P5, P9 and P10)**. For geothermal energy implementation, this value is related to the distance between the location where the geothermal energy is produced, and the location where the energy is used. For gas production, this distance is of less importance since gas can be transported over long distances. For the population of Groningen, this led to the feeling that the gas that was produced from underneath their houses, was transported to the western part of the Netherlands, while the population in Groningen now deals with the damaged houses **(P3, P4 and P5)**. Warm water needs to be produced as closely as possible to the location where people use the energy, to limit the loss of energy. This difference can lead to a difference in public acceptance. In geothermal implementation, the disadvantages of the technique, such as noise, traffic and increased seismicity, are located closer to urban areas, as this is where the people live that use the produced energy. On the other hand, people might be more willing to accept the disadvantages and uncertainties if they use the produced energy for themselves **(P3 and P9)**. Currently, municipalities are starting up programs where the people that live close to an operation area have the greatest benefit from the operation **(P3)**; for renewable energy sources, politics agreed that 50% of the revenues will go to the local communities.

For the distribution of advantages and disadvantages, the time scale is important: it is possible that the people that initially experience disadvantages like noise and traffic during the implementation of the well, benefit from the well in terms of renewable energy later on in the project. This difference asks the public to consider the longer term, rather than short–term only. For the initiators, it might be beneficial on the long–term to start thinking about mitigation measures in case the value of the houses near geothermal projects drop over time. Two examples of these measures are for the initiators to pay for the difference in house price, or to give the local public a discount on the price they pay for the locally produced geothermal energy. However, these measures will need to be discussed and tested before put into practise.

11.2.3. Utilities and necessities

The third value that influences the public acceptance of a new technology like geothermal energy implementation is the balance between utility and necessity **(P3, P4 and P5)**. Looking at the gas production again, people often do not recognise the need for gas production anymore, since the movement of the energy transition is going from fossil energy sources towards renewable energy sources. That is where the public starts asking questions like *'We need to implement renewable energy sources, so why do they start drilling here?'* **(P3)**. Now for geothermal energy implementation, the public is much more aware of the need than for gas production **(P5)**. **P5**: *'This energy transition is the first transition in which people will not directly benefit in terms of comfort. But if we do nothing, the costs will go up. There are benefits, but these benefits are not reached instantly.'*

11.3. Technical uncertainties influencing the three values of public acceptance

Now that the three values that influence the public acceptance of geothermal energy implementation in an area have been discussed, the technical uncertainties that influence these values can be discussed. In this section, the technical uncertainties that have been described in Chapter 10 will be linked to one of the three key values of public acceptance (Table 11.1).

Table 11.1: Technical uncertainties grouped per key value.

Safety perception	**Distribution advantages / disadvantages**	**Utilities / necessities**
(Induced) seismicity	Location of geothermal well	Ultra–deep geothermal energy
Well design, well integrity and corrosion	Noise, traffic and heavy equipment	
Unfamiliarity with the subsurface: temperatures, injection pressures and reservoir integrity	Co-production of chemicals, radioactive material, oil and/or gas	
Co-production of chemicals, radioactive material, oil and/or gas	Connection to locally produced heat	
The use of hydraulic stimulation of the reservoir		

1. **Safety perception:**

   - (Induced) seismicity – earthquakes that happen as a result of geothermal operations can roughly be discriminated into two categories: a) earthquakes that are noticed by the local public, and b) earthquakes that have such a low magnitude that they are not felt immediately **(P1, P2, P4, P5, P7 and P8)**. Earthquakes that are noticed immediately have a direct influence on the perception of safety of the local public. Earthquakes that are not noticed immediately have a lower magnitude, but can still cause damage to properties over a longer time, and thereby influence the perception of safety over a longer time.
   - Well design, well integrity and corrosion – over the past, it turned out that the first wells that were used in geothermal applications, were leaking after a few years due to corrosion processes. Once a geothermal well is located nearby a drinking water extraction area or a rural area, the corrosion processes influence the perception of safety of the local public **(P1, P4, P5, P6, P7 and P8)**.
   - Unfamiliarity with the subsurface: temperatures, injection pressures and reservoir integrity – when there is no or not enough sufficient data available about the composition of the reservoir in the subsurface, this might influence the public's perception of safety since the effects of the operation on the subsurface are uncertain as well **(P1, P2, P6, and P10)**.
   - Co-production of chemicals, radioactive material, oil and/or gas – uncertainty about the co–production of radioactive material might influence the perception of safety of the local public **(P2, P5, P6, P7, P8 and P10)**.
   - The use of hydraulic stimulation of the reservoir – as a result of public resistance to and the communication process of shale gas production in the Netherlands (Sections 9.2.2 and Appendix I) 'hydraulic stimulation' as a method to increase the production from a reservoir with a low permeability has a negative association amongst the public **(P3 and P4)**. Currently, it is expected that in geothermal energy implementation, hydraulic stimulation of the reservoir will not be needed in the majority of the projects **(P2)**, but if it needs to be applied, it can influence the feeling of safety of the local public **(P1, P3 and P4)**.

2. **Distribution of advantages / disadvantages:**

    - Location of geothermal well – the location of a geothermal well determines to a great extent who of the local public benefits and who deals with the disadvantages of the geothermal well **(P1, P2, P4, P5, P6 and P9)**. This holds for the complete implementation and production period.
    - Noise, traffic and heavy equipment – this technical uncertainty will most likely influence the acceptance of the people that live close to the production site in the drilling phase of the project **(P1, P2, P6, P9 and P10**.
    - Co-production of chemicals, radioactive material, oil and/or gas – since it is still uncertain how the co–produced oil and gas will be treated in geothermal energy production, it is still uncertain whether this is a disadvantage or an advantage for the local public **(P2, P4, P6 and P10)**.
    - Connection to locally produced heat – since heat can not be transported over unlimited distances, geothermal energy needs to be produced (relatively) close to its consumers **(P2, P8 and P10)**. Therefore living close to a geothermal project can result in the connection to the heat network, and thereby consuming renewable energy which is produced locally **(P10)**.

3. **Utilities / necessities:**

    - Ultra–deep geothermal energy – in ultra–deep geothermal energy, there is still a lot of uncertainty about how and where implementation can take place. For now, it is still uncertain if the potential risks of UDG weigh up to the potential benefits of this technique **(P1, P2, P4, P5, P7 and P10)**. Also, it is not sure yet if UDG application will be necessary in the Netherlands or if there are other ways to produce energy for industrial applications **(P9)**.

There is one technical uncertainties of Chapter 10, that has not been linked to one of the three key values of public acceptance. This uncertainty is:

- Cooling of the water – Since it is still uncertain what the degree of cooling of the water in the subsurface will be during production, and how this cooling influences the production duration of the well, this uncertainty is not directly linked with one of the three key values of public acceptance.

In the previous section, an analysis was done on which technical uncertainty in geothermal energy implementation has the largest impact on the three pillars of public acceptance of this technique. Based on the interviews, ideas about the impact of each on the three pillars on the public acceptance of geothermal energy implementation can be provided.

11.4. Ranking the pillars of social acceptance

THE three pillars of public acceptance do not have an equal impact on the public acceptance of geothermal energy implementation **(P1, P3, P4 and P5)** (Figure 11.3).

The triangle in Figure 11.3 is based on the pyramid of needs as designed by Maslow [Maslow, 1954]. In Maslow's pyramid, the essential elements for survival (food, drinks, shelter, etc.) are placed at the base of the pyramid, working towards factors that develop a level of self–actualisation, such as personal development (learning to play an instrument, etc.). In other

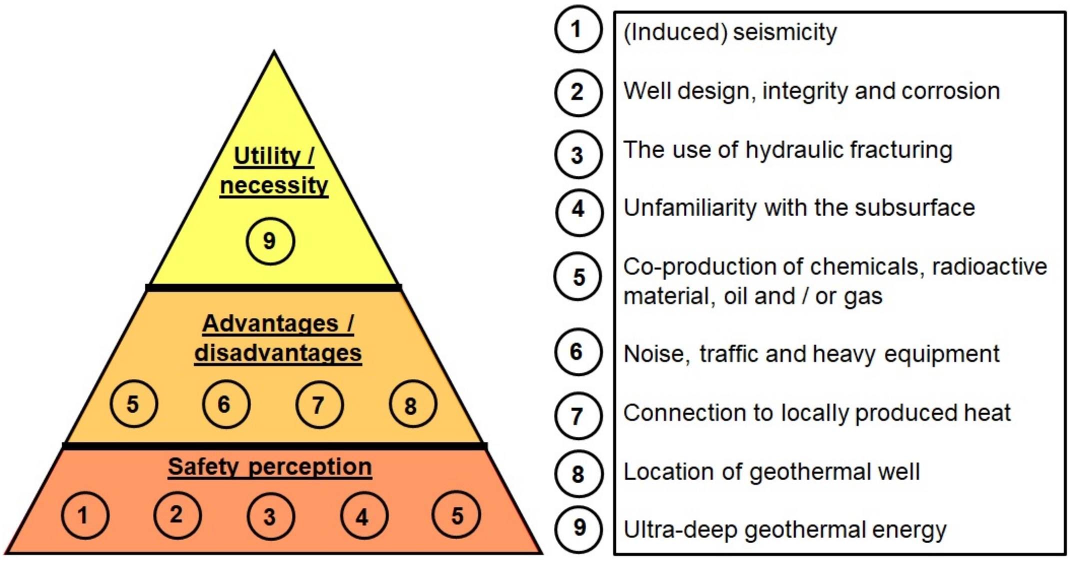


Figure 11.3: Visualisation of the three pillars of social acceptance: safety perception, distribution of advantages / disadvantages and utilities / necessities.

words, the most important factors are placed at the bottom of the pyramid. The same was done in the triangle of Figure 11.3: the most essential, constraint that has the most impact on the level of social acceptance is placed at the bottom of the pyramid, and from there one can work upwards towards the less decisive factors. The technical uncertainty that is ranked (1) in Figure 11.3, (induced) seismicity, is the most important technical uncertainty in geothermal energy implementation, according to the interviewees. This is a result of the earthquakes due to the gas production in Groningen. For the rest of the technical uncertainties, the numbers in front of the technical uncertainties do not label them with respect to importance within each pillar of social acceptance.

As described in Section 8.3, the following three concepts play a key role in the level of social acceptance of the local public [Rosso-Ceron and Kafarov, 2015]:

1. procedural justice;
2. distributional justice;
3. trust.

The social perspective that was developed in Groningen affected the level of trust in the authorities that take the initiative in a geothermal project. In the process where the gas production in Groningen lost its social license (Section 9.7), damage to property and concerns about dyke breaking led to the feeling of insecurity and increased distrust and anger [Bal *et al.*, 2019]. Distrust forms a barrier to social acceptance of a local public towards a transition process [Dowd *et al.*, 2011; Rosso-Ceron and Kafarov, 2015; Stigka *et al.*, 2014]. Based to this level of distrust in the authorities (mainly the national government and the operator) and due to the social perspective towards mining operations that was formed in Groningen (Section 11.1) the technical uncertainties that are linked to the safety perception will have the highest impact on the level of social acceptance. Therefore, the pillar of 'safety perception' was classified as having the most impact on public acceptance of geothermal energy implementation (Figure 11.3). By placing safety perception at the bottom of the triangle, it is emphasised that this pillar forms the foundation of social acceptance; this pillar decides to the largest extent if public acceptance occurs or can be increased. In other words, public acceptance implies and demands a feeling of safety for the local public. In the interviews, this was emphasised by the fact that safety perception was the most mentioned factor of impact on the level of social acceptance during the interviews.

One of the main elements of procedural justice is the access to relevant information for all stakeholders in the communication process [Sovacool and Dworkin, 2015]. For the context of the communication process between the initiators and the local public of a geothermal project, a link can be made with the information–integration theory (Section 8.4.4): this theory describes how people collect information about other persons, objects, and situations to form attitudes or predispositions towards a certain topic. The information–integration theory contains two factors: valence and weight. In the communication process, some information will influence the attitude of the public more than other types of information. Based on the knowledge from Groningen (Sections 9.7 and 9.7.2), where the decreasing levels of safety perception had a major impact on the level of social acceptance, the assumption is made that the same situation can arise for geothermal energy if the technical uncertainties are not communicated or communicated too late. Since both gas production and geothermal energy production are classified as mining operation (Section 10.1), the parallel between the communication of technical uncertainties and the level of social acceptance is appropriate.

In the case of gas production in Groningen, there was a difference between what the industry and the government acknowledged as 'safe' and what the local public considered to be safe; for geothermal energy implementation as well, stakeholder (group) has its own perception of what safety is. Now in the case of geothermal energy implementation, this experience led to distrust amongst the people that live close to potential areas for geothermal energy production **(P1, P3, P4, P5, P7 and P8)**. Once the safety perception of the public is changed and this leads to concerns or opposition, it is difficult for the relevant stakeholders to change this perception back to more realistic or acceptable values **(P1)**. In other words, changing the feeling of safety, has the most impact on the proceeding of the project, compared to advantages/disadvantages and utilities/necessities.

Once the perception of safety is satisfied, one can proceed to the next pillar of public acceptance: the distribution of advantages and disadvantages. The distribution of advantages and disadvantages strongly links to the level of control that the public has in the production of geothermal energy and the economic benefit that the public has from the operation. As mentioned in Section 8.3, economic factors influence the level of acceptance towards a transition process [Zhang and Moffat]: if people know that the transition brings them economic benefit, they are likely to have a more positive attitude towards the transition. On the other hand, if the transition affects them in a negative economic way, such as happened in Groningen, they are likely to develop a negative attitude towards the transition. The distribution of advantages and disadvantages of the geothermal energy project plays a role in the acceptance by the public, as is explained by the strong link with the concept of distributional justice, which is one of the concepts of social acceptance by the local public. In this aspect improvements can be implemented that were learned and developed based on the gas production in Groningen**(P3, P4, P5, P9 and P10)**: once a potential risk is being introduced in a certain area, the local people want to know what is in it for them **(P5)**. Moreover, the extent to which a group of people has control in a transition process, partly determines the attitude towards this transition process [Baronas and Louis, 1988; Kemp and Loorbach, 2006]. Based on this, the assumption is made that if the local public is provided with a certain extent of control over the distribution of the produced heat, people will develop a more positive attitude towards the production of geothermal energy in their neighbourhoods. Successful tests with this concept have been executed in Ternaard (gas production, **P3 and P4**) and Harlingen (salt production, **P3**).

By viewing the implementation of geothermal energy from the perspective of the ongoing energy transition in the Netherlands [Provoost *et al.*, 2019; Rijksoverheid, 2019b; Schoof *et al.*, 2018], the Dutch population is well aware of the need of geothermal energy implementation [Kramers *et al.*, 2012; Van Heekeren and Koenders, 2010]. Based on this observation, the pillar of 'utilities and necessities' was classified as the pillar that has the least impact on public acceptance in the phase of implementation of a geothermal energy project.

11.5. Chapter summary

FROM 1986, earthquakes have been measured in the Dutch province of Groningen, where gas is produced from a region that is assumed to be tectonically inactive. Examples of social impacts of the earthquakes in the area are damage to properties, feelings of insecurity and increased distrust and anger. Between 1986 and the moment of this study, a combination of distrust, contradicting decisions, a lack of technical expertise and the struggle for compensation of people that live in the earthquake region have led to the loss of the social acceptance for the parties that exploit the Groningen gas field. By engaging more with the community and establishing the value of gas extraction to the local people, the NAM tries to regain its social acceptance in the area.

Based on the expert–interviews, three pillars for public acceptance of geothermal energy implementation are distinguished: a) safety perception; b) the distribution of advantages and disadvantages, and; c) utilities and necessities. By analysing the interviews, the technical uncertainties as described in Chapter 10 have been linked to the following pillars:

1. **Safety perception:**
    - (induced) seismicity;
    - well design, well integrity and corrosion;
    - unfamiliarity with the subsurface: temperatures, injection pressures and reservoir integrity;
    - co–production of chemicals, radioactive material, oil and / or gas;
    - the use of hydraulic stimulation of the reservoir.
2. **Distribution of advantages / disadvantages:**
    - location of geothermal well;
    - noise, traffic and heavy equipment;
    - co–production of chemicals, radioactive material, oil and / or gas;
    - connection to locally produced heat.
3. **Utilities / necessities:**
    - ultra–deep geothermal energy.

From these three pillars of public acceptance, safety perception was ranked as having the most impact on the level of public acceptance; once a situation is perceived as being unsafe by the public, public resistance might increase and for the involved communicators, it is difficult to bring the safety perception back to the realistic situation.

In the next chapter, the results of Chapter 10 and this chapter will be combined in the design of the communication approach for technical uncertainties in geothermal energy implementation. The foundation for the design was constructed in the theoretical model in Chapter 8, by the description of a generic communication model. In the next chapter, the acquired data will be combined into a more specific communication approach (Figure 11.4).

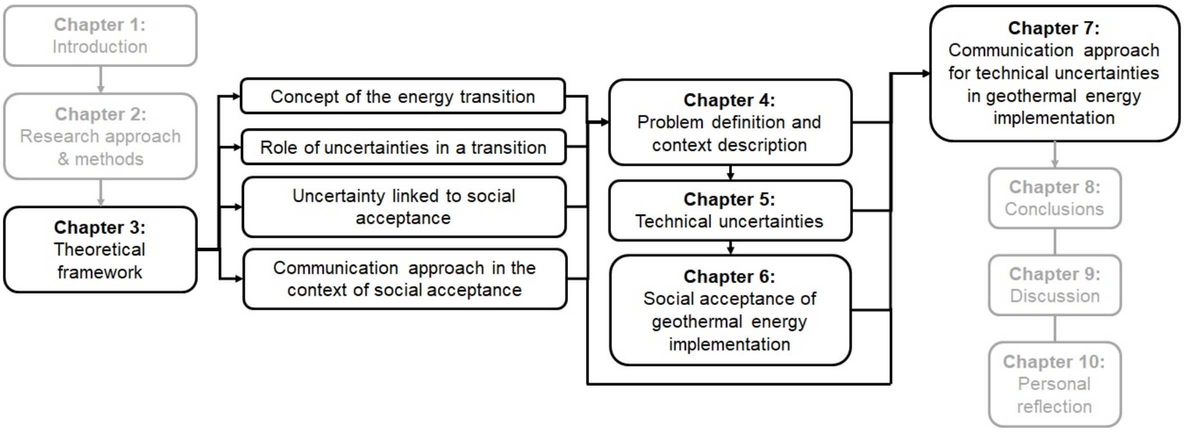


Figure 11.4: In Chapter 12, the communication approach for the communication of technical uncertainties towards a local public during the implementation of a geothermal project will be designed.

12

Communication approach for technical uncertainties in geothermal energy implementation

THE theoretical framework in Chapter 8, the context description in Chapter 9, the technical uncertainties that have been identified in Chapter 10 and the links between these uncertainties and the level of social acceptance of geothermal energy implementation in Chapter 11 all build up towards this chapter. In this chapter, the design of a communication approach of technical uncertainties to public to increase public acceptance for geothermal energy implementation will be provided, thereby answering research question of this study as provided in Chapter 6:

- How can technical uncertainties that are present in the implementation process of geothermal energy be communicated by the initiators of a geothermal project to the local public in the perspective of the energy transition in the Netherlands, to increase the level of social acceptance when taking into account the social sentiments that have been developed with respect to the production of gas in the Netherlands?

The main methods that have been applied to construct this chapter are visualised in Figure 12.1. The results that were obtained by desk research and literature research were combined with the interview results into a draft version of the communication approach. During verification discussions (Section 7.3), this draft version was discussed with different stakeholders.

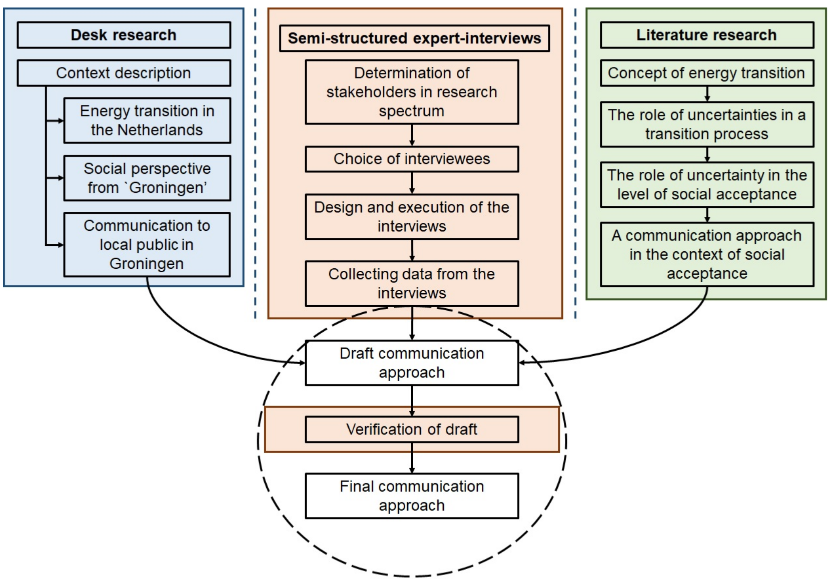


Figure 12.1: The different methods applied in previous chapters lead to the design of a communication approach in this chapter.

Based on their feedback and ideas, the draft version was adjusted to the final approach as presented in this chapter.

12.1. Criteria for a communication approach

BASED on different aspects that have been discussed in previous chapters, the design criteria of an approach for the communication of technical uncertainties from the initiators of a geothermal project to the local public of the project can be determined. By the end of the design phase, the communication approach should:

1. define a **goal** of the communication process.
2. provide a **structured** overview of the different steps in the communication process and the different choices that will need to be made.
3. be applicable for both technical experts and communication–experts in the communication of technical uncertainties in any case of geothermal energy implementation in the Dutch energy transition.
4. provide an overview of the **timing** of the different steps in the communication process.
5. provide an overview of the **stakeholders** that are involved in the communication process and the stakeholders that are involved in the context of geothermal energy implementation, but not in the communication process.
6. determine which of the communicating actors has the **ultimate responsibility** over the procedure of the communication process.
7. provide an overview of the **technical uncertainties** that play a role in the geothermal project.
8. indicate the impact of the technical uncertainties on the **level of social acceptance** by the public.
9. provide an overview of the communication methods that will need to be applied in the communication process.

12.2. The generic case: a communication model

IN the introduction of this report (Chapter 6), a model that links the concepts of a communication model, an approach and a communication plan has been provided: indicated by the red dashed lines in Figure 12.2, a generic communication model is located on the left side of this visualisation.

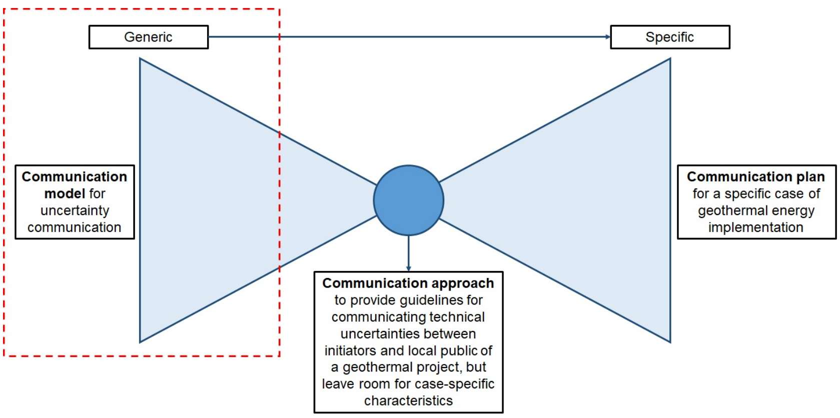


Figure 12.2: The model provided in Chapter 6 focusing on a generic communication model.

Based on the communication model constructed in Chapter 8 [Oomkes, 2013], the communication model displayed in Figure 12.3 can serve as a basis for the communication of technical uncertainties in the implementation of a geothermal project.

The generic model offers room for the communicating actors that play a main role in the communication process to make decisions on the goal, the situation, the communicating actors and their reference frame. The communication model that is visualised in Figure 12.3 is applicable in many different situations in which two communication actors are present; the model offers no guiding in the scope of the model, nor for the communication channels that can be used in the conversation process. The only thing the model does restrict is the amount of communicating actors; communicator A and B are visualised in the model.

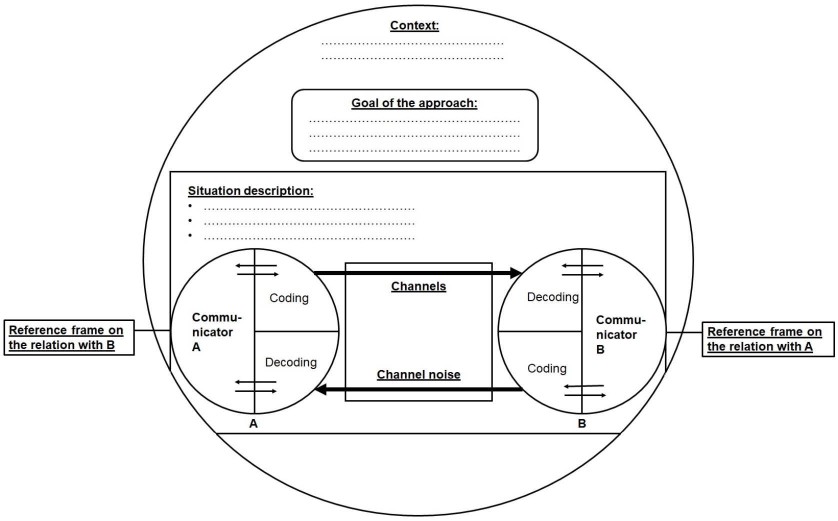


Figure 12.3: The generic communication model constructed based on the theoretical framework for the communication of technical uncertainties.

Based on the design criteria that have been listed in Section 12.1, this generic model is not suitable for the goal of the communication process that is the topic of this study, since the model is applicable in too many different situations and offers no insight in the context and the situation of the communication process. Also, the reference frames that influence the communication of the communication actors are not detailed and different communication channels are not addressed. The structure that is needed according to the design criteria is offered, but no guidelines or tools were provided help the communicating actors.

In this research, data that provide information about the different steps of the communication model have been collected. In the next section, these data will be implemented into the communication model, thereby working towards a communication approach. This communication approach offers specific guidelines, but leaves room for the communicating actors to make their own choices during the communication process.

12.3. Detailing the communication model: a communication approach

THE previously discussed communication model was found to be too generic based on the design criteria that focused on applicability and structure. In this section, relevant parts of the communication model will be detailed for the context of social acceptance of geothermal energy implementation. Based on the results described in previous chapters, different parts of the model can be detailed and addressed, resulting in a more specific communication approach (red dashed frame in Figure 12.4).

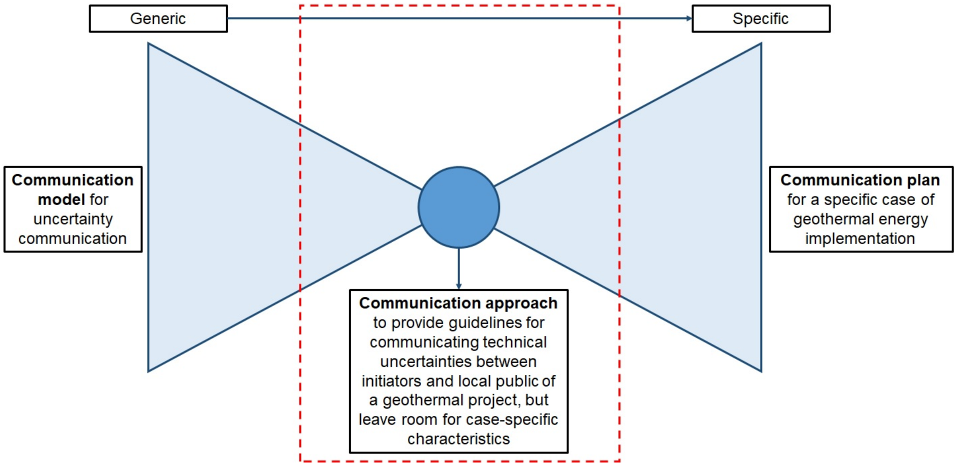


Figure 12.4: Detailing the communication model towards a communication approach.

This approach offers guidelines to each of the steps in the model, but leaves room for the communicating parties to make their own (argumented) choices. In reality, there are many factors, both internal and external to the communication process, that influence the communication process. In Appendix J, additional information and examples of questions to start the communication process are included.

Where the communication model proposed by Oomkes [Oomkes, 2013] (Figure 12.3) starts with a description of the context, goal and situation of the communication process, and works via the communicators and their reference frames towards the message and the communication channels, the order of the elements of the communication approach presented in this chapter will be different (Figure 12.5). The colours in the approach indicate the different elements that are connected to one aspect or step in the communication approach.

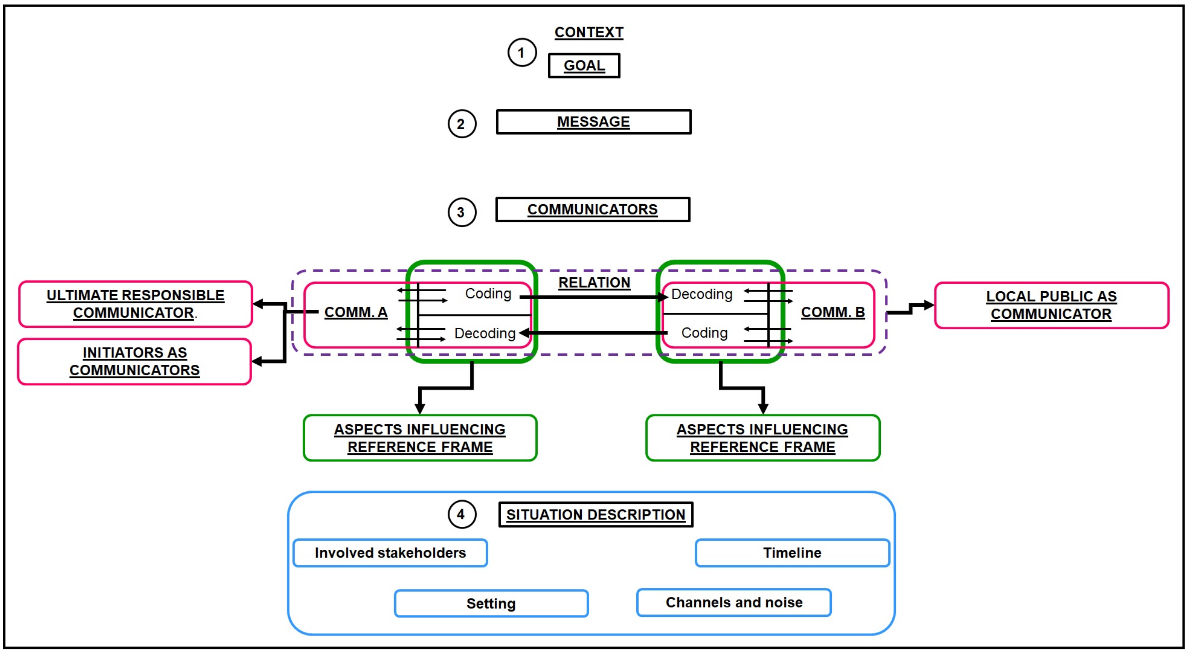


Figure 12.5: Visualisation of the aspects of the (empty) communication approach.

The choice to change the order of the elements of the communication model as proposed by the end of the theoretical framework in Chapter 8 is based on multiple arguments. First, the communication **context and goal** (step 1 in Figure 12.5) for the communication approach designed in this study are set at the beginning of the approach. This context and goal, which follow from the theoretical framework and the context of this study (Chapters 8 and 9) will be the same for each communication process on which this communication approach is applicable.

Second, the different technical uncertainties that can be present in a project and their link with the level of social acceptance of geothermal energy implementation have been identified in Chapters 10 and 11. From the context and the goal of the communication approach, these technical uncertainties form the **message** (step 2 in Figure 12.5) in the communication approach. For each case of geothermal energy implementation, different technical uncertainties might be applicable, but the overview presented in this study provides a base for the identification of the technical uncertainties that are specific for a certain case of geothermal energy implementation.

Third, the **communicators** (step 3 in Figure 12.5) will be identified once the message has been addressed in the communication approach, the **reference frames** from which they participate in the communication process will be addressed.

Then, the last step of the communication approach will be the identification of the situation in which the communication process takes place (step 4 in Figure 12.5). Within the scope of the communication approach, the situation description contains the most case–specific aspects and characteristics. In the situation description, four key elements will be addressed: a) the stakeholders involved in the geothermal project, b) the timeline of the project and the integration of the social and technical processes, c) the setting of the communication process, and d) the applied communication channels and noise.

By constructing the communication approach according to the steps mentioned above, the approach first focuses on the aspects that are the same for each communication process and have been chosen as a result of analyses done in previous chapters (context, goal, message and main communicators). Aspects that ask for more case–specific attention – the situation in which the communication process takes place – will be described following the previously mentioned aspects.

It should be mentioned that the order in which the different elements of the communication approach are presented (top–down in the figures) offers some guidance during the description of the approach. However, this does not mean that these steps are fixed. As will be explained later, for example, the communication channels and methods that are described in the situation description, partly depend on the technical uncertainties that are communicated (the message). Nevertheless, the communicating channels are description in the situation–section of the communication approach, since the communication channels that can be applied in a conversation also depend on the location, setting, the public, etc. In other words, the situation in which the communication process takes place offers both constraints and opportunities for the communication process.

In the next sections, the aspects of the communication approach mentioned previously, will be described.

12.3.1. Context and goal of the communication approach

As described in Chapter 8 and 9, the context of the communication approach is defined by the concept of social acceptance of geothermal energy implementation (Figure 12.6). Based on this context definition, the urgency for the communication approach that is designed in this chapter can be recognised. From the context of social acceptance of geothermal energy implementation, the goal of the communication approach (Figure 12.6 is *to* *communicate the different technical uncertainties that are present in the geothermal project in order to increase the level of social acceptance of geothermal energy implementation.*

12.3.2. Message: communicating technical uncertainties in the perspective of social acceptance

From the context and the goal of the communication approach as described above, the message in the communication process can be provided. Based on the results of Chapter 10 and 11, the message in the communication approach are the technical uncertainties that are relevant for the level of social acceptance in the case of geothermal energy implementation (Figure 12.6).

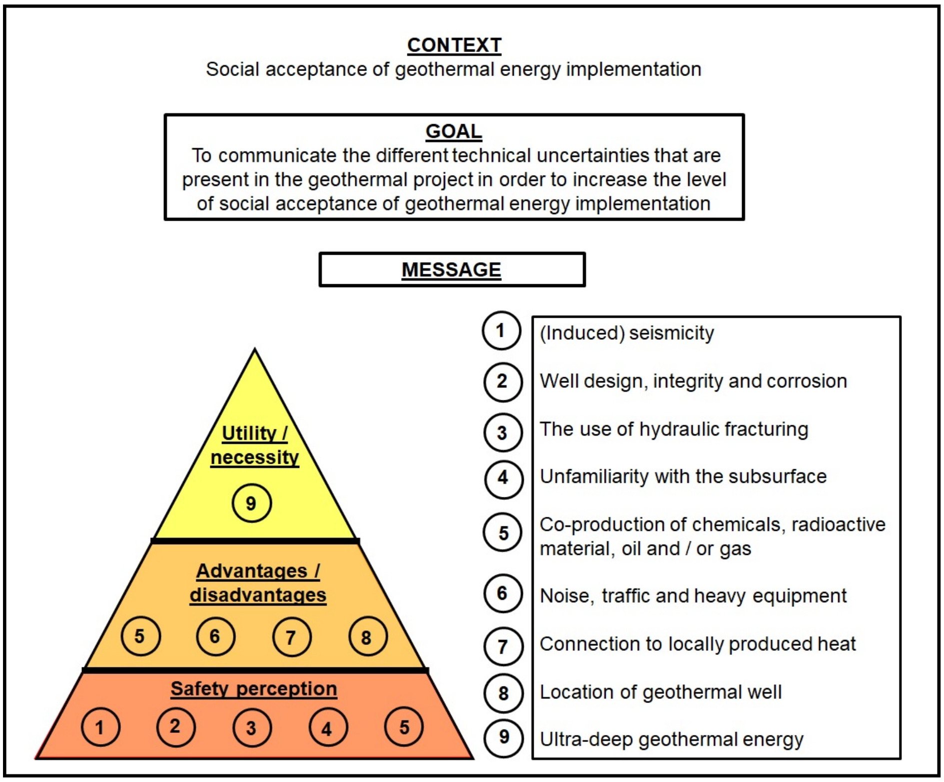


Figure 12.6: The technical uncertainties (Chapter 10) linked to different pillars of social acceptance (Chapter 11) as message in the communication approach.

The three levels of the pyramid of social acceptance (Figure 12.6) indicate a different level of impact on the level of social acceptance. The technical uncertainties that link to the level of safety perception have potentially the largest impact on the level of social acceptance. Based on this overview, the communicating parties can discuss the technical uncertainties that are most relevant in the specific case. The process of the identification of technical uncertainties that are relevant for a specific case was not in the scope of this research.

12.3.3. Sender and receiver in the communication approach

The communication model by Oomkes [Oomkes, 2013] includes two communicators (A & B, Figures 8.4 and 12.3). In this next step of the communication approach, these communicators will be appointed:

1. Based on data from the the interviews, the following four stakeholder groups were grouped and appointed to be the senders: the 'initiators of a geothermal project' (Figure 12.7):

- The Ministry of Economic Affairs and Climate Policy, which has both an economic and environmental interest in the development of geothermal energy. The environmental interest lies in the (inter)national climate goals that have been set for the implementation of geothermal energy. The economic interest comes from the benefits from the production of gas and the fact that water production is less beneficial (in economic terms) than hydrocarbon production. Moreover, the ministry is also the stakeholder that authorises the permit requests for geothermal projects.

- The municipality where the geothermal project will take place. Locally, municipalities are organising departments that are concerned with the implementation of geothermal doublets. If present, representatives from these departments would be interesting to invite as communicating actors in the communication process.

- The operator that will exploit the geothermal well.

- States Supervision of Mines, which will be the independent advising and controlling party in the geothermal project.

Currently, the majority of the initiating parties did not train communication–experts yet in the field of geothermal energy implementation **(P2, P8, P9 and P10)**. Therefore, the communication process to the public is mainly organised by policy–makers, technical experts other people that organise the communication process besides their other work activities. For the implementation of this communication approach, it is advised to appoint experts in the field of (uncertainty) communication in the communication process. Multiple interviewees explained that communication–experts are being appointed in their organisations for this task in the near future **(P2 and P3)**.

Each communicator in the communication process brings its own set of expertise and knowledge; based on this knowledge, each communicator is responsible for the identification of the technical uncertainties in their fields of specialisation (Figure 12.7) from the total overview of technical uncertainties (Figure 12.6) **(P1, P4, P5 and P10)**. According to literature, alignment of the different stakeholders is important (Section 8.4.4). A start is made by appointing the communicator that has the ultimate responsibility in the communication process. Based on the results of this study, it is suggested to appoint the municipalities as responsible party, due to its central position in the research spectrum and links with other stakeholders in the communication process. In addition, the communicators need to decide whether if and how they will tell the same story during the process, and what the influence of one shared message is on the success of the conversation (Figure 12.7). In the interview, **P10** was convinced that one shared message can be communicated by the initiators to the local public in the process of communicating technical uncertainties in the implementation of a geothermal project. This way, there is no potential for the situation of different communicators telling different stories. The communication of each technical uncertainty can be supported by the different stakeholder groups to give the message more power **(P10)**.

2. The local public (Figure 12.7) is defined as the people that live within a radius of 5 km distance from a geothermal project location.

   Overall, it is easier for the senders to address people who have already a clear opinion than residents who do not express their views and ideas; information and knowledge therefore are easier communication to the people that are already well–informed

[Oomkes, 2013]. Therefore, and for an effective communication process, pro– and opponents of geothermal energy implementation can group themselves to strengthen their voices **(P10)**. However, how this grouping process should take place was left out of scope of this research. The communication approach presented in this study includes the local public as one communicating actor. In reality, the local public consists of many subgroups, which can be classified based on their opinion towards geothermal energy implementation, for example. In communication processes around geothermal energy in general, **P9 and P10** experience that the people that have the strongest opinions about geothermal energy production, determine the conversation to a large extent, while people that do not have a clear opinion or feel a boundary to speak openly about their opinion, are not heard in the communication process. One option to approach this problem is to actively involve local people that have different backgrounds, interests in the projects and represent different parts of the community. This can be done by personally ask people to participate in the communication process **(V3 and V4)**.

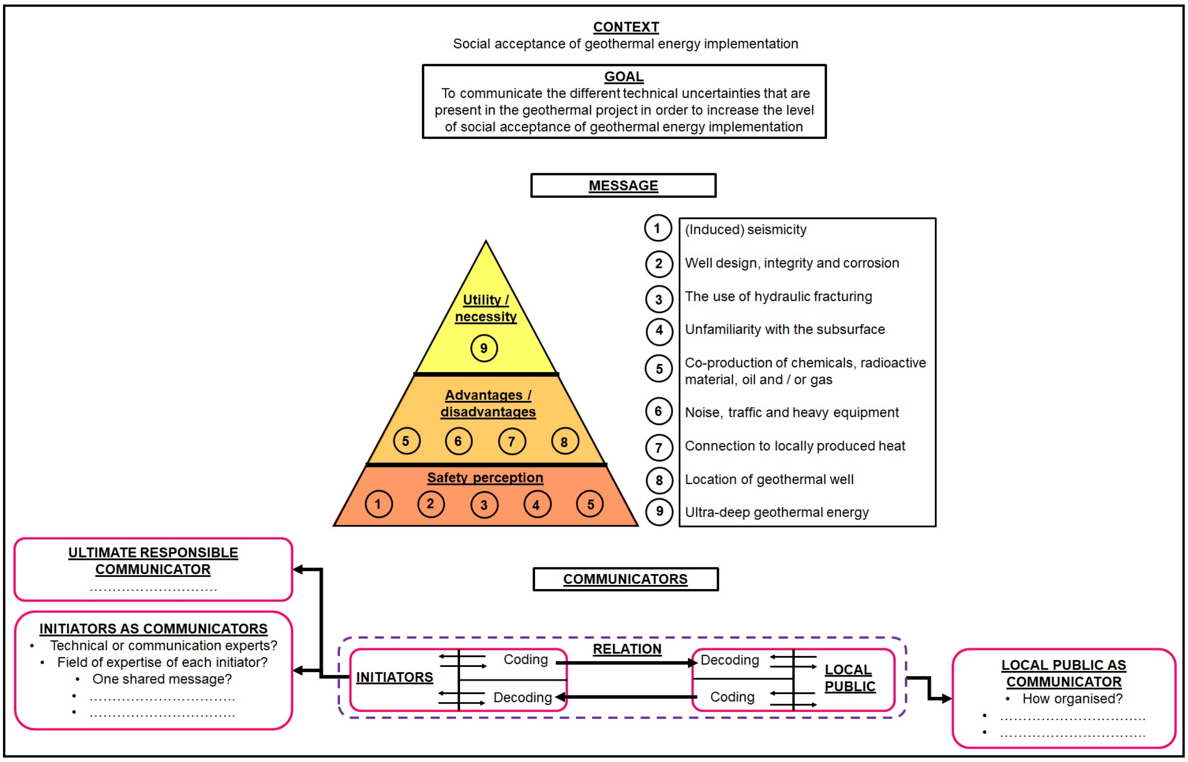


Figure 12.7: The role of the communicators in the communication approach.

The relationship between different communicators in the communication approach For the communication process of technical uncertainties, a relationship will need to be build between the initiators of a geothermal project and the local public. A relationship serves as a basis for an effective communication process [Littlejohn and Foss, 2008]. In Figure 12.7, the relation between the initiators and the local public is displayed in a dashed line to indicate that the relation between these communicators is not a fixed components: the type of relationship can vary over the time of a geothermal project and depends on multiple variables, such as trust and credibility of the communicators. For the case of geothermal energy implementation, the relationship is not always an equal one; some would say that the local public has less power in the initiators of the project. However, as described in Chapter 8, social acceptance of geothermal energy is of vital importance for the success of the energy transition. That means that even if the relationship between the public and the initiator is not equal in terms of decisive power, the public does have the power to affect the continuity of the project by expressing concerns, fear and feelings of anger. In the most extreme case, the local public make a claim on the duty of care of the Dutch government.

In the next section, the elements influence the reference frames of the communicators will be explained.

12.3.4. Coding and decoding from a reference frame

In the reference frame of actors who communicate in the perspective of social acceptance, the three factors of a) procedural justice, b) distributional justice, and c) trust play an important role (Section 8.4.4). These factors are influenced and determined by different aspects.

The data for the construction of the reference frame of the initiators was collected during the semi–structured expert–interviews and the verification discussions. The data that contribute to the definition of the reference frame of the public was collected during the expert–interviews, existing knowledge of the social perspective related to the gas production in Groningen [Bal *et al.*, 2019; Van Bruggen, 2015; Van Thienen-Visser and Breunese, 2015] and the verification discussion with **F1** (Section 7.3). However, it should be noted that each public in each case of geothermal energy implementation has its own frame of reference in the communication process. The verification discussion that was organised in this study provided clear insights, but the interviewed people are not representative for all public ever in all cases of geothermal energy implementation.

- For the communication of technical uncertainties, the control theory of procedural justice (Section 8.3) implies that both the initiators and the local public want to be acknowledged in the communication process and that a higher level of control increases the feeling of meaningful contribution to the communication process. In the practice of geothermal energy implementation, the public needs to have the opportunity to express its feelings, concerns and ideas about the geothermal project. There are different methods that allow these expressions, such as the availability of a telephone number that people can call in case they have questions, or a weekly moment in which the initiators are available for questions **(F1)**.

  For the public and the initiators to be able to contribute to the communication process in a meaningful way, the communicators need to have a certain level of existing knowledge about the other communicators, the goals and the procedure of the communication process. In this light, it might be interesting to organise a meeting with all communicators together at the start of the communication process, to increase the level of knowledge about each other and to discuss pre–existing opinions and ideas about the project.

  Being trustful in the communication process is one of the conditions for procedural just communication [Folger and Bies, 1989]. For the initiators of a geothermal project, this implies that openness, fairness, credibility and transparency are important values towards the local public. These values and their implications will be discussed in Section 12.3.5.

  For the both the initiators of a geothermal project and the local public, the way information about the technical uncertainties in the geothermal project has been identified plays an important role in the reference frame for the communication according to the information–integration theory (Section 8.4.4). Many people collect information for example by searching on the internet. Thereby they will find loads of reliable and relevant information, but also information that will contribute to misinterpretations or ideas that will not be representative for the specific geothermal case in their neighbourhood.

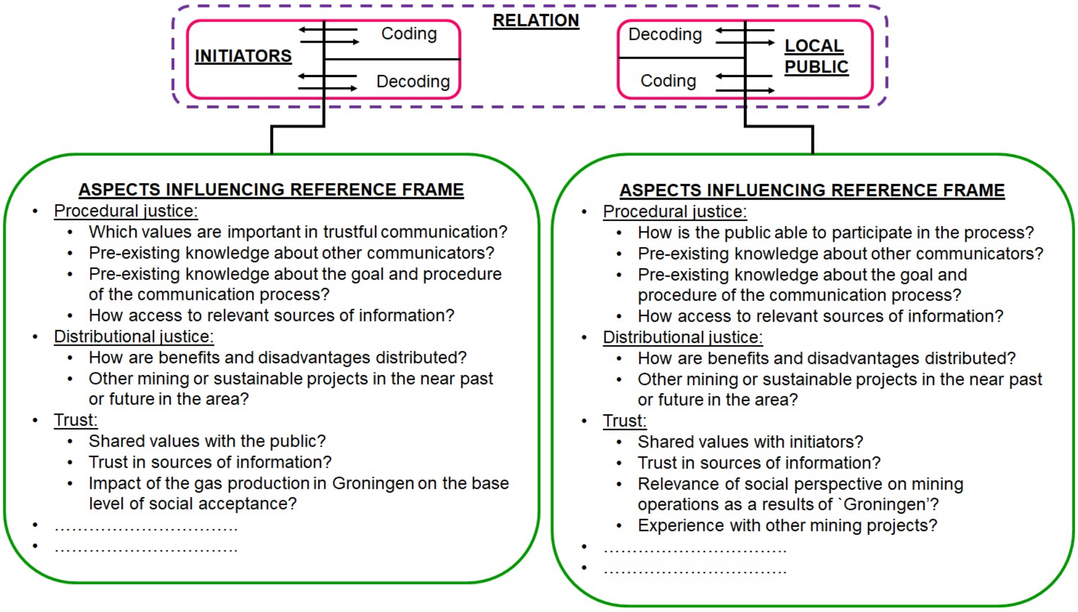


Figure 12.8: Aspects influencing the reference frame of the main communicators in the communication process.

- In geothermal projects, the level of distributional justice is determined by the extent to which advantages and disadvantages are distributed over the public. Also, the level of distributional justice can be expressed in the extent to which the public has control over this distribution. Considering the concept of selective acceptance, for the initiators it is important to stress the aspects that are beneficial for the local public, as these aspects make the people more likely to accept the geothermal project.

  For geothermal energy implementation, it is interesting for the initiators to discuss how the public can be involved in this process prior to the communication procedure. Currently, pilots in which the public was able to monitor the subsurface during the mining activity have been successful in the province of Friesland **(P3)**. Since geothermal energy production will take place closer to densely populated areas, involving the public in the distribution of the produced energy or by providing real–time insight in the drilling process might increase the level of social acceptance.

  The extent to which the local public of an area experiences distributional justice can be influenced by other sustainable or mining projects that play a role in the region. In the province of Groningen, for example, the distribution of benefits and disadvantages of geothermal energy will be placed in the larger context of the gas production and earthquakes. Or if, for example, a neighbourhood has been confronted with plans to construct a wind farm close to the same location of the geothermal project, this might influence ideas and prejudices about the geothermal project. The initiators need to be aware of these societal challenges. The municipalities play a main role in the identification of these projects. Therefore, the level of distributional justice in an area always need to be considered in a context that is larger than 'just' the current geothermal project.

- The third factor influencing the reference frame of the communicators is the current level of *trust*. The current level of trust can be shaped by experiences with other stakeholders in the past, or by public opinion due to news items in the media **(P9)**. The extent to which the two communicating groups share values amongst each other needs to be identified by the communicators, since a higher level of shared values increase the level of trust [Riad, 2007; Wiener, 1988]. Examples of values that can be shared by both the initiators and the public in the implementation of a geothermal project, are sustainability, transparency and fairness. For each specific geothermal project, these values can be addressed by the organisation of a 'value–night' by the initiators, where both the public and the initiators will be able to express the values they find relevant in the geothermal project.

Both the public and the initiators need to be able to trust the sources of information that are used in the geothermal project. Therefore, the role of independent information sources, such as the Dutch geological survey (TNO), for example, in the communication process needs to be investigated in the future. In current society, it is inevitable that the public will source for information from the internet. However, not all information available on the internet is applicable for the case of geothermal implementation in their neighbourhoods. The initiators need to be aware of these sources of information for the public: it should be no surprise that the initiators are not the only sources of information for the public. For an effective communication process, the public needs to have access to independent and trustful sources of information that are relevant for their specific case of geothermal energy implementation and the initiators need to be willing to share information that is relevant for the public.

The social perspective that was developed in Groningen had an impact on the level of trust towards mining operators and the national government in the Netherlands (Section 9.7) [Bal *et al.*, 2019; Van Bruggen, 2015]. In future geothermal operations, the level of trust of the public in the initiators might be impacted by this social perspective. In this sense, the initiators need to be able to address these concerns: the initiators need to be prepared to compare the current geothermal project to the gas production in Groningen and to be able to name the differences and similarities. In the interviews, it was discussed that the scale of geothermal energy production cannot be compared to gas production in Groningen **(P2)**. To increase the level of trust, the initiators need to be able to address this comparison, for example by making a graphical fact-sheet that addressed the similarities and differences in terms that the public is familiar with.

A last factor that influences the level of trust of the public is the experience that an area has with mining operations. From the social perspective developed in Groningen, the implementation of geothermal energy in Groningen raises different questions and concerns than in other parts of the country. The initiators therefore need to be well–aware of mining operations in the past, and ideas and answers to address these concerns need to be prepared prior to the communication process.

Figure 12.9 links the reference frame of the communicators (in green) to the already existing steps of the communication approach.

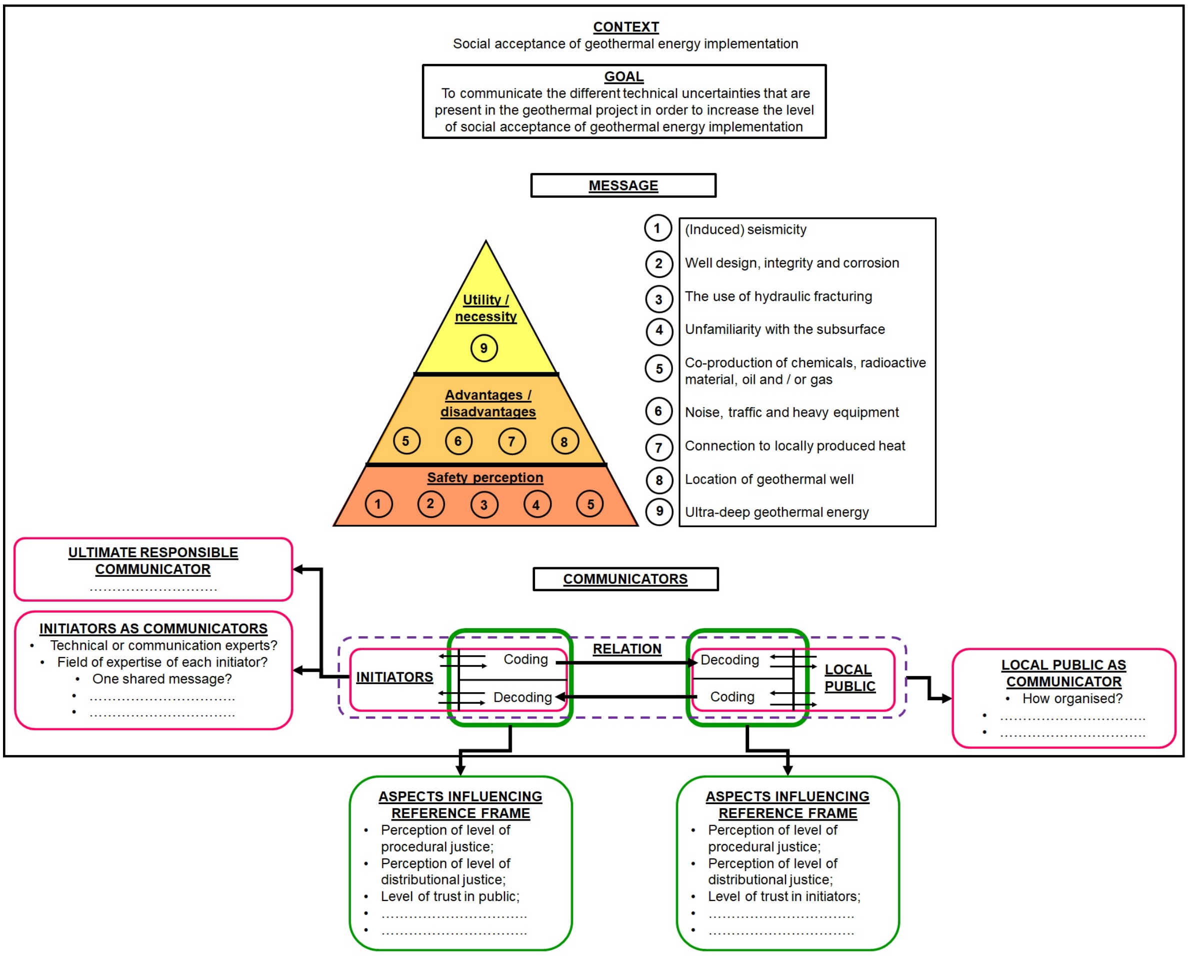


Figure 12.9: Aspects influencing the reference frame of the main communicators in the communication process.

From the semi–structured interviews, different aspects of the reference frame of both the initiators and the public can be addressed:

1. **Pre–existing knowledge influencing the communication process:** the process of selective receiving (Section 8.4.4) can be activated by an existing level of knowledge for the different communicators and influence the interpretations of the message. To recognise the process of selective receiving, an overview of the existing knowledge might be beneficial in the communication process:

   A. For the initiators of a geothermal project, the different aspects of pre–existing knowledge have been identified:

      - **The Ministry of EZK:**
        - is experienced with the authorisation of permit requests since the ministry had the same role in the authorisation of gas production requests **(P3, P4 and P5)**;
        - is, due to Groningen, aware of the need of damage protocols and places where people can go in case they experience damage or other disadvantages from the implementation of geothermal energy **(P4)**;
        - has the ultimate responsibility of the climate policy in the Netherlands, and the level to which the goals for the energy transition are met.
      - **The municipalities:**

    - are in charge of the implementation of the 'Transitievisie Warmte' before 2021 **(P10)**;
    - are often aware of the social issues that play a role in the level of social acceptance of geothermal energy implementation.
  - **The operator:** can be experienced in the implementation of a gas production project, or maybe even has experience with the implementation of a geothermal project **(P9)**.
  - **States Supervision of Mines:**
    - contains a set of knowledge regarding the safety and environmental issues that can play a role at each phase of a geothermal project **(P1)**;
    - is aware of different project in the Netherlands that were successful or not, and uses this knowledge to analyse the health, safety and environmental risks and uncertainties that are present at the start of a new geothermal project.

B. Pre–existing knowledge of the public:

  - is influenced by the extent to which the public has access to relevant sources of data **(V2)**.
  - depends on the experience that people have with mining operations in their neighbourhood **(P9)**;
  - might include information about other stakeholder groups or communicating parties.

2. **Levels of control of the initiators:** Discussing the extent to which the initiators in a geothermal project have a certain level of control can be difficult, since hierarchy and power differences between the initiators and the local public may influence the level of control. Moreover, the democratic political system in the Netherlands limits the power of the national and local governments to a certain extent, as will be discussed in Section 14.4.3. Nevertheless, different initiators in the approach each own different tools to control the communication process:

   - **The Ministry of EZK:**
     - has the ultimate responsibility in meeting the (inter)national goals of the energy transition **(P4)**
     - plays a decisive role in the continuation of geothermal project via permit authorisations;
     - depends on the knowledge and input of the other stakeholders to make a well-based decision.
   - **The municipalities:**
     - have a role comparable to the ministry, but at smaller scale **(P10)**;
     - controls the balance of different interests at the local scale to a large extent **(P3)**.
   - **The operator:** is in control of the practical issues that are part of a geothermal project **(P9)**.
   - **States Supervision of Mines:** has the highest level of control in the process of geothermal energy implementation, as SodM is authorised to close down a geothermal project when safety and environmental issues form risks for the people that are involved in the project **(P1 and P8)**.

3. **Values emphasised by initiators:** In the interviews, different interviewees emphasised the importance of certain values in the communication of technical uncertainties to a local public. For an effective communication process, these values will need to be shared by each initiator:

    - **Fairness:** Considering the influence of the social perspective due to gas production in Groningen on the level of trust in the initiators by the local public, communicating in a fair way is key in the communication of what uncertainties are present in the geothermal project **(P3, P4, P6 and P10)**. **P3** indicates that communicating in a fair way contributes to an increase in trust in the communicating actor; trust in the initiators by the local public is of vital importance for the success of the geothermal project. When **P10** was asked about the potential for selective sending in relation to a fair way of communication by the initiators, it was discussed that *'it is better to inform people beforehand, even if there are still uncertainties. In the end, people will find out anyway if the initiators knew in advance about certain consequences of the geothermal activity. Be open in what is still unknown or which aspects are still under investigation.'*
    - **Cooperation:** The level of cooperation within each communicating group has an impact on the level of social support for the implementation of geothermal energy **(P1, P3, P5, P7, P8 and P10)**. Cooperating communicators determine how the implementation of geothermal energy is framed towards the local public **(P8)**.
    - **Transparency:** For the initiators, it is important to be aware of the concept of selective sending **(P5 and P10)**: in open technical uncertainty communication, there might be a need to inform the public with knowledge that is not beneficial for the continuity of the project. From 'Groningen', the initiators of geothermal projects learned that not communicating uncertainties and aspects of the project that are still under investigation, in the end decreases the level of social acceptance; for the communication process around geothermal energy implementation, uncertainties and unknown aspects will need to be communicated once they are identified **(P1, P3, P4, P5, P6 and P9)**. One example of transparent communication mentioned by **P3, P4 and P5** is the development of a central counter for damage reports. This way, the public is made aware of the potential risks of geothermal energy, but at the same time, the first step towards a solution is taken.
    - **Credibility:** the gas production in Groningen influenced the safety perception of the local public in a negative way, which resulted in a decrease of trust towards the initiators of the gas production **(P3 and P5)**. For geothermal energy implementation, increasing and maintaining this level of trust is of key importance in the creation of social acceptance **(P1 and P9)**.
    - **Predictability:** From the gas production in Groningen, it was learned that constantly changing decisions by the initiators influenced the social acceptance of the gas production in a negative way. **P1** mentioned during the interview that communicating in a predictable and consequent way might benefit the level of social acceptance for geothermal energy implementation.

Now that the context, the goal, the message, the main communicators and their reference frames have been identified in the communication approach, the aspects that form the situation of the communication process will be addressed in the next section.

12.3.5. Situation description

Each implementation process of geothermal energy takes place in a specific situation within the context of the communication approach: the level of social acceptance in geothermal energy implementation. In this section, the elements that are represent the situation will be described (Figure 12.10). During the research, four elements of the situation have been identified:

1. the stakeholders involved in the geothermal project;
2. the setting in which the communication process takes place;
3. the communication channels and methods that are used in the communication process, and the noise that is present during the communication process;
4. the timeline of the technical aspects of the geothermal project, and the timing of the communication of technical uncertainties alongside or integrated with the technical timeline.

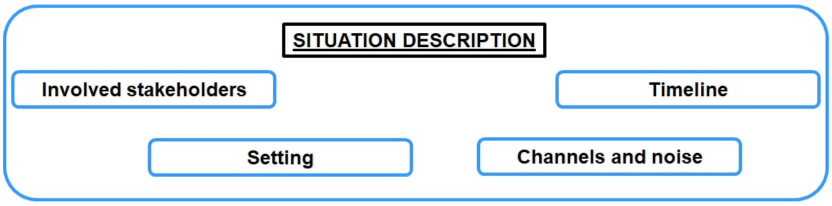


Figure 12.10: The different elements of the situation description in the communication process.

Involved stakeholders
The first step in the situation description is to define the stakeholder groups that are involved in the geothermal project, including the initiators of the project (Figure 12.12). In the process of geothermal energy implementation, there are various stakeholder groups that interact with each other. Amongst others, there are the Dutch national government, provinces, municipalities, operators, the public, States Supervision of Mines, the heat distribution companies, the media, etc. In each process of geothermal energy implementation in a Dutch neighbourhood, *at least* the following stakeholder groups will play a role **(P1, P3, P4 and P5)**:

- The Dutch national government; the Ministry of Economic Affairs and Climate Policy. This ministry is responsible for the authorisation of permit requests regarding geothermal projects in the Netherlands.
- The department of the municipality in which the geothermal project will take place that is in charge of the implementation of the project. In general, these departments are specialised in the implementation of techniques that determine the continuity of the energy transition, such as the building of a wind farm or the drilling of a geothermal well.
- The operator that will exploit the project.
- States Supervision of Mines; SodM is concerned with the supervision on health, safety and environmental issues that might arise in the geothermal project. SodM has both an advising and a controlling task; if safety or environmental issues cause a risk for the people involved in the project, SodM is authorised to stop all activities.

- The company or party that is concerned with the distribution of the heat once it is produced.
- The part of the local public that will consume the heat that is produced from the geothermal well.
- Companies that will consume the heat that is produced from the geothermal well.
- The part of the local public that lives close to the production site, but will not benefit from the produced heat as these people are not connected to the heat network (yet).
- The local and national news media, which has the ability to present certain aspects of the geothermal project to their public.
- TNO: the Dutch geological survey that is responsible for the mapping of the subsurface in the Netherlands.
- EBN: EBN is the state–owned party that is in charge of the implementation of the geothermal projects on behalf of the Dutch government.

In reality, additional case–specific stakeholder groups can be involved in the geothermal, such as local residents that grouped themselves into a movement of local opposition or proposition towards mining operations in an area. In order to obtain an overview of the positions of the stakeholders in the total spectrum of the geothermal project, and to be able to identify tension or even problems between different stakeholders, it is of key importance to map the different stakeholder groups that are present in the field of a geothermal project.

Setting
The setting of the communication approach comprises the definition of the location of the communication process, the choice for plenary or one–to–one conversations, the need for physical attendance of each of the communicators, etc. Since the location where the communication process takes place determines to a certain extent the content, and thereby the success of the communication process [Oomkes, 2013], the choice of the location is an important step in the communication approach (Figure 12.12). The communicating parties need to decide whether the same location is used for different encounters, or if it is beneficial for the communication process to change the location at different stages of the communication process. Depending on the public (for elderly people it is more difficult to physically attend the communication process, for example), the choice for one or multiple locations can be made. For the communication process, the physical attendance of the different communicators will be beneficial, instead of people calling via video–calls. On the practical side of the communication process: arranging the space with tables and thereby creating a more intimate atmosphere will create a different ambience than a setting that is suitable for a plenary meeting **(P10)**. The setting of the communication process shares a close link with the practically available communication methods and channels. Therefore, these aspects will be discussed in the next section.

Communication channels and noise
From theory (action–assembly theory) and the interviews, is was known that the communication of different technical uncertainties asks for different communication channels **(P10)**. The pillar of safety perception is valued to be of vital importance in the level of social acceptance: these technical uncertainties will be addressed using personal communication methods **(V1)** (Figure 12.11). Once in a while an update in the local newspaper about the development of the project will not be enough; for technical uncertainties that address the safety perception personal contact is needed **(F1)**. This can be done by organising one–to–one questions hours at a location that is suitable for these meetings (see

previous section about the setting). Or, for example, by adjusting the flyer and poster material to the specific location so that people recognise their own houses in the info–graphics **(P10)**. Or engaging the public in ways to monitor vibrations in the geothermal well and streaming these data to the public; this way, people can see what happens in the subsurface **(V1)**. However, the opportunity for real–time monitoring of the well is expensive; therefore, the operator of the project needs to make an estimation of the balance between increased social acceptance of the project and increased project costs.

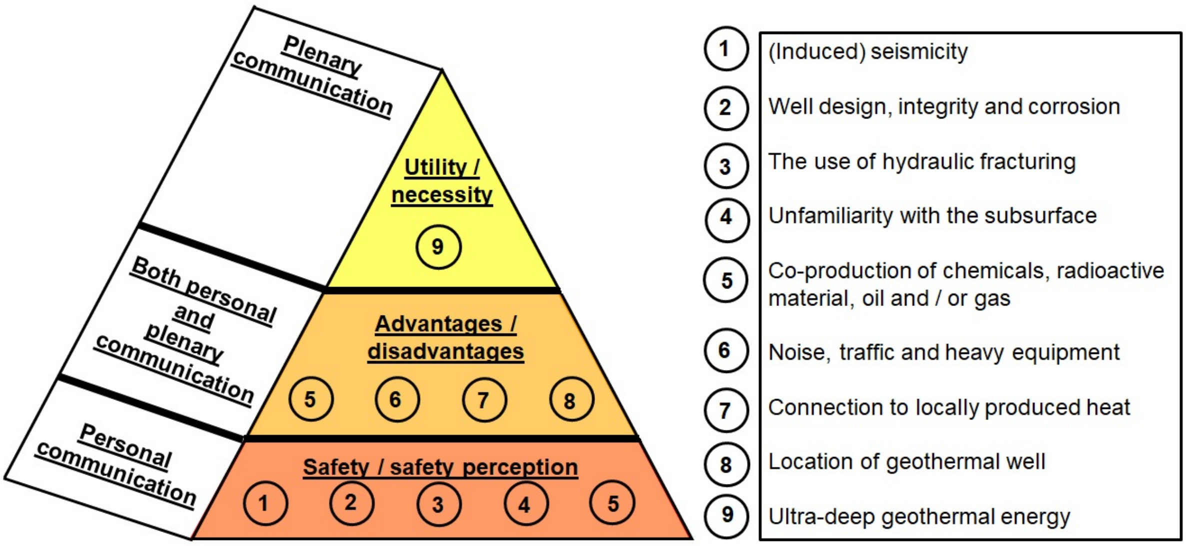


Figure 12.11: Addressing different technical uncertainties asks for different communication methods.

Technical uncertainties that are linked to the top of the pyramid (utility / necessity) can be addressed in a less personal way, since these technical uncertainties have the least impact on the level of social acceptance (Figure 12.11). For these technical uncertainties, the communicators can think of the design of a web page that shows the frequently asked questions, or by showing short movies in which a communicator that is trusted by the public, explains why a geothermal project is needed in the neighbourhood.

Ideally, the communication of technical uncertainties during the implementation of a geothermal energy project is both a one–sided and a two–sided process **(P4)**: the initiators send a message to the public, and the public has the opportunity and the need to react of this message. In the interviews, the geothermal experts indicated that the initiators are aware that for a fruitful conversation process, the public needs to be involved in an active, meaningful and fair way **(P3, P4, P9 and P10)** (see Section 8.3 about procedural justice, [Erdogan *et al.*, 2001]). The public needs to see the face behind the organisations. This can be achieved by organising question–hours or information–evenings **(F1)**.

In the communication of technical uncertainties from the initiators to the local public, the communicators have the choice between different communication channels, e.g. linguistic, graphical or numerical methods. The message that is communicated determines to a large extent the used communication channel. For example, some of the identified technical uncertainties can be addressed in a linguistic way ('the potential for seismic activity in this area is close to zero') than in a graphical or numerical way ('the probability of an induced earthquake with a magnitude of 3.7 on Richter's scale is 15% over thirty years'). Different methods of communication have different impacts on the safety perception of the public.

The chosen communication channels partly depends on different characteristics of the public **(F1)**. In line with the elaboration–likelihood theory (Section 8.4.4), the feelings that live in a municipality or neighbourhood determine to a large extent the communication methods that are applied in the communication process. This central route increases the likelihood that the public critically overthink the content of the communication process; the technical uncertainties in geothermal energy implementation. In other words, the higher the interest and the motivation towards geothermal energy implementation, the more likely it is that the technical uncertainties are overthought in a critical way. Furthermore, a neighbourhood that is resided by elderly people asks for different communication methods than an area where students live. For students, an e–mail or a website with frequently asked questions might be enough for the communication of technical uncertainties, whereas in an area with elderly people house–to–house visits or information evenings that people can attend, address the message in a more efficient way.

Channel noise in this communication approach comes from different sources. If the public experiences a lack of trust towards one or more of the communicating actors, this can cause noise that influences the interpretation of the messages; a lack of trust often influences the credibility in the communicating party. Also unrealistic ideas about the impact of technical uncertainties on the level of safety in the area can create noise in the communication process. **P7** mentioned the examples from geothermal projects abroad where mistakes were being made, that can influence the safety perception of the public for geothermal energy implementation.

Timeline
The last step in the context description of the communication process is its place in the (technical) timeline of the project. This way, the technical planning of the project can be visualised and ideas about at which stage of the technical timeline the communication of the technical uncertainties needs to take place, can be shared amongst the communicating actors (Figure 12.12).

As discussed in the theoretical framework in Chapter 8, there is a balance in transparency and openness of the communicators in the communication of technical uncertainties to the local public. The communicators can discuss which technical uncertainties need to be addressed and when, and what information needs to be communicated. Uncertainty communication that is not thought through can lead to commotion and a decrease in trust in the initiators. In the verification discussion with **P10**, it was mentioned that from the perspective of the communication about the gas production in Groningen, it would be best to communicate the technical uncertainties at the moment they are recognised in the geothermal project. This way, the public does not feel as if information is being held back by the communicators. Therefore, each technical uncertainty needs to be communicated to the local public in a fair and transparent way **(P10)**. In the verification discussion with **F1**, it was mentioned that the initiators can consider to to communicate the technical uncertainties that affect the perception of safety first. Moreover, the technical uncertainties of which the level of knowledge will not be increased in the near future, can be communicated. For the public, this is better than being informed about uncertainties that will soon be certainties. Lastly, technical uncertainties for which methods have been identified to decrease the level of uncertainty can also be communicated to the public.

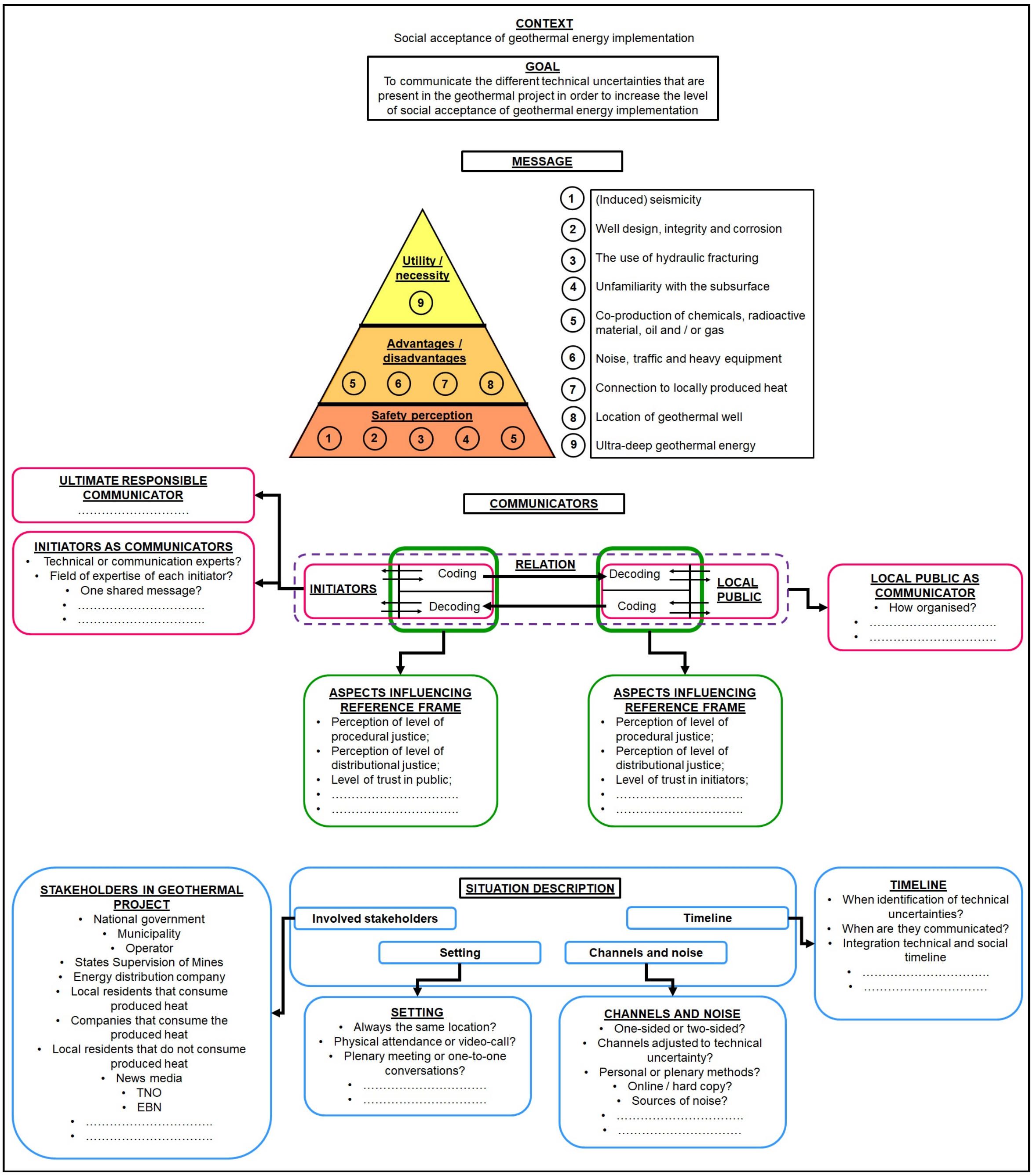


Figure 12.12: The communication approach including the different aspects discussed in this study.

12.4. Detailing the communication approach: a communication plan for a specific case of geothermal energy implementation

THE communication approach that was presented in the previous section is less generic that the communication model as presented in Section 12.2. In this communication approach, the different steps and choices that need to be addressed in the communication process have been discussed. However, for the communication of technical uncertainties to a local public in a specific case of geothermal energy implementation (Figure 12.13), many specific choices will need to be made by the communicating actors.

In each case of geothermal energy implementation, different stakeholders can be added to the list in Figure 12.12. The initiators have been chosen such in the communication approach that these parties will always be one side of the communication process, but the

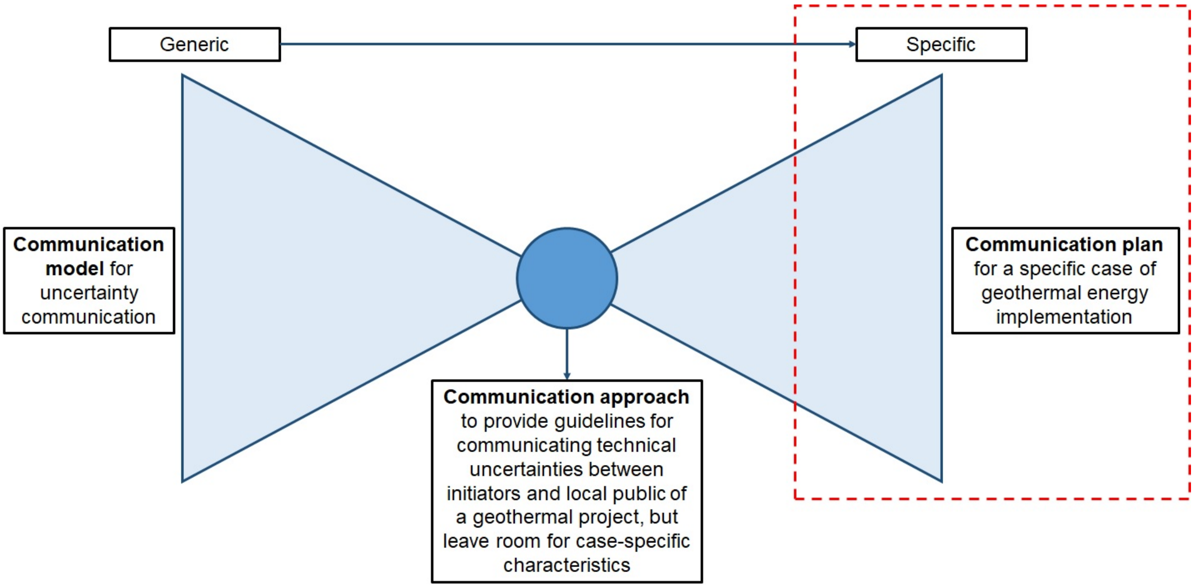


Figure 12.13: From the communication approach to the communication in a specific case of geothermal energy implementation.

composition of the 'local public' varies per geothermal energy case. The characteristics of this public have an impact on many aspects of the communication process. Each public has an own reference frame, which depends on many different factors – level of existing knowledge, experience with other mining operations, etc. Due to the width of variations in this reference frame, each geothermal energy case asks for specific communication methods and channels. Therefore, the application of the communication approach in a specific case of geothermal energy implementation is included as a recommendation for future research (Section 14.6).

12.5. Credibility and reliability of proposed approach

THE communication approach as designed in this study has been constructed based on the study of relevant literature and semi–structured expert–interviews. To identify different communication methods and the reference frame of the public, verification discussions have been organised.

The communication approach as presented in this section forms a starting point for the communication of technical uncertainties. From here, the implications of the approach in reality will need to be tested. However, looking back at the design criteria that have been set in 12.1, the communication approach meets the different criteria:

1. The goal of the communication process is addressed in the approach.
2. The communication approach offers a structured overview of the different steps in the communication process. Different arguments to the choices that will need to be made by the communicators have been provided.
3. The approach is much more detailed to the topic of uncertainty communication in the context of social acceptance than the communication model in Section 12.2, but still generic enough to be detailed for different situations of geothermal energy implementation. In a specific case of geothermal energy implementation, the communicators make argumented choices based on this approach.
4. The approach provides an overview of the timing of different steps in the communication process.

5. Space is offered in the approach for the identification of the different stakeholders and their roles in the communication process. Stakeholders of the geothermal project have been listed in the approach as well.
6. In the approach, there is room for the identification of the communicating actors that has the ultimate responsibility over the communication process.
7. In the approach, the technical uncertainties that play a role in the geothermal project are addressed as being the message of the communication process.
8. The level of social acceptance towards the geothermal project is addressed in the development of the reference frame of the communicators.
9. Different communication methods and channels are addressed in the approach; due to the massive choice of communication channels and methods in real communication situations, an overview is provided in this approach.

The information that was retrieved from the verification discussions was merged with information from the semi–structured interviews in the design of the communication process. This was done since the focus of the semi–structured expert–interviews was mainly on the identification of the technical uncertainties. These interviews had a minor focus on the communication of these uncertainties. During the design process, newly collected data from literature and desk research was combined with information from the expert–interviews to design a draft version of the communication approach. During the phase of the verification discussions, the approach was constantly reviewed and updated with relevant insights.

12.6. Chapter summary

ALTOGETHER, until now an approach to organise the communication process of technical uncertainties between the initiators and the local public systematically was lacking. This gap is filled by the approach for technical uncertainty communication as proposed in this chapter.

The final design of the approach includes the description of the context and the situation, in which the involved stakeholders, the location of the communication process and the design of a technical timeline of the project are addressed. In this stage of the communication process, one of the stakeholder groups is assigned as ultimate responsible communicator.

The communicating parties in the approach are the initiators of a geothermal project, and the local people. Each of these communicators communicates from its own reference frame. The actual messages in the communication approach are embodied by the technical uncertainties that are linked to a specific pillar of social acceptance (Chapters 10 and 11). In this study, safety perception has been ranked as the most influential pillar of social acceptance, and thereby the messages that contain technical uncertainties that are linked to safety perception need to be communicated in a way that suits the importance of the message, to prevent a decrease of social acceptance or the rise of public resistance.

In the previous three chapters, the results of this study have been analysed. In the next chapter, the conclusions of this study will be provided (Figure 12.14).

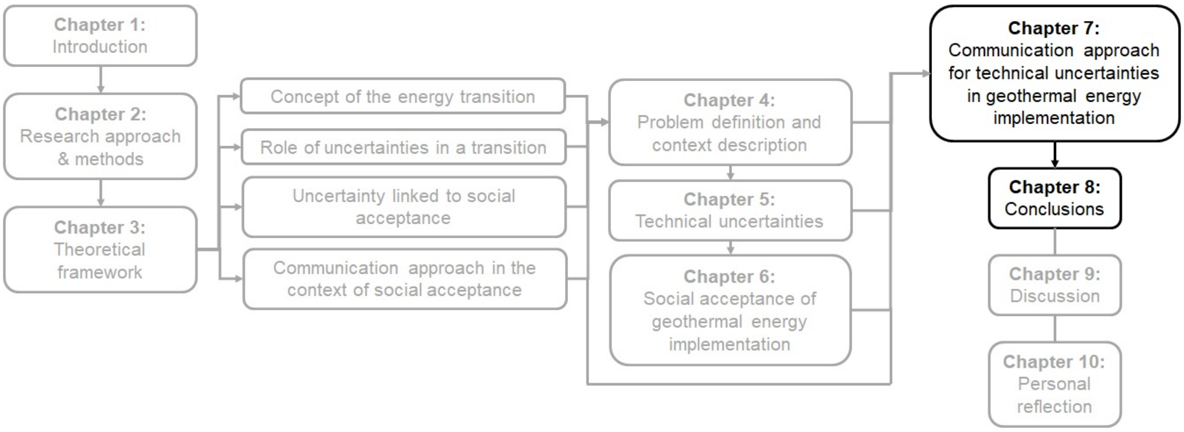


Figure 12.14: From the communication approach to the final conclusions of this study.

13

Conclusions

THE aim of this study was to design an approach for the communication of the technical uncertainties that are present in the implementation of geothermal energy production between the initiators of a geothermal project and the local public, once the technical uncertainties and their influence on the level of social acceptance of the geothermal project have been identified. The goal of this communication approach will be to communicate the technical uncertainties that are present in a geothermal project in order to increase the level of social acceptance of geothermal energy implementation. The two sub–objectives following from this main objective, were:

1. To provide an overview of technical uncertainties that are present in the implementation of geothermal energy.
2. To identify how these technical uncertainties influence the social acceptance of the implementation of geothermal energy production in the Netherlands.

Now that the study resulted in an overview of the technical uncertainties that can identified in specific cases of geothermal energy implementation, and the design of an approach for the communication of these technical uncertainties to increase the level of social acceptance in geothermal energy implementation projects, conclusions will be drawn in this chapter.

13.1. Objectives for geothermal energy in the Dutch energy transition

AS a result of a desk research that focused on the (inter) national goals for geothermal energy, conclusions to answer the first sub–question of the study as defined the introduction in Chapter 6 are drawn:

- Which objectives for geothermal energy implementation in the Netherlands have been set by the Dutch government?

At the international climate conference that was held in Paris in 2015, the following goals were set for each country that signed the agreement:

1. A reduction of the greenhouse gas emissions of 20% with respect to 1990 by 2020, a share of 20% of the energy mix made up by renewable energy and a reduction of 20% in the energy consumption;

2. A reduction of the greenhouse gas emissions of 49% with respect to 1990 by 2030 and a share of 27% of the energy mix made up by renewable energy;
3. A reduction of the greenhouse gas emissions of at least 95% with respect to 1990 in 2050.

Following this climate agreement, the Dutch government set goals for the implementation of geothermal energy in the Netherlands:

1. In 2030, at least 5% of the total produced heat needs to be produced from ca 175 geothermal doublets. This means that until 2020, 3 doublets per year needed to be drilled and between 2025 and 2030, 20 doublets per year need to be opened.
2. In 2050, at least 23% of the total amount of heat needed, is produced from ca 700 geothermal doublets. This means that from 2030 onward, 26 doublets need to be opened per year.

These national goals (macro–level) for geothermal energy will be translated by municipalities (meso–level) into regional energy policies and transition documents towards a sustainable heat consumption. These documents need to be finished off by the end of 2021. Based on the ca. 700 geothermal doublets that need to be working in 2050 to meet the national geothermal energy goals, on average two wells per Dutch municipality will have to be drilled. In this perspective, geothermal energy will be a crucial source of energy in the energy transition.

Due to the production of gas from the field in Groningen, which started commercially in 1963, the economy of the Netherlands relied heavily on hydrocarbons over the past decades. Up to 2050, hydrocarbons will probably make up for the largest share in the Dutch energy mix. As a result of an increasing number of (induced) earthquakes in the gas production area, the level of trust in the authorities (the national government and the operator) decrease and the level of public resistance increase. This decrease of social acceptance was partly accelerated by the way the authorities communicated the uncertainties and risks to the local public; negative consequences of the gas production have structurally been denied to the public. As a result, the Groningen field will be closing from 2022 onward, and to reduce the dependency on small gas fields or other countries for energy, the share of geothermal energy in the total energy mix will increase over the coming years.

To be able to draw a parallel between gas and geothermal production as mining operations, and thereby being confronted with comparable social sentiments, an analysis of the technical uncertainties in geothermal energy implementation needs to be done. By comparing these technical uncertainties to the technical aspects of gas production, the influence of the technical uncertainties in geothermal energy implementation on the level of social acceptance can be studied. Therefore in Section 13.2, the technical aspects of gas productions and geothermal energy production will be compared.

13.2. Comparing gas and geothermal energy production techniques

ANOTHER topic studied was the comparison of gas and geothermal energy production techniques. Based on the study of these techniques, technical uncertainties in geothermal energy were identified during the interviews. In the introduction of this report (Chapter 6), sub–question two has been defined as follows:

- How similar are the techniques for geothermal energy and gas production in the Netherlands?

In geothermal energy production, water that is heated from the Earth's core is produced from aquifers using an injection and a production well. Geothermal energy production can be classified based on the technique of production (closed–loop vs. open–loop) or on depth (up to 500 meters, 500 – 4,000 meters, and more than 4,000 meters depth). In the Netherlands, the temperature of the subsurface rises about three degrees Celsius per 100 meters depth. This results in a water temperature of approximately 70-80 degrees at 2,000 meters depth. Each geothermal project consists of at least two wells: an injection and a production well. In the production well, a pump is installed to pump the warm water from the reservoir. After the heat is extracted from the water at the surface by flowing the water through a heat–ex-changer, the cooled water is pumped back into the reservoir by using an injection well.

Geothermal energy production from more than 4,000 meters depth, so–called Ultra–Deep geothermal energy (UDG), is a technique that is used to produce water with such a temperature that it can be used in (light) industrial applications. The water needs to have a temperature of more than 100 degrees Celsius. Due to the history of gas production in the Netherlands, there is a large knowledge base about the Dutch subsurface up to roughly 3,000 meter depth. In this perspective, more research is needed about the deeper subsurface to make UDG possible in the Netherlands. Furthermore, induced earthquakes, resulting from the enhanced reservoir stimulation in case the permeability of the reservoir rock is too low to produce the water, might be a risk for the industrial or residential areas where UDG is applied. Since in geothermal energy production the distance between the production site and the customers needs to be as small as possible to keep the water at the right temperature, induced seismicity as a result of UDG production is considered to be a negative consequence.

Conventional gas is produced by drilling a well into the gas reservoir. Since the density of gas is lower than the density of the surrounding rock, the gas will flow from the reservoir to the surface through the well, if the permeability of the reservoir rock is high enough for the gas to flow. At the surface, the gas is treated to make it suitable for transport through pipelines.

Gas and geothermal energy can be compared to the extent that both operations are classified as 'mining operations'. In both operations, wells are drilled into the Earth's subsurface. Heavy equipment is needed at the plant for both gas and geothermal energy production. The most significant difference is that in geothermal energy production, both an injection and a production well are needed, while gas production only knows a production well. This is because the water needs to be pumped to the surface where gas flows to the surface due to density differences, and the cooled water is injected back into the reservoir.

Now that the techniques of gas and geothermal energy production have been identified and described, the aspects of geothermal energy implementation that are still uncertain can be identified.

13.3. Identification of technical uncertainties

By conducting 9 semi–structured expert–interviews with 10 experts from different stakeholder groups, 22 technical uncertainties in the process of geothermal energy implementation have been identified to provide an answer to the third sub–question of this research:

- What are the similarities and differences between the technical uncertainties that are recognised in geothermal energy implementation, and the technical aspects of gas production in The Netherlands?

The clustered technical uncertainties are listed in Table 13.1:

Table 13.1: Technical uncertainties in geothermal energy implementation in the Netherlands.

	Technical uncertainties in geothermal energy implementation
1	(Induced) seismicity
2	Location of a geothermal well
3	The use of hydraulic fracturing
4	Well design, well integrity and corrosion
5	The distribution and storage of the produced heat
6	Unfamiliarity with the subsurface: temperatures, injection pressures and reservoir integrity
7	Co–production of chemicals, radioactive material, oil and/or gas
8	Noise, traffic and heavy equipment during drilling process
9	Cooling of the water
10	The potential for ultra–deep geothermal energy in the Netherlands

Gas and geothermal energy production are comparable to the extent that both activities are classified as mining operations: in both operations, one or more wells is/are drilled into the subsurface. In both production processes, heavy equipment is needed at the production site, and the working activities of the employees working at the plant are comparable.

On the other hand, there are certain differences between gas and geothermal energy production that have been identified in the research. Due to density differences, gas comes to the surface without the need for pumping, whereas water needs to be produced by using pumps in geothermal energy production.

In gas production, no material is put back into the reservoir: after the production time, the reservoir is 'empty' and abandoned. In geothermal energy production, the saline water is pumped back into the reservoir by the injection well after the heat is extracted at the surface. By doing so, the pressure in the reservoir is maintained at the same level.

Other than geothermal energy, gas can be transported over long distances (think for example of the Russian gas that is consumed in The Netherlands). Hot water can not be transported over long distances without losing its heat. Therefore, geothermal energy production needs to take place closer to the area where the heat is used, which is often in residential or urban areas.

Techniques for geothermal energy production are still in development, compared to the almost sixty years of experience with hydrocarbon production in the Netherlands. Therefore, innovation of the geothermal energy sector needs to take place, so that not only greenhouse owners use geothermal energy, but also the people that live in residential areas use energy from a sustainable source. In the Netherlands, gas production caused a lot of damage to houses in the areas where the gas was produced. For geothermal energy production, the method of damage monitoring and methods to compensate for damage to properties is not yet defined.

For most geothermal energy projects, the expectation is that hydraulic stimulation of the reservoir will not be necessary to enhance fluid flow in the reservoir. However, if fracking would be applied in a reservoir, experts expect that this will take place on a smaller case than on which fracking is applied in gas production. Lastly, economically spoken, gas is a more profitable fluid than water, which has consequences for the attractiveness of geothermal energy as investment.

The technical uncertainties that have discussed in this section were identified from interviews with stakeholders at different positions in the research spectrum. Now that the technical uncertainties have been identified, their link with the level of social acceptance will be provided in the next section.

13.4. Social acceptance for geothermal energy implementation

Now that an overview of technical uncertainties that can play a role in the different projects of geothermal energy implementation in the Netherlands, these uncertainties can be linked to the concept of social acceptance. By doing this, an answer to sub–question sub–question four of the research as defined in Chapter 6 can be provided:

- How do technical uncertainties influence the level of social acceptance of geothermal energy implementation?

Over the past thirty years, earthquakes in the Dutch province of Groningen, which was assumed to be tectonically stable, have been assigned to the gas that is produced from the Groningen gas field. Local residents of the province experience social impacts caused by these earthquakes, such as damage to properties, a feeling of insecurity and increasing distrust and anger. Over the past thirty years, the gas production in Groningen lost its social license due to a lack of technical expertise, contradicting decisions and the struggle for (financial) compensations by the inhabitants of the earthquake area.

Over the years, 'Groningen' became the national reference frame for safety and environmental issues. Since the techniques for gas production and geothermal energy production are to a large extent comparable, the pillars of social acceptance for geothermal energy implementation have been identified from the semi–structured expert–interviews. The three pillars of social acceptance are; a) safety perception; b) the distribution of advantages and disadvantages, and; c) utilities and necessities of a geothermal project. To address the technical uncertainties that play a role in the social acceptance of geothermal energy implementation, the technical uncertainties is linked to one of the three pillars in Table 13.2 (Section 11.3):

Table 13.2: Technical uncertainties grouped per key value.

Safety perception	**Distribution advantages / disadvantages**	**Utilities / necessities**
(Induced) seismicity	Location of geothermal well	Ultra-deep geothermal energy
Well design, well integrity and corrosion	Noise, traffic and heavy equipment	
Unfamiliarity with the subsurface: temperatures, injection pressures and reservoir integrity	Co-production of chemicals, radioactive material, oil and/or gas	
Co-production of chemicals, radioactive material, oil and/or gas	Connection to locally produced heat	
The use of hydraulic stimulation of the reservoir		

From these three pillars of public acceptance, safety perception was ranked as having the most impact on the level of public acceptance. There are multiple arguments for this decision, a few of which where addressed based on the theoretical framework provided in Chapter 8. The ranking of the three pillars is based on three factors that determine the level of social acceptance: a) procedural justice, b) distributional justice, and c) trust. The social perspective towards mining operations in general as developed in Groningen decreased the level of trust of the public in the authorities. For geothermal energy implementation, a parallel can be drawn because both operations are classified as mining operations. Moreover, a high level of procedural justice, and so a possible increase of the level of social acceptance, implies that the communicators have access to relevant information. However, the information–integration theory implies that some information will have more weight in the communication process than other information. From this reasoning and the parallel with the resistance to gas production, it is concluded that the pillar of safety perception has the highest impact on the level of social perception; once a situation is perceived as being unsafe by the public, public resistance might increase and for the involved communicators, it is difficult to bring the safety perception back to the realistic situation.

The perception of safety of the public determines the extent to which the public is willing to accept the distribution of advantages and disadvantages of the project, and to understand the necessity and utility of the project for the local area; the pillar of safety perception is the most important factor in the level of social acceptance (Figure 13.1). The link between the distribution of advantages and disadvantages of geothermal energy implementation and distributional justice is found in the extent to which the public have control in the distribution of (dis)advantages in a geothermal project. Lastly, the pillar of utilities and necessities of a geothermal project was classified to have the least impact on the level of social acceptance, since the perspective of the Dutch energy transition and the crucial role of geothermal energy in this transition, provides an explanation for the need of geothermal energy as energy source in the Dutch residential areas.

In Figure 13.1, the ranking of the three pillars of social acceptance in geothermal energy implementation have been visualised (Section 11.4).

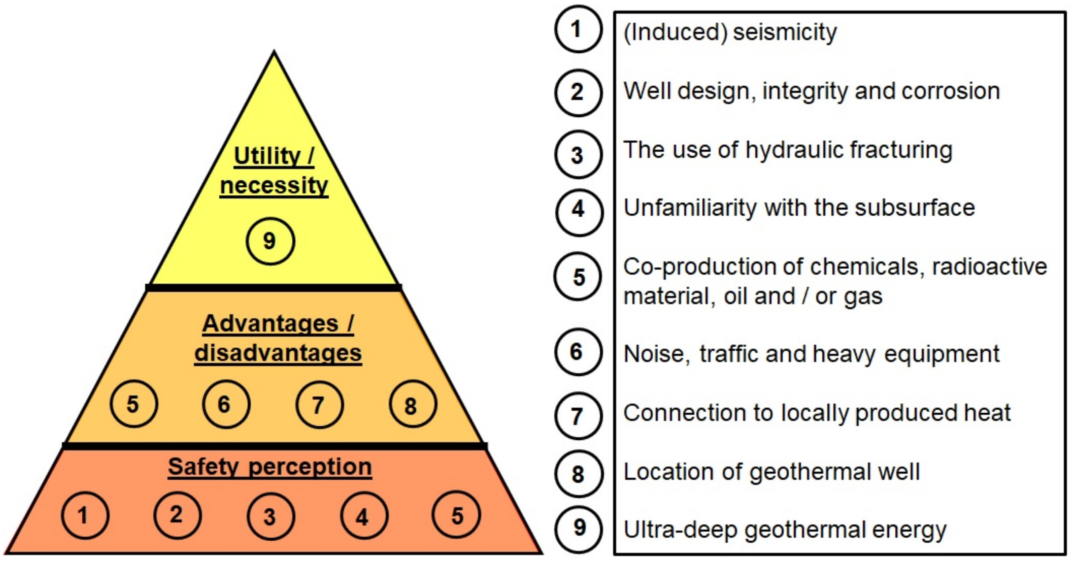


Figure 13.1: Visualisation of the three pillars of social acceptance.

13.5. Design of communication approach

Now that the relevant data has been collected in previous chapters, an answer can be provided to the research question of this study as provided in Chapter 6:

How can technical uncertainties that are present in the implementation process of geothermal energy be communicated by the initiators of a geothermal project to the local public in the perspective of the energy transition in the Netherlands, to increase the level of social acceptance when taking into account the social sentiments that have been developed with respect to the production of gas in the Netherlands?

The decision for the design of a communication approach was made to find the middle between a generic communication model applicable in each type of conversation, and a communication plan that is only applicable in specific situations of geothermal energy implementation. The approach offers guidelines and arguments, but also leaves room for own choices and interpretations.

The description of the context (Chapter 9), the identification of the technical uncertainties in geothermal energy implementation in the Netherlands (Chapter 10) and their link to the different pillars of social acceptance of this energy production technique (Chapter 11) finally led to the design of an approach for the communication of technical uncertainties to a local public by the initiators of a geothermal project in Chapter 12.

The communication approach consists of the following steps and choices that need to be addressed by the technical experts and the communication–experts that will be appointed in the near future by the communicating actors:

1. **Description of the context and the goal of the communication process.** The context of the communication approach is the level of social acceptance of geothermal energy implementation, and the goal is defined as *'to communicate the different technical uncertainties that are present in the geothermal project in order to increase the level of social acceptance of geothermal energy implementation'*.
2. **The message in the communication approach.** The message that will be communicated in the approach are the technical uncertainties that were identified in Chapter 10 and linked to the level of social acceptance in Chapter 11.
3. **Definition of the communicating actors in the communication approach.** From the list of stakeholders as defined in step 1, the initiators and the local public are appointed as communicating actors in the communication process. The communicating initiators of a geothermal project are representatives of the Ministry of Economic Affairs and Climate Policy, the municipality, the operators and States Supervision of Mines. One of these initiators needs to have the ultimate responsibility over the communication process and take the lead in it. In this study, the municipalities are suggested to be responsible for the communication process, as the municipalities are located in the centre of the stakeholder spectrum. The public will need to decide how representatives are appointed to participate in the communication process.
4. **The definition of a reference frame to code and decode the messages.** In the definition of the reference frame that the initiators and the public use to translate the messages in the communication process, the factors of procedural justice, distributional justice and trust play a key role. The level of procedural justice focuses on the access to relevant information for the communicators, and aspects that are needed to grant a meaningful participation of each of the communicators in the communication process. Distributional justice in the reference frame focuses on the extent to which the outcomes of the communication process can be controlled by the communicators and lastly, the factor trust includes the extent to which the communicating actors share the same values. In the factor trust, the social perspective on mining operations that was developed in Groningen, and the experience with the other communicator in the past, play a key role.

5. **The situation description** was described in four different elements:

    - the stakeholders involved in the geothermal project. This inventory focuses not just on the communicating parties, but on all stakeholders that are involved in the geothermal project. The exact list of stakeholders will vary per geothermal project, but in this study a basis for the list of stakeholders was provided.
    - the communication channels and noise. Technical uncertainties that have been coupled to different pillars of social acceptance (Chapter 11) will need to be communicated in a different way: technical uncertainties linking to the perception of safety will need to be communicated in a personal setting (flyers adjusted to the specific case of geothermal energy implementation, real–time monitoring of the subsurface, one–to–one setting information evenings), whereas technical uncertainties linking to the utility and necessity of the geothermal project can be addressed in a more plenary setting (news media, websites, social media).
    - the timeline of the technical project and the communication process. A lack of openness and transparency by the initiators can lead to the situation where the public feels as if relevant information is being held back from them (impact on the level of procedural justice) and they are fed half–truths. On the other hand, too much openness about the technical uncertainties and their impact in the geothermal energy project can lead to confusion or even a decrease in trust by the local public. A compromise can be found in addressing technical uncertainties that are present in a geothermal project openly if they have an impact on the level of social acceptance and if methods to decrease the level of uncertainty have been identified.
    - the setting in which the communication process takes place. The setting is closely linked with the communication channels that are used in the communication process and comprises the location of the communication process, the choice for a plenary or one–to–one setting and the need for each communicator to be physically present at the communication process.

The final communication approach as designed in this study containing the previously mentioned aspect is visualised in Figure 13.2.

Now that the design of the approach has been provided in this study, the practical implications of the communication approach will need to be tested in a case of geothermal energy implementation. With more than 700 geothermal wells to drill, there are many opportunities to test the communication approach as designed in this study.

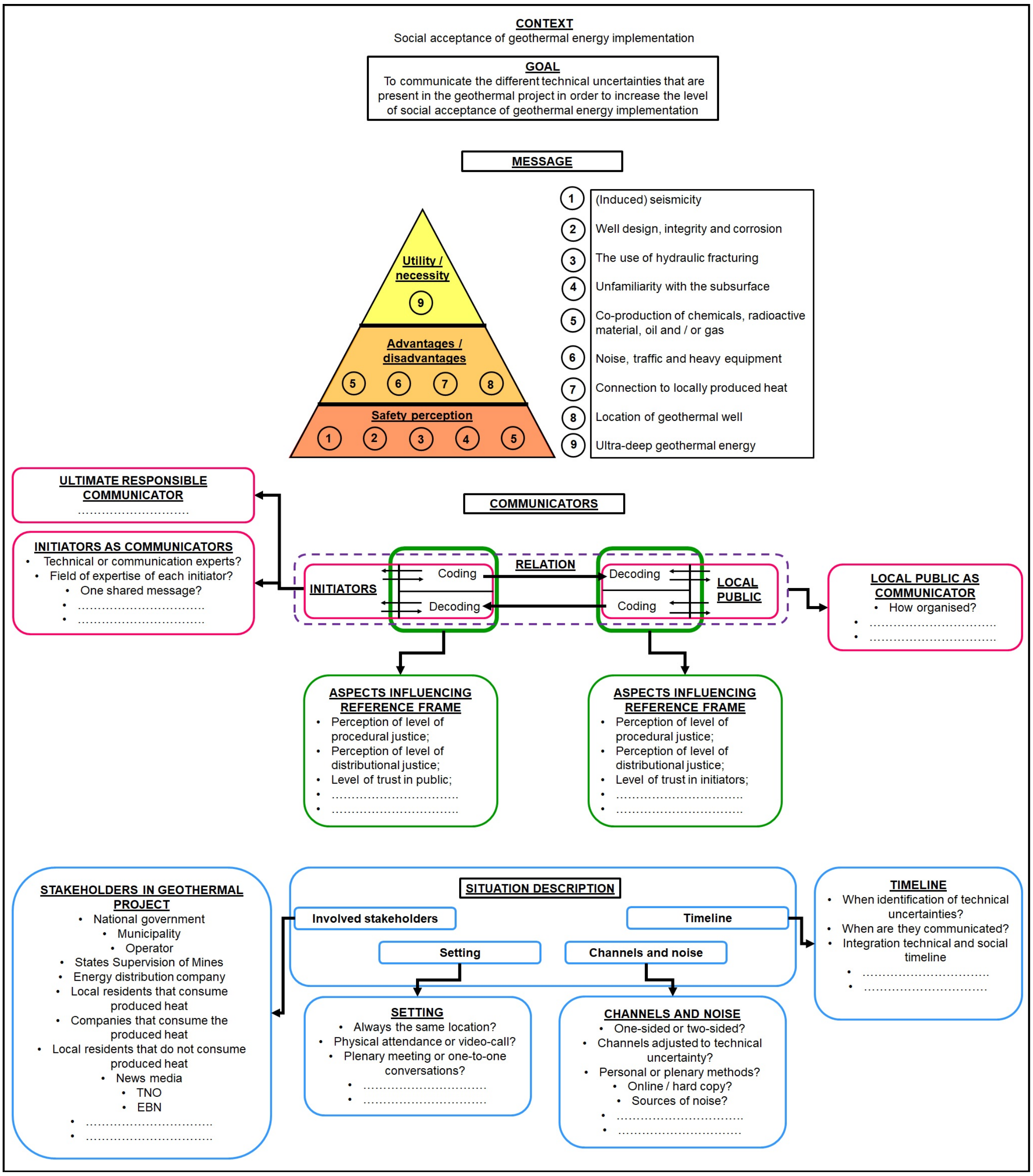


Figure 13.2: The final communication approach as designed in this study.

13.6. Chapter summary

In this chapter, the answers to the sub–questions and the research question of this study have been provided. The answers were based on desk research, semi–structured expert–interviews or retrieved from a literature study that resulted in a theoretical framework. However, there is still a lot that can be discussed about the results and conclusions. Therefore in the next chapter, the results will be placed in a larger context (Figure 13.3).

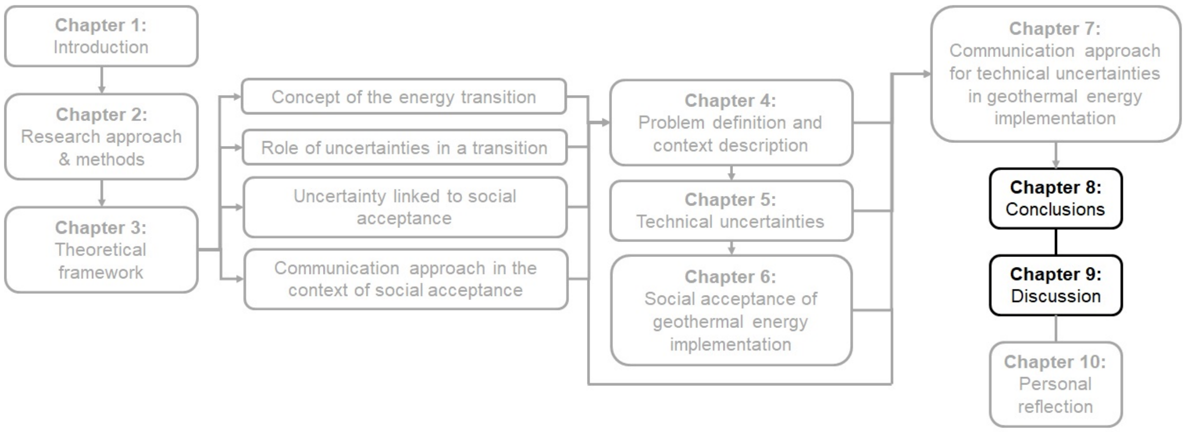


Figure 13.3: In this chapter, the answers to the research and sub–questions of the study have been provided; in the next chapter, these conclusions will be discussed.

14

Discussion

In the previous chapters of this report, the results and conclusion of the research have been described. During the processes of data collection and processing, assumptions and choices have been made. Therefore in this chapter, the results, conclusions and choices will be discussed.

Following the line of the research, a reflection on the research approach and the data acquisition methods will be provided in Section 14.1. Then in Section 14.2, the position of the study in the context of existing literature will be analysed: the decisions that have been made during the construction of the theoretical framework, and tools from literature that felt out of the scope of this research, will be addressed. In Section 14.3, the contribution of this research to existing literature will be defended. This section is followed by a discussion of the obtained results in Section 14.4, where the results and conclusions of the study are placed in a larger context. In Section 14.5, the limitations of this research are described, followed by Section 14.6 in which recommendation for future research are provided. In conclusion, Section 14.7 provides recommendations for practice and how the results of this study might develop in the future.

14.1. Reflection on research approach and data acquisition methods

The research as described in this report is a *qualitative* and *exploratory* research. The qualitative aspects of this research resulted in the execution of nine semi–structured expert–interviews. The different interviewees each ad a different position in the research spectrum and shared their views on the communication of technical uncertainties in geothermal energy implementation.

The exploratory aspect of the research is reflected in the exploration of the technical uncertainties that are present in geothermal energy implementation and the design of the communication approach to communicate the relevant technical uncertainties to a local in order to increase the level of social acceptance. Despite the exploratory research approach, some aspects of the communication approach have been addressed by providing specific recommendations. This is a result of the data acquisition methods of doing semi–structured expert–interviews – which will be described below – with people that are involved in the implementation of geothermal energy in the Netherlands. Some of these people work with the practical aspects of this communication process every day, and therefore communicate from their own specific reference frame. In this study, the different elements of the communication process between the initiators and the local public of a geothermal project have been explored and aspects that need attention have been identified. This was done based on data collected by three different methods.

Three main methods of data collection applied in this study. A desk research has been conducted to describe the problem that is addressed in this study, and to provide the context of the research. A literature study resulted in a theoretical framework that addressed specific topics from the context of the study from a theoretical perspective. This theoretical framework provided a knowledge base for the interpretation of the research data. The third method of data collection was the execution of nine semi–structured expert–interviews. Based on the context description that was provided by desk research, different stakeholders from varying areas in the research spectrum could be identified. Secondly, the interviews provided data to link the different technical uncertainties to the level of social acceptance of geothermal energy implementation.

Each of the interviewees communicated from its own reference frame during the interview. In this study, mostly policy–makers and technical experts have been interviews. Therefore, the choice for these people to be interviewed in this study determined to a large extent the outcomes of the research. For the local public, an attempt was made to identify different aspects that are present in the reference frame by organising a verification discussion with people living to close to an area that is appointed for geothermal energy implementation. However, also for these people it is true that their reference frames are not applicable in any case of geothermal energy implementation. Since it is not an option to create one generic reference frame, an attempt was made to explore the different aspects of the reference frame in the interviews and verification discussions.

The combination of desk research, interviews and literature study provided a knowledge base that made the description and links between different results available. The choice to construct a theoretical framework that discussed different topics that needed a theoretical analysis made it possible to link different aspects in the communication of technical uncertainties. Looking back at the order in which the different methods have been applied over the research period, some improvement can be made for future studies. When the context of the research was determined, the different stakeholders were approached for doing the interviews. However, by the time of the interviews, the theoretical framework of the research was not fully constructed yet. Therefore, the interviews had a strong focus on the identification of technical uncertainties, and a minor focus on the communication of these uncertainties. In the end, in the interviews enough data was collected to construct the approach designed in this study. Looking back at this period by the time of the end of this study, finishing the theoretical framework first would also have been an option. This way, more emphasis could have been on the practical implications of uncertainty communication in the interviews. On the other hand, the verification discussions that were organised with communication–experts offered the opportunity to validate the results in a communication–context. At this point, it was a logical step to round off the identification of technical uncertainties and their link with social acceptance, and focus on the practical implications of the communication approach.

14.1.1. Input from the verification discussions during the design process of the communication approach

As discussed in Section 7.3, the different stages and aspects of this approach have been discussed with policy–makers and communication–experts that work in various corners of the field of geothermal energy production. The input that resulted from these discussions was integrated into the design of the communication approach. In this section, the most important input from the verification discussions will be discussed.

Firstly, **V1** suggested splitting out the initiators of a geothermal project into the different stakeholder groups (national government, municipality, SodM and the operator) in the approach. This way, the connections between the different initiators would be visualised and the fact that the 'initiators' is not one homogeneous group of people. However, in the final version of the approach it was decided to include the different stakeholder groups into the group of 'initiators' for two reasons. The first reason is that the relationships and communication *between* different initiators was not part of this study. Secondly, splitting up the different initiators into individual parties in the approach would suggest the need to investigate the specific communication between individual initiators and the public. Therefore, the initiators were grouped in the final approach for simplicity reasons.

Secondly, in discussion with **V2** it was decided to split up the boxes of existing ideas, feelings, opinions, etc. into three aspects that form the reference frame in the communication process for each of the communicating actors into *knowledge*, *control* and *joint values*. This tripartition of the reference frame made it possible to address each aspect individually, thereby creating an overview of the level of knowledge that is present in a communicating actor, and which aspects need more investigation. However, for the final design of the communication approach, these three concepts were found to be too restricting and therefore left out of the approach.

Lastly, in discussion with **V3 and V4**, the utility of specific communication methods, such as the possibility of real–time monitoring of the subsurface, or the development of custom–made poster and flyer material have been discussed. The input from trained communication–experts on the applicability of the approach was a valuable source of information during the design process.

14.2. Context of existing literature

THE theoretical framework as discussed in Chapter 8 of this report, serves as a basis for the information that was extracted from the semi–expert interviews that were held during the study. This way, the communication approach that is proposed in this research can be placed in a *transition process*, with the goal to increase *social acceptance* by *communicating technical uncertainties* to a local public. In this section, relevant choices and links that were made during the literature research, will be described in this section.

14.2.1. Risk versus uncertainty communication

In this research, the choice has been made to focus on the communication of uncertainties rather than on the communication of risks. Risk is defined as the product of the probability of a consequence and its magnitude [Bordia *et al.*, 2007; Young *et al.*, 2003]. From the perspective of the gas production in Groningen, the magnitude of certain consequences of geothermal energy production can be estimated to a certain extent, such as the impact of induced seismicity on the area where the geothermal well drilled. However, both the impact and the probability of the consequences of geothermal energy implementation are still surrounded by a lot of uncertainty in this phase of the energy transition. Therefore, it was decided to focus on what is still unknown and uncertain in the implementation of geothermal energy projects rather than focusing on the probability of these events as well.

14.2.2. Phases of the energy transition

In Section 8.1.2 of this report, four main activities that make up one cycle in the process of transition management, have been described: a) strategic, b) tactical, c) operational, and

d) reflective [Loorbach and Rotmans, 2006; Loorbach, 2009]. Considering the data that was studied during this research, these activities can be applied on the ongoing energy transition in the Netherlands, but also on the process of geothermal energy implementation as a sub–transition from fossil fuels to renewable heat production in this energy transition.

The first experiences concerning geothermal energy implementation around 12 years old [TNO & EBN, 2018]. Over the last 10 years, which comprise the *strategic* activity, mainly greenhouse owners pioneered in the field of geothermal energy implementation, who first focused on the production of heat for their companies only. These greenhouse owners were the visionaries, the frontrunners. By this time, the potential for geothermal energy as renewable energy source in the Dutch heat consumption was explored, but no translation to geothermal energy production in the residential areas was made yet. However, over the years the awareness of the necessity of renewable energy sources – due to (inter)national climate agreements – grew, resulting in an exploration of the opportunities for geothermal energy as a replacement for gas in the heat consumption. Due to these national climate goals and agreements, the national government acted as transition manager, which was emphasised by lawsuits, such as the Urgenda–case [Trouw, 2019].

Considering the collected data that was used in this report to describe the context of the study, the process of geothermal energy implementation in the Netherlands is currently at the second activity: the tactical activity. After a decade of exploring the potential of geothermal energy as heat source – thereby also keeping an eye on the developments abroad – long–term visions and methods to implement geothermal energy in the residential areas are being developed at the moment. The municipalities play a key role in this process, as they are responsible for the development of the local heat transitions. Within the different stakeholder groups in geothermal energy implementation, the number of 'geothermal departments' and employees that are specifically trained for the implementation of geothermal energy is increasing. For this study, multiple people working at these departments have been interviewed. This all falls within the development of a transition agenda, as described by [Loorbach and Rotmans, 2006]. The communication approach that is designed in this study focuses on these people, of which some will have a technical and others a more communication–oriented background.

The two remaining activities will play important roles in the future of geothermal energy implementation. In the operational activity, the uncertainties in the transition process are explored. For the implementation of geothermal energy, the identification of the technical uncertainties in this study can be used as a starting point. In the future, the implementation of geothermal energy will need to monitored and the different actors that play a role in this field need to be evaluated as well. By setting goals for the implementation of geothermal energy for the years of 2020, 2030 and 2050, these would be good times to evaluate the implementation process. If the goals are not met, action needs to be taken. However, the exact implications of these actions are not in the scope of this research.

14.2.3. Procedural and distributional justice in a larger context

The goal of this research was to design an approach for the communication of the technical uncertainties that are present in the implementation of geothermal energy between the initiators of a geothermal project and the local public, once the technical uncertainties and their influence on the level of social acceptance of the geothermal project have been identified (Chapter 6). In the larger context of geothermal energy implementation in the Dutch energy transition, this communication process is used as a way to increase the level of social acceptance, by addressing relevant technical uncertainties, rather than a goal.

The aspects that were retrieved from literature to identify the level of social acceptance, were procedural justice, distributional justice and the level of trust. In literature, the concept of procedural and distributional justice are related to the process of decision–making as well: procedural and distributional justice are two aspects that contribute to a positive attitude that is necessary to construct cooperative relations within a decision–making process [Korsgaard *et al.*, 1995]. In the communication approach designed in this study, the concepts of procedural and distributional justice have been addressed as requirements for positive attitudes as well. In both the communication process between initiators and the local public as defined in this study, and decision–making processes in general, the concepts of procedural and distributional justice are important concepts that determine the setting, the conditions and the limitations of the process.

All in all, the implications of procedural and distributional justice can be integrated in a context of decision–making and communication processes.

14.2.4. Emotional dimension of uncertainty communication

The communication of technical uncertainties in a geothermal energy project takes place on the intersection between technical data and the emotional responses to the communication of uncertainty by the local public [Brashers, 2001]. However, the perception of the public towards uncertainties and the risks that these uncertainties imply, are not always aligned with scientific assessments [McComas, 2006]. When uncertainty is considered as a danger or a threat, negative emotional responses may arise, whereas positive emotional responses find a place when uncertainty is framed as beneficial [Brashers, 2001]. The bias of the public, for example if the public has a positive attitude towards geothermal energy implementation at the start of the communication process, determines to a certain extent how the messages in the communication process are perceived. In other words, the emotional dimension of communication mainly focuses on the reference frame of each of the communicators and in the words of **V1**: '*The process of communicating technical uncertainties is more than words and numbers; feelings and thoughts are involved as well.*'

The communication approach as designed in this study primarily focuses on the different steps and choices that need to be made by the communicating actors, but the impact of the communication on the emotions of the communicators has been left out of scope. However in the verification discussion **V1**, the role of emotions and feelings of the public in the communication process was discussed. **V1** emphasised the idea that words and procedures only are not enough to address uncertainties on an emotional level. The emotional dimension of the communication process goes further than the steps that have been addressed in this communication process; over time, emotions that influence the communication process vary due to different levels of knowledge, trust and control of the communicators.

14.2.5. The communication of *technical* uncertainties to increase social acceptance

The context of maintaining or increasing the level of acceptance towards a specific technique (geothermal energy production) or an innovation process (the energy transition), is a context that spreads out over multiple dimensions (time, space), multiple levels (macro, meso and micro) and many different stakeholder groups. Inherently, the implementation of geothermal energy as sustainable energy production technique in the Dutch energy transition is surrounded with many uncertainties. In the scope of this research, the communication of technical uncertainties has been chosen as main focus, but the communication of technical uncertainties are not the only factors influencing the level of social acceptance towards a technique.

The two main sources of uncertainty are a lack of knowledge (epistemological uncertainty) and variability [Walker *et al.*, 2003]. From these sources, different types of uncertainties arise. *Epistemological uncertainty* is related to many different aspects of policies, modelling and science procedures [Walker *et al.*, 2003]. This type of uncertainty is related to measurement errors, imperfect models, ambiguity, inconsistent knowledge, etc. The technical uncertainties that form the topic of this study can be considered as being a subcategory of epistemological uncertainty, since a lack of knowledge in the technical domain contribute to the overall level of epistemological uncertainty.

The *variability uncertainty* consists of three aspects. On the meso– and macro–level, societal variability influences the level of variety uncertainty [Walker *et al.*, 2003]. On the micro–level, human behaviour can consist of non–rational behaviour, or deviations from a standard behavioural patterns. Also, differences between what people say and do (the cognitive dissonance) are a source of variety uncertainty. A third sub–category of variability uncertainty are technological surprises, which are new developments or unexpected consequences of technologies [Walker *et al.*, 2003].

By placing the technical uncertainties in the larger context of these two main sources of uncertainties, more factors that influence the level of social acceptance than the communication of technical uncertainties have been addressed. In reality, the types of uncertainties coming forth out of these sources of uncertainty, such as social and methodological uncertainty, will influence the communication process, but in this research, other types of uncertainty than technical uncertainty were left out of scope.

14.2.6. Certainty versus uncertainty communication to increase social acceptance

In this study, the decision was made to design an approach for the communication of technical *uncertainties* rather than communicating the technical *certainties* that are present in a geothermal project, when the aim is to increase social acceptance of a technique or transition process.

The reason for this choice can be found in the social perspective that was formed by the gas production in Groningen [Bal *et al.*, 2019]. In this case, different types of uncertainties were not communicated to the local public [Van Bruggen, 2015]. This situation led to a decrease in trust in the authorities that are responsible for the process of gas production; these authorities were mainly the national government and the operator that exploits the project. For the implementation of geothermal energy production, lessons for the communication towards the local public from 'Groningen' need to be learned. Therefore, the role of uncertainties in the communication towards the local public can no longer be ignored. For the communication of technical uncertainties in geothermal energy implementation, 'openness' needs to be one of the guiding factors to prevent that uncertainties that influence the social acceptance of geothermal energy in a negative way, are being misinterpret. Following from the communication in Groningen, there is a risk that the public feels it is blocked from relevant information, or that not all (negative) consequences of a mining operation like geothermal energy is being communicated. In this case, the lack of transparent information will impact the level of social acceptance in a negative way.

All in all, the balance between the communication of certainties and uncertainties is a delicate one. Too much openness about uncertainty in a geothermal project might increase criticism about the project, or may signal incompetence of the authorities [Van der Bles *et al.*, 2020]. On the other hand, no communication of uncertainty might lead to a decrease in trust or even public resistance over time [Johnson and Slovic, 1995]. The role of geothermal energy in the Dutch energy transition is too crucial for it to be fired off due to public resistance, as happened to carbon capture and storage and shale gas in the Netherlands.

The communication approach that is presented in this study forms a starting point for this process of technical uncertainty communication.

14.3. Contribution to existing theory

In this study, different aspects have been addressed that are not covered yet in existing literature. In this section, these aspects will be described.

14.3.1. Identification of technical uncertainties in the implementation of geothermal energy

Geothermal energy production is still a relatively young energy production technique in the Netherlands. Despite the high density of papers that describe the technical aspects of this technique, a structured overview of the technical uncertainties that *can* play a role in a geothermal project was lacking. A possible reason for this gap in literature might be the role of geothermal energy in not only the Dutch energy transition, but also for the global transition from fossil fuels to sustainable energy as main energy source. Over the past 50 years, not only the gas production in Groningen and the negative consequences for the local public contributed to the development of a negative social perspective towards mining operations in general, there were also the disaster with the blowout of the BP platform Deepwater Horizon in 2010 and the scars in the landscapes of Texas due to shale gas production. Closer to home, there was the implementation of carbon capture and storage and shale gas production that led to an increase of public resistance to these mining operations. In some of these projects (shale gas, carbon capture and storage), the level of public resistance was so high that the project was not finished. The role of geothermal energy production in the energy transition is too important to let this happen. Therefore, authorities might be hesitant towards the communication of uncertainties in the implementation of geothermal energy.

However, in this study it is argued that the communication of technical uncertainties to the local public now, might prevent the development of public resistance towards geothermal energy in the future. This lesson can be learned from the gas production: identifying what is (still) unknown or uncertain opens ways to mitigate the possible negative consequences in the future. For the implementation of geothermal energy, the acknowledgement of technical uncertainties as the potential for (induced) seismicity opens ways to already start the development of damage control counters.

14.3.2. Identification of three pillars of social acceptance for other cases of transition

From the interviews that were organised during this study, three factors influencing the level of social acceptance of geothermal energy implementation have been identified: the safety perception of the public, the distribution of advantages and necessities of a geothermal project and the utilities and necessities of the project. Each of the technical uncertainties that was identified in the research, was linked to one of these three factors.

In current society, the implementation of geothermal energy is not the only case where there is potential for the development for public resistance or a decrease in social acceptance by the local public. In the Dutch energy transition, wind farms will need to be installed and areas where solar energy can be produced need to be appointed. The coming fifty years are going to be interesting in the sense of turning in on comfort and living standard, and not everyone will accept these development automatically.

This study offers a framework for the different aspects that can influence the level of social acceptance in a technical innovation. By expressing different cases of technical innovation in the same variables, for example the aspects influencing the level of social acceptance, different cases of technical innovation and levels of social acceptance in the energy transition can be compared. By doing so, knowledge gathered in different projects in the energy transition can be shared and used in different contexts. However, the practical implications of applying this communication approach to situations different than geothermal energy implementation will need to be tested in reality.

14.3.3. The design of the communication approach

In this study, the communication model as proposed by Oomkes [Oomkes, 2013] was taken as a starting point. During the study, this model offered both advantages and barriers to describe the process of technical uncertainty communication to a local public. First, the bilateral aspect of the model offered the possibility to identify two main communicators in the communication process. For the implementation of geothermal energy production, these communicating actors were defined as the initiators of the geothermal project, and the local public. However, in reality the initiators of a geothermal project are not as homogeneous as they were projected in this study. For example, the communication between different initiators in a geothermal project has not been included in this study. In the scope of the design of a communication approach, describing the characteristics of the communication within the communicating group was not relevant. However, in a real case of the communication of technical uncertainties, the communication amongst different stakeholders which are addressed as one communicating actor, analysed. For the overall outcome of the communication process, these internal relations might be of importance.

Secondly, the characteristics of the relationship that is, ideally, build up between the different communicators, is not addressed by the model. In the final communication approach as presented in this study, the relationship between the communicators was present. However, the characteristics of this relationship vary per geothermal energy implementation case, and should therefore be addressed in the communication process to emphasise the importance of a trustful and credible relationship.

For the communication of technical uncertainties in geothermal energy implementation, the approach designed with the model of Oomkes as starting point forms a first identification of the steps that need to be taken. The choice for this model as a starting point for the communication approach determined the outcomes of this study to a large extent. By reviewing the available data collected during the desk and literature search, and the interviews, the decision was made to change the order in which the elements of the communication approach were discussed in this report: the situation description, which is the most case–specific element of the communication approach, was discussed after the context, the goal, the message, the communicators and their reference frames had been discussed. By the end of this research, this was a fruitful decision as the approach now builds from what is known for each case of communication (the context, the goal, the message and the communicators) to the aspects that will need to be specified more each individual case: the involved stakeholders, the setting, the communication channels and the timeline of the communication process.

The choice to place the situation description as the final element in the communication approach, whereas Oomkes places the situation as one of the first aspects in the communication model was based on new insights that were collected during the verification discussions. This choice implicated that the design of the approach so far had to be reviewed, but in the end this led to a more consistent and applicable communication approach.

Looking back on the process of the communication design, it can be concluded that it is easier to determine the desired end–state of the communication process, than addressing the required steps to obtain this end–state. For example, it is easier to say that the initiators of a geothermal project need to be aware of the current level of social acceptance of the local public towards geothermal energy, than to identify and address the steps to become aware of this level of social acceptance. This partly has to do with the way these aspects were scoped in the interviews: it took a few interviews to 'practice' the questions that needed to be asked to collect the the data that was needed.

Moreover, there was the split of the communication approach to be generic enough to be applicable in any case of geothermal energy production where the technical uncertainties need to be addressed by the initiators of the project. On the other hand, there was the potential of resulting in a communication approach that was too generic and therefore missed the implementation of relevant data that was collected during the study. Therefore, if there were a next step in this research, that step would be to test the designed communication approach for the case of geothermal energy implementation on the campus of Delft University of Technology.

14.4. Discussion of results

ONE of the main challenges during the study was to follow the central line of the research design and decide with should and what should not be included in the research. In reality, there were many more factors, ideas and choices, both internal and external to the communication process, that influenced the design of this communication process. In this section, the conclusions of the previous chapter will be placed in a larger context to determine the research in the spectrum of communication to a local public and opposition to change. This will be done by discussing the choice for a local approach in geothermal energy implementation over a national approach, followed by a validation of the assumptions that were made in the research. Then, the communication of technical uncertainties in a democracy as the Netherlands will be discussed. Continuing, the implications of distributional justice as main factor in social acceptance will be explained. Then, a discussion about the time dimension of this study is provided. Lastly, a parallel between the communication to a local public during the Corona–crisis and the communication of technical uncertainties in geothermal energy implementation will be provided.

14.4.1. The choice for a local over a national communication approach

In 2020, there are officially 355 municipalities in the Netherlands. Looking at the goals for the implementation of geothermal energy in the coming thirty years, around 700 geothermal doublets will need to be installed between the time of this research and 2050. In theory, this suggests that on average, two geothermal doublets will be installed per municipality. For now, there is no clear indication of where all these doublets will be installed and if they will influence each others production rates.

By considering the number of doublets that will be installed to meet the national goals for geothermal energy implementation and the number of doublets per municipality, a nationally organised strategy for geothermal energy in the Netherlands seems a logical option, since most of the Dutch citizens will be faced with a geothermal well close to their house. As a result of this, the communication approach as proposed in this study would have taken the national government and the public as main communicating actors, instead of the initiators of a geothermal project. However, currently the implementation of geothermal energy is organised on a local scale and during the research, no indications were found that a national strategy is currently being developed by the national government.

The local scale of this study was chosen for multiple reasons. First, at different locations in the Netherlands, different technical uncertainties as identified in this research, play a role in the implementation of geothermal energy. Secondly, due to different levels of knowledge, different needs of control and different joint values that are shared by communities, the frame of reference by the local public is different for different regions. Overall, it was discussed with **P7 and P8** that a national communication approach for geothermal energy implementation would not address the subjects that are specifically important to a certain region. During the interview with **P7 and P8**, it was discussed that every geothermal project is different in terms of location, stakeholder groups, challenges and (technical) uncertainties. Therefore, it was concluded that, rather than focusing on the design of a general communication strategy on the communication of technical uncertainties from the national government to the local public, it would be useful to design the communication strategy that includes more stakeholder groups than just the national government. By focusing on an area on the local scale, the technical uncertainties that are present and their role in the creation of social acceptance can be investigated specifically for this area, and the communication process can be adjusted to the needs of the local public. Lastly, the communication approach that focuses on the small scale, offers more potential for personal relationships, respect and the possibility to execute the communication program in an personal en informal setting.

14.4.2. Validation of assumptions

In this study, the parallel is drawn between geothermal energy implementation and the production of gas in the Dutch province of Groningen. During the interviews, this parallel was discussed with the interviewees. They confirmed that both activities are classified as mining operations **(P1, P2, P3, P4, P7 and P9)**. The techniques for gas production in the Netherlands have been implemented so many times and over a time–span of more than 60 years, that the interviewees declared there are currently no technical uncertainties anymore in the techniques of gas production. For the implementation of geothermal energy, this is different. The techniques of how to extract the water from the subsurface are comparable to gas, but water is not the same fluid as gas. Therefore, the identification of the different technical uncertainties as provided in this study offers a first step to address the technical consequences of geothermal energy implementation.

A second assumption that was made in this study was that there is a potential for a lack of social acceptance for geothermal energy production in the future. This assumption is based on the social perspective towards gas production, which is a mining operation as well as was discussed above, that resulted from the earthquakes and the lack of effective communication with the local public in Groningen. During the interviews, the interviewees were asked about the potential for public resistance towards geothermal energy. Most of the interviewees responded that the current level of social acceptance of geothermal energy is high enough to prevent the organisation of public resistance, but the current situation does not guarantee a stable or increasing level of social acceptance in the future **(P1, P2, P4 and P7)**. Comparable to Groningen, the level of social acceptance might change if geothermal energy turns out to have so many negative consequences, that the balance of the distribution of advantages and disadvantages starts to shift. In this perspective, a parallel was drawn between the level of social acceptance of geothermal energy and gas production to be able to provide an identification of the technical uncertainties present in geothermal energy implementation.

14.4.3. Communicating with the public in a democracy

In the Netherlands, we live in a democratic political system [Tweede Kamer der Staten – Generaal, 2020], meaning that each four years, every Dutch citizen of 18 years and older of age has the right to vote for their representatives in the national and regional parliaments. This political dimensions add extra weight to the social perspective of geothermal energy implementation. Both national and regional politicians depend on the power they have been given by the Dutch population; if society does not agree with the policy that the parliaments sets out, this might have consequences for the composition of the parliament.

In the perspective of the ongoing energy transition, different interests sometimes lead to complex social situations. The national government is responsible for the goals set for geothermal energy implementation on a national level, the regional and local governments currently translate these goals into local energy policies **(P3)**. If there is a discrepancy between the sustainable ambitions of the local public and a (local) politician, or vice versa, the implementation of geothermal energy can become a political issue. This is more a possibility for the local governments (municipalities) than for the national government **(P3)**, since the municipalities are concerned with the translation of national climate goals into sustainable solutions that fit in the municipality. This is where resistance can arise.

On a national level, the level of trust of the public in the government was massively impacted by the loss of the social license of the gas production in Groningen [Bakema *et al.*; Van der Voort and Vanclay, 2015]. This means that the implementation of geothermal energy in the Netherlands offers the Dutch government the opportunity to regain its trust. The communication approach proposed in this study offers a structured overview the steps that can be taken to increase this level of trust in the future.

14.4.4. Distributional justice in a non–hierarchical communication process

The role of distributional justice in the final communication approach can be discussed, since the different communicating actors can have an unequal level of power in the communication process. The national government, and often the operators as well, are massive institutions that possess a lot of power in the execution of a geothermal project. For a local public, it can be overwhelming, or at least different from the ordinary situation, to actively communicate with these institutions. In this perspective, actively addressing a certain level of control in the outcomes of the communication process and the distribution of advantages and disadvantages in the geothermal project, are things that might not automatically be considered by the public.

On the other hand, there are the initiators of a geothermal project. Providing the public a certain level of control over the distribution of the produced energy might signal doubt, insecurity, or even worse, incompetence. However, for an effective communication process to increase the level of social acceptance, distributional justice is considered to be one of the main ingredients. Therefore, the communication–experts and policy makers of these authorities need to determine on how to address this issue before the actual communication processes take place. This way, providing the public with a level of control will lead to a more trustful and therefore efficient communication process.

14.4.5. The dimension of time in the design of a communication approach

The dimension of time is a vital component of the communication approach as designed in this study. The implementation of geothermal energy as renewable energy source in the Netherlands is in the take–off phase, and massive goals have been set by the Dutch government. Both the initiators and the local public of geothermal projects are relatively inexperienced with the techniques and the technical uncertainties that accompany the implementation of geothermal energy. In the coming years, experience will start to grow. For most people, the implementation of geothermal energy in their neighbourhoods it still a remote scenario, but this is going to change. The extent to which positive and negative results are obtained in geothermal engineering will determine the level of social acceptance of geothermal energy implementation; if people hear positive results of the technique, they will probably have a positive attitude towards the implementation and idem for negative results. As a result of this, the communication approach as proposed in this study will need to be revised once geothermal energy is implemented at the large scale in the Dutch energy transition. Over time, uncertainties might become certainties, which would have an impact on the communication process of technical uncertainties.

14.4.6. Communication to a general audience as social theme

In the current society, there are multiple subjects in which trust in the (national) government and communication to a general audience form central themes. The radius of 5 km to determine the scope of the 'local public' is for this section expanded to the size of the Netherlands; in this section, mass communication to the Dutch population will be discussed. Considering Dutch society over the past year, one can think of the farmers gathering the city centre of The Hague with their tractors in November 2019 during the crisis around the emissions of nitrogen, or the Corona–crisis that the country is currently facing.

Communication during the Corona–crisis
Parallels between a) the communication of uncertainties in geothermal energy implementation, and b) the communication to the general public during the Corona-crisis were drawn in a conversation with **V2**, who works at a communication advisor at the Ministry of General Affairs in The Hague. In the communication about the Coronavirus, the senders are the Dutch national government (represented by prime minister Mark Rutte and the ministers Hugo de Jonge and Martin van Rijn) and the National Institute for Public Health and the Environment (RIVM, represented by the managing director Jaap van Dissel). The receiver is the general public that has no specific medical or virological background. The context is to create a support base for the so–called 'intelligent lock–down'; a strategy where the expansion of the virus is slowed down by closing public facilities and prescribe the strategy of 'social distancing', thereby forcing people to maintain 1.5 meters distance between each other. The situation is defined by uncertainty; in the words of the prime minister, the country has never experienced such a crisis during times of peace. Decisions have to made without any frame of reference or certainty about the consequences. It is unknown how people will respond to the mitigation measures and the economic consequences. The time dimension plays an important role in this process; decisions have to be taken quickly based on a small base of information, because the virus expanded exponentially.

In the communication about the Coronavirus, the same three factors influence the attitude and interpretation of the communicator and the receiver as is the case for geothermal energy implementation. The level of *knowledge* of the public is based on the available information and the trust in the sources of this information. The distribution of fake news about the virus itself, ideas how people can test themselves or opinions about the mitigation measures are not easy to control and for messages that are distributed outside the official channels, it is difficult to determine the validity. The difference between the level of knowledge of the public and the national government / RIVM is that the public receives its information from multiple sources of information (social media, international news media, friends or family that work in a hospital, etc.), while the national government and the RIVM communicate that they base their knowledge on the experts that work at the RIVM. On a political level, the governments of different countries consult each other about the different steps in this crisis, but to the receiver, one confined message is being communicated. *Control* refers to the extent to which people have the opportunities to control their ways of handling the mitigation measures, and the extent to which they are forced to follow the guidelines as set out by the senders. The factor of *joint values* refers to the extent to which the public feels that can form a community and that this community supports the same values. In times of social distancing, forming a physical community is almost impossible, but these times activate the creative characteristics of people. That is why social initiatives are raised everywhere in the country, while keeping the obliged distances of 1,5 meters.

The communication process during the Corona–crisis is mainly one–sided from the sender (national government / RIVM) to the receiver (the general public). The main communication channels in the Corona–crisis by the senders are press conferences that are held roughly every week to inform the people. These press conferences are broadcast live by the main news media (NOS, RTL, radio, etc.). During this exceptional situation, the prime minister and King Willem–Alexander each held a public speech on television in which they spoke directly to the Dutch nation. News media, such as the NOS, RTL and national newspapers, interpret the current situation and describe them in news items and articles. The communication from the public to the national government and the RIVM is mainly indirect. This is illustrated by the fact that when the schools and universities were not officially closed, parents decided to let their children stay at home to prevent them from being infected with Corona, while this was not in line with the official advice by the government. In reaction to this, the government decided to follow this social movement and close the schools and universities, while this was not directly needed to contain the virus.

By drawing the parallel between communication in geothermal energy implementation and the communication to the general public during the Corona–crisis, it is shown that mass communication to a general public is a theme that re–occurs in different social contexts. The common denominators of these processes are that social acceptance is of vital importance for the process. The communication process takes between a sender and a receiver, which can consist of multiple stakeholder groups.

14.5. Limitations of this research

IN the research, specific choices and assumptions have been made based on the reference frame of the researcher and the conditions under which the research was performed. In this section, the limitations that have been recognised in the research, will be addressed and described.

14.5.1. The time dimension of the research

As mentioned in Section 8.3, community acceptance has a time dimension; over time, the level of social acceptance of a certain project varies. Currently, the implementation of geothermal energy in the Netherlands is in the take–off phase and the social acceptance of the technique is high. People are willing to implement the geothermal well in their neighbourhoods – as long as the well is not located in their backyards **(P10)**. Municipalities that apply for a permit at the Ministry of EZK are sometimes so positive about their plans, that SodM needs to warn them to consider the risks and realistic consequences that might be involved in a geothermal project as well **(P1)**. However, now that the step towards the implementation of geothermal energy in urban and residential areas becomes more and more realistic, some resident groups start to ask questions about the techniques and risks involved in the projects. Most communication experts and policy makers are aware of the impact of the communication around the gas production in Groningen, and are therefore planning to communicate openly about the potential negative consequences of geothermal energy in an earlier stage than happened in Groningen. Nevertheless, these plans need to be made specific in the coming years before the optimism about geothermal energy flattens or even turns into an overestimation of the risks.

14.5.2. Generalisation of the 'initiators'

In this study, the communication between the initiators of a geothermal project have been grouped into one communicating actor. For this reason, the communication between the different initiators during the communication of technical uncertainties, but also during the rest of the implementation of the geothermal project, taken into consideration for the design of the communication approach. This is a simplification of the reality, where the different initiators of a geothermal project communicate on a regular basis with each other. For the communication between the initiators and the local public, the communication within the group of initiators was left out of scope. However, by testing the communication approach in a case of geothermal energy implementation, the influence of this internal communication process needs to be verified.

14.5.3. Generalisation of the 'local public'

The public in this study was assumed to be living close (radius max. 5 km) to the project location. However, in reality this public is a heterogeneous group of people, who all have different ideas, opinion, prejudices, fears and feelings about the geothermal project that will take place in their neighbourhood. Also, the boundary of the 'local public' was set at the radius of 5 km from the project location. In reality, this boundary is less solid; people living within the 5 km radius might not be involved in communication process, or people living at 10–15 km distance or even further, are following the news on the project from day to day. Nevertheless, for each project it might be useful to determine the boundary of the local public and the people living further away from the project location – for example, by working with and inner, middle and outer circle seen from the project location. For each project, the communication experts need to decide on the different communication methods for the different circles of public, such that also the people that live further away from the project location that the direct neighbours feel involved in the communication process around the project.

14.5.4. Cooling of the water: one technical uncertainty left out of scope

One technical uncertainty that had been defined in Chapter 10 based on the expert–interviews, was left out of scope in the definition of public acceptance of geothermal energy implementation in the remainder of this report. This uncertainty is the cooling of the water.

The cooling of the water is an uncertainty that can be addressed by measuring the temperature of the water aquifers over the production time of the geothermal project. Overall, this uncertainty is assumed to have little impact on the life duration of the projects **(P2, P5 and P6)**, as the minimum expected life duration of the projects will be thirty years. Moreover, this technical uncertainty focuses on the future of the geothermal project and therefore has no direct impact on the public acceptance in the implementation phase of a project. After thirty years, the cooling of the water might be one of the factors that influence the decision to abort the project.

14.5.5. Stakeholders left out of scope

Both on the sides of the senders and the receivers in the communication process, there are stakeholder groups that have been left out of scope for this study. Initiators that have been taken into account in this study, are the Ministry of Economic Affairs and Climate Policy, the municipality where a geothermal project is started, States Supervision of Mines and the operator that will exploit the geothermal project. Representatives of these stakeholder groups have been interviewed. The first stakeholder group that has not been taken into account in this research is the Dutch Geological Survey (TNO). TNO manages the geological data that is available about the Dutch subsurface. Due to the history of oil and gas production, TNO holds a large database of subsurface data up to 3,000 meters depth (roughly the maximum depth of oil or gas production). TNO is therefore the main source of information to increase the level of knowledge about the geological aspects of the technical uncertainties in geothermal energy implementation, such as the potential for induced seismicity or the need for hydraulic stimulation. TNO currently has no major role in the communication process of geothermal energy, but has an important supporting role by providing the initiators of a project with information. Based on the interviews, it is not expected that the role of TNO in the communication process will change into a communicating role. Therefore, TNO was left out of scope for this study.

A second stakeholder group that was left out of scope of this research is the regional government of a province where a geothermal project will take place. The provinces forms the governmental step between the municipality and the national government. At the starting phase of this research, the actual role of the provinces in the communication process was not clear, and therefore the decision has been made to focus on the role of the national government and the municipalities in this study. Moreover, the 'Warmte transitievisies' (heat transition vision–documents), which will indicate how municipalities will make the transition to sustainable and renewable heat production in 2050, have a central focus on the implementation of renewable energy production methods by municipalities. These vision–documents follow the goals that have been set for geothermal energy production by the national government. Based on these vital roles of the municipalities and the national government in the currently ongoing processes of geothermal energy implementation, the provinces have been left out of scope for this research.

A third stakeholder group that was not included as initiator in this research, is the Stichting Platform Geothermie (the Dutch Platform Geothermal Energy, **SPG**). The platform includes approximately participants, who share an interest in the development and the implementation of geothermal energy in the Netherlands. Participants of the platform are regional governments, knowledge institutions and companies. In consultations with the Ministry of Economic Affairs and Climate Policy, the SPG represents the geothermal sector in the Netherlands. At the beginning of this study, it was decided to leave SPG out of scope because SPG represents only parties that have an (economic) interest in the development of geothermal energy, and is not one of the active initiators of a geothermal project.

Furthermore, in a 'real' case of geothermal energy implementation, the role of the news media in the communication process will need to be specified. For this research, the news media have been left out of scope, to limit the complexity of the different stakeholders. Also, the role of the media in the communication process varies per situation (local / national newspaper, amount of readers, etc.). For the communication process, the communicators and the media need to decide if the media will fulfil the role of independent messenger in the process and addresses the news items from both the perspectives of the initiators and the local public, or if the media has a more subjective opinion in favour of one of the communicators.

14.5.6. Bias of the researcher

In this research, the focus was on the communication of technical uncertainties instead of focusing on methodological, social or epistemological uncertainties. This choice was merely based on the expertise of the researcher in the field of reservoir geology and petroleum engineering; due to a base existing knowledge on the techniques of both gas and geothermal energy production, relevant technical uncertainties could be identified.

Doing this research as part of a combined thesis project with an MSc-program of Reservoir Geology came with both benefits and disadvantages. First of all, the researcher was well aware of the technical aspects of gas and geothermal energy production, and therefore able to focus on the technical uncertainties of the project. This allowed the researcher to ask in–depth questions about the technical uncertainties from a scientific point of view when policy–makers and other people that did not have a background in petroleum engineering were interviewed.

The choice for the different stakeholders in geothermal energy implementation that have been interviewed in this study resulted a communication process from the perspective of the initiators of a geothermal project. As a result of the focus towards technical uncertainties in geothermal energy implementation, these interviewees were challenged to review the technical aspects and uncertainties of geothermal energy in the Netherlands critically and compare them to the applied methods for gas production. However, most of the interviewed stakeholders had a economic or social interest in the implementation of geothermal energy implementation. The local public was not included as one of the interviewed parties. This choice was made on purpose, under the assumption that the local is a very heterogeneous group of people. In the verification phase of the design, three people living close to the location of a future geothermal well were asked for the aspects that determine the reference frame in the communication process. However, these were still only their opinions, ideas and experiences. For a more detailed, and maybe less biased, idea of the reference frame of both communicating parties, the communication approach can be detailed and tested in a specific case of geothermal energy implementation.

During a verification discussion with **V1**, it was discussed that technical facts and numbers are important in geothermal energy implementation, but the ways how these facts are communicated and received are just as important. In Dutch, she mentioned that: *'With numbers only, you are not going to make it.'* Therefore, in this research the technical uncertainties were linked to different methods of communication. By adjusting the method of communication to the message, e.g. the technical uncertainty, one might find a way to focus on the message, instead of the way how this message was communicated.

Lastly, being trained in the field of reservoir geology and petroleum engineering sometimes was a disadvantage during the research, as the researcher had her own ideas about the potential of certain technical uncertainties, or the perceived impact of these uncertainties. Therefore, there was the risk of having a confirmation bias during the interviews and the interpretation of the data. For example talking about induced seismicity; the approach of induced seismicity when small amounts of vibrations are tolerated for the greater good of geothermal energy production, can easily lead to resistance by the local public as soon as the vibrations are felt by the people that live close to the production area. This approach might be 'safe' from a scientific point of view, but not from the perspective of the local public. This balance must be maintained by the science communicator that works on the intersection between society and technology. Also, being trained in the field of gas production and geothermal engineering created the potential for focusing too much on the 'sending'–part of the communication approach, since the researcher had own ideas about what messages can be communicated to increase the level of knowledge of the public. During the verification discussion with **V3 and V4**, the aspects of a communication approach in which the senders have a role that is too prominent for a fruitful dialogue with the receivers, was discussed. The balance between sending and receiving messages is important for the feeling of being heard and respected in the conversation.

14.6. Recommendations for future research

SOON, hundreds of geothermal wells need to be drilled to meet the goals for geothermal energy implementation as set by the Dutch government. The process of how the technical uncertainties in geothermal energy implementation can be communicated to a local public will be conducted at the start of each project. Therefore, it is recommended for future research that specific communication experts are appointed in the most significant stakeholder groups – Ministry of EZK, municipalities, provinces and operators – to guide the process of communication with the local public. Also, it is recommended for the local public to organise the pro– and opposition of geothermal projects into groups that can actually participate in the communication process. This can be done by appointing people who are willing to act as communicator in the process. By doing so, it might be easier for people to join a group that shares their opinion, and thereby allowing them to participate in the communication process.

Secondly, future studies offer opportunities to focus on the role of stakeholder groups that were left out of scope for this study, in the process of uncertainty communication in the Dutch energy transition. Examples are a) the role of the provincial governments in the communication process of technical uncertainties to a local public, or b) the consequences if TNO, the Dutch Geological Survey, has a role in the communication of subsurface data to increase the level of knowledge about the subsurface in which there will be drilled during the geothermal project.

Thirdly, the focus on this study was on the communication of technical uncertainty from the perspective of the initiator. This choice was based on the expertise of the researcher and the social perspective on mining operations that was developed in Groningen. However, for future research it is recommended to study the different aspects of the reference frame of the local public and its exact impact on the communication process. It might be an idea to do this for one specific case of geothermal energy implementation, since the reference frames of the public in different geothermal projects vary to a large extent.

Furthermore, considering the role of the 'local public' as communicator in the approach that is designed in this study, the steps that might need to be taken in case there are individuals in the public that are experts in geothermal energy implementation or uncertainty communication themselves, need to be considered. If this is the case, this might be beneficial for the communication process if these people decide to cooperate in the process. On the other hand, it is possible that these people will draw their own conclusions and doubt the expertise of the experts that participate in the communication process. In the extreme case, these individuals might undermine the effectiveness of the communication process. To test this, the steps to include these people into the communication process without providing them the opportunity to undermine the process, can be practised in a role play before being executed in a real case of communication.

The last recommendation for future research is to adjust the communication approach that is proposed in this study to the different stakeholder groups that have been distinguished. Each stakeholder group has its own perspective on the communication process in a geothermal project, and this perspective determines to a large extent the attitude and effectiveness of the communication process. One recommendation is to design different scenarios for the communication approach, for example at different moments in time of the project, or focusing on the communication process as seen from the perspective of one specific stakeholder group. This way, the process can be adjusted to different stakeholder groups, and thereby increasing the level of usefulness of the communication approach.

14.7. Recommendations for practice

In the future, the communication approach proposed in this study can be used as starting point in the communication process. Each process where geothermal energy is implemented in a certain area is different. Therefore in the future, it might be useful to turn the communication approach proposed in this study into a living document in an online environment, for example. By doing so, the communicators of each project can exchange experiences, ideas, do's and don'ts, etc. during the communication process. Residential areas where the same technical uncertainties influence the level of public acceptance of geothermal energy implementation can cooperate to increase their knowledge of the project. This way, the wheel does not have to be reinvented at the start of each communication process.

In the case of a geothermal energy project, a way to implement this communication approach into the project and align it with the technical timeline of the project need to developed. One of the ways to do this is to couple this communication approach with the permit request for the geothermal project at the Ministry of Economic Affairs and Climate Policy. This way, the initiators of the geothermal project need to consider the communication with the local public before the permit can be granted. However, the communication approach needs to be fully tested before it can be integrated with the permit request for geothermal energy implementation.

The last recommendation for practice is linked to the current social situation in the Netherlands: the Coronavirus made it impossible to physically meet people to participate in a communication process. In this study, the impact of the Coronavirus has not been taken into account, since the interviews were conducted in the pre–Corona period. However, no one knows how this virus will develop in the coming months or years. Ideally, the communication of technical uncertainties takes, due to the link with social acceptance and the neat balance between social acceptance and resistance, place in person. However, solutions for the communication of technical uncertainties while maintaining the rules for social distancing should be implemented in the communication approach if it turns out that physical meetings are impossible for the coming period. The responsible stakeholder groups should come up with ideas to continue the communication process, such as online information evenings, or online communication methods such as websites, social media or e–mail updates. At all times, the communicating parties should prevent the scenario that online communication becomes the source for a decrease in social acceptance, but the design of an online communication approach is left to another researcher.

14.8. Chapter summary

In this chapter, the conclusions of this study have been placed in the context of existing literature and the contribution to literature has been described. The conclusions and results have been discussed and limitations of the research have been explained. Lastly, recommendations for future research and practise have been provided.

Now that the results and conclusions of this study have been discussed and limitations and recommendations have been addressed, the next and last chapter of this report is dedicated to a personal reflection on the research, the research period and the double–degree MSc program. Doing research is not about collecting and interpreting relevant data, but it is also a process of personal growth and reflection. The chapter places the research in the larger context of personal development and closes this thesis. In Figure 14.1, this last step is visualised.

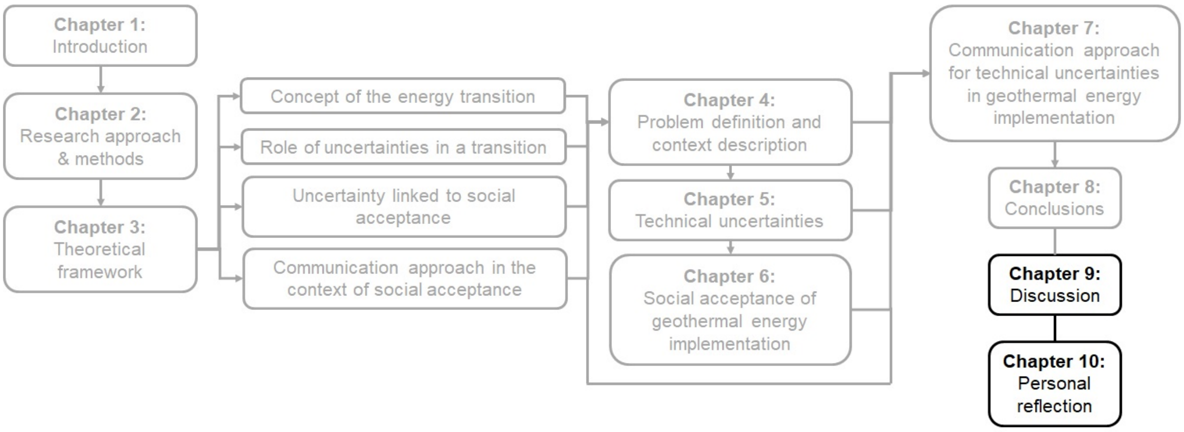


Figure 14.1: The last step of this report: a personal reflection on the research and the MSc–period.

15

Reflection on double–degree MSc program and a combined thesis

AFTER one year, two months and ten days, this thesis project has come to an end. Over this period of time, there have been a lot of moments of joy and energy, but also moments of stress and the feeling of being lost in the research. Looking back at this significant period of time as a double degree MSc–student, this reflection focuses on the process of personal development that I went through during this thesis project.

This reflection contains three parts. First, a reflection on the combined MSc thesis research will be provided. Secondly, the added value of doing a double–degree MSc–program will be discussed, followed by a personal reflection on the research period from the perspective of personal grow and development.

15.1. Personal reflection on the research

LOOKING at the final product of this combined MSc thesis project, the end result is less a combination of the two MSc programs than I expected at the start of this thesis trajectory. Over the project duration, a detailed scope for each thesis was developed. I think a main reason for this is that the subject of the Reservoir Geology thesis research was already filled in by the time the Science Communication study started. For the geology–part, I became part of an already existing project team, and the research was centred around a shale gas bearing area in the Outback in Australia. It took a while to discover that doing a science communication–related research that focuses on a subject in Australia from the Netherlands, was not going to work due to time and distance differences, but also due to cultural and social difference. As a Dutch student, there was no easy way to test, validate or discuss results of the thesis in an easy way, let alone doing interviews with an 8.5 hours time difference and no way to physically meet interviewees, focus groups or any type of project stakeholder.

In the end, doing the research focusing on the communication of technical uncertainties towards a local public in the Dutch energy transition provided a lot of joy. The subject is much one of this time and both technical experts as communication advisers at different levels in companies and society are working on the implementation of geothermal energy to make the energy transition a success. I was happy to add a focus on 'sustainability' and 'energy transition' in a thesis that also finishes off a master programme in Petroleum Engineering.

The two researches I conducted were very different in style, research methods and final result. In terms of style differences: at the start of the geology–research, the focus was clear as I continued the work of a previous MSc–student in an area to the west of the research of 2018. Based on the supervisors' experiences with previous research in Northern Territory and the overall line of the NT–Work project, the outline of the thesis was clear from the start. Guidance by the supervisors was always in line with this project and directed towards a clear goal: to provide an overview of the present–day geological architecture of a specific area in the Northern Territory. The style of the Science Communication research was completely the other way around: instead of supervisors guiding me on a pre–paved pathway, I was in charge of the project and the process of doing the research. I was the one who steered the research and the supervisors watched me from the sideline. Of course, they provided me with feedback when I asked for this, or they steered in the case I drifted away from the focus of the study, but none of them knew by the start of my thesis research what the research process would result in.

In terms of research methods, this difference in research style resulted in the geology–research being more a research that worked straight from A to B based on the available geological data, whereas the Science Communication–thesis included many loops of scope definition, problem discovering, solution development and (personal) reflection. This difference in research style both hindered and supported the studies during the research period. On one hand, the two ways of doing research offered opportunities to zoom out from one topic while working on the other, while, on the other hand, constantly shifting between the two different subjects and the two ways of doing a research, including working with two different teams of supervisors, was confusing at times. The straight–forward way of working for the geology–part sometimes made me skip a few steps in the science communication research, whereas for the geology–part, being too reflective and personal was a pitfall.

Looking back over the research period, I approached the Science Communication–research the same way as I approached the Reservoir Geology–study for a long time: I tried to go in one straight line from the problem definition, to collect the required data, interpret the data, draw conclusions and discuss the results. However, in the final phase of the Science Communication research, I realised that the design of the communication approach asked for a different research approach. This way, I learned to see the differences between a technical research and a social sciences research. The importance of feedback loops, iterations of the process and moments of reflection became clear to me. After the design process that resulted in the communication approach, I realised I went through the phases of the double diamond–model, as it was explained to us over the courses in the MSc–program. After the definition of the problem statement, I collected data by conducting interviews. These data were combined into a design draft for the communication approach, which was verified and updated in multiple feedback loops until the approach that is presented in this report, was finished. Looking back at this process that the identification of these steps beforehand would have saved time and energy. On the other hand, going through these phases and reshaping the process during and after each phase learned me to trust my knowledge and motivation to come to the conclusions that fit the research. In the end, being able to conduct the two completely different researches at the same time learned me to be flexible in the research approach and to adapt to different ways of working in a research team.

A last point of reflection on the research came to me after the university closed its doors due to the lockdown measures because of the Coronavirus pandemic that reached the Netherlands by the second half of March 2020. After March 13th, the university, and more specifically 'het afstudeerhok' (room C118 of the Faculty of Applied Physics) was no longer open for students. From this day, I finished my thesis from home, and also the defence will be organised via a video–call with the supervisors and all the friends and family I invited. This period of working on my thesis from home made me realise a few things. Firstly, I became conscious of how much I need fellow students around me to spar and share ideas with. I learned that I an a researcher who partly thinks by expressing these thoughts into words. By formulating my problem or idea orally, I often came to a solution quickly, whereas if I worked solely at my desk at home, there was a higher risk of ending wrapped up in my own ideas and thoughts. In this period, Zoom–sparring–sessions with fellow students and multiple feedback meetings with the supervisors helped a lot to bring this thesis to a higher level.

Zooming out, I realise I would not have been able to conduct this research all by myself as that is how I worked during the last weeks of this thesis period. I need people around me to reflect with, to ventilate frustration or share concerns. As long as I do not depend too much on other people's ideas or my supervisor's approval in the continuation of the research, I think this is a welcome characteristic of me as a researcher. Over this period, I experienced so much love and support from my fellow–students and friends, that I would not have got to this extent if everything was 'normal'.

15.2. The added value of doing a double–degree MSc program

LOOKING back on the past five years, doing a double degree MSc–program in which the studies of Reservoir Geology and Science Communication were combined was one of the best choices I have made in my short scientific career so far. One of the main arguments for this is that I think that one cannot function in a self–consciousness way as a petroleum engineer without reflecting on ones impact on the society that we live in. The different courses in the MSc–program of Science Communication, such as Science Journalism and High–Tech Marketing, but also courses that focused on branding towards a larger public, such as Communication Policy & Strategy offered opportunities to focus on the dimension of science communication in a larger context than just my own frame of reference. This process was emphasised by the different people, who all have different backgrounds and interests, that I met during over the past years. These fellow students helped me to put things in perspective, while each of them had his or her own perspective on the discussed topics.

This program gave me the opportunity to explore both my technical and social–scientific qualities. For me, the one cannot without the other; in science, being good in what you do is important, but being able to explain to other, non–scientific people *why* you do something is just as important since in the end, most scientific research will finally affect the society that we live in. For me, acting on this intersection of science and society offers both challenges as opportunities. The perspective of the ongoing energy transition while being trained as a petroleum engineer, challenges me to make choices that is in line with a more sustainable energy consumption in the future. This idea was a guiding light during the design of the Science Communication research. This way, the subject of the Science Communication research, which had a strong link with the effect of an innovation process on society, formed the perfect way to close off this double–degree program.

15.3. Personal development during research period

DURING the period of the thesis research, I grew both as a person, but also as a scientific researcher. I learned how to take the lead in a scientific project, to set and meet deadlines and how to design my own research project. Being in charge of my own learning process and research progress made me realise that I enjoy learning from other people and decide what I need for the research. During this study, I learned for example how to write in a scientific way: every word needs to deserve it to end up in the final report. From the combination of doing a literature research and semi–structured expert–interviews, I learned to adjust the interview questions to be relevant in the support of the research.

Over the research, I grew as an independent researcher. With this, I mean that making choices was never my strongest point, and working with five capable supervisors who each had their views and ideas about the thesis, there was the risk of processing all different types of feedback, and trying to gratify each supervisors. In this process, there was a chance that I left my own view on the research on the side. In addition to this, doing this research made me a more self–consciousness person. This thesis research made me see the amount of work that I am capable of doing in a certain amount of time, and I learned to be satisfied with the result. Over the research period, I learned to have the hide of an elephant: in the beginning, feedback or critical supervisors easily upset me – I think this has to do with the previous point I made, that I wanted to gratify each supervisor by taking his or her feedback into account. Now that I am at the end of this thesis period, I learned more about my scientific qualities (curious, precise, strong in organisation, 'a digger'), so that I can handle feedback on my pitfalls (wanting to include every single step of the research in the report, trying to include all different kind's of viewing points in the report) in a better way.

The result of this thesis is both a reflection and a confirmation of who I am: both a technical and social scientific student. I am happy to say that I went through each phase of a combined thesis research: looking back, I am able to identify periods of ups and downs. In the future, I would be happy to explore my analytical qualities in an environment that challenges me to make a connection with the local public. In a few months, I hope to find a challenging position on the intersection between technology and society!

III

Appendices

A

Link Daly Waters Arch and Batten Fault Zone

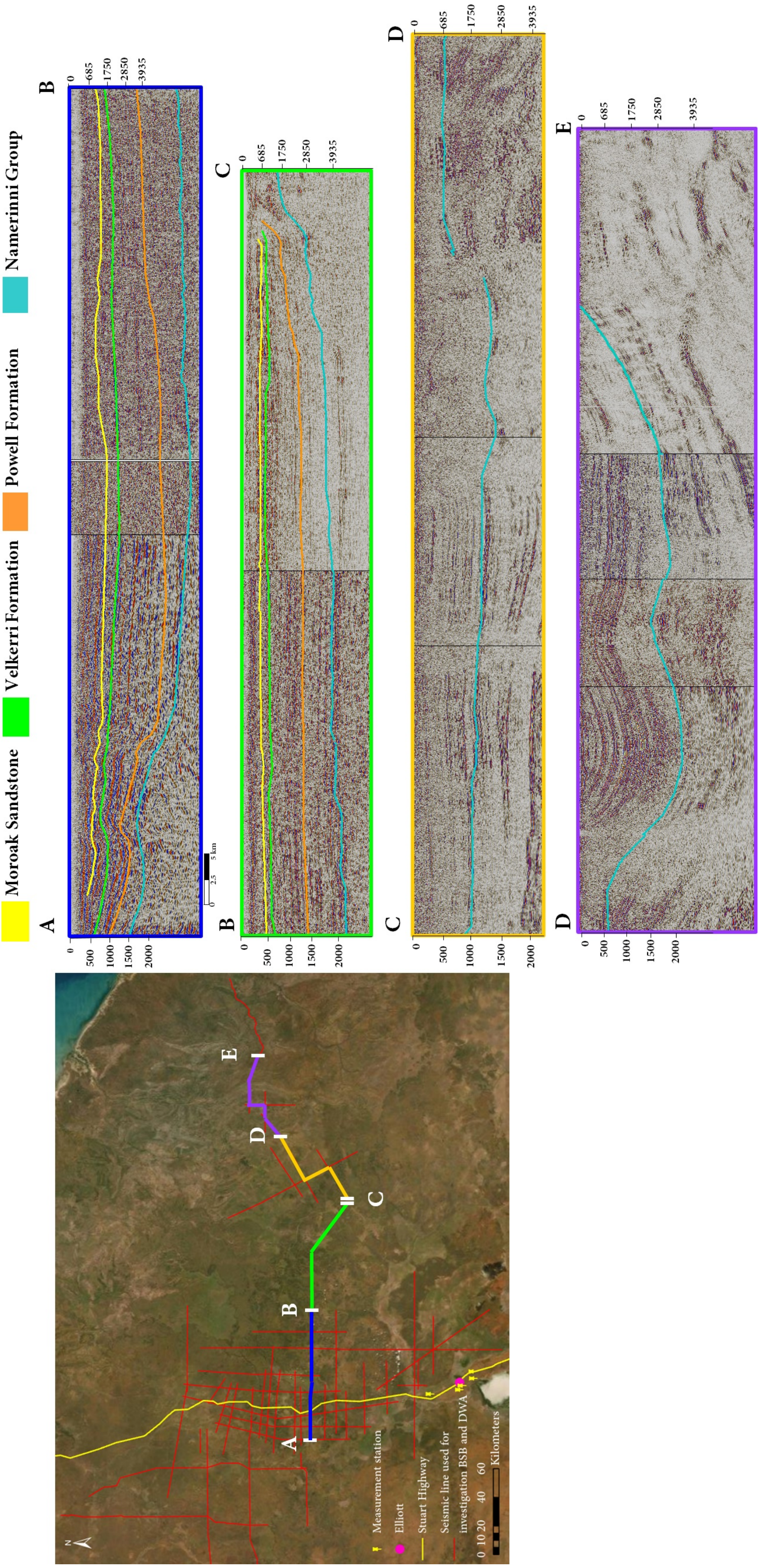


Figure A.1: Seismic sections of the Daly Waters Arch (west, A) to the Batten Fault Zone (east, E). Seismic interpretation of the Batten Fault Zone was done by Pragt [Pragt, 2018].

B

Time-depth conversion of 2D seismic data

Table B.1: Conversion table used for time-depth conversion of 2D seismic data. Data calculated using the graph of Figure B.1.

TWT [ms]	TWT [s]	Depth [m]	TWT [ms]	TWT [s]	Depth [m]
250	0,25	235	**1250**	1,25	2325
300	0,3	300	**1300**	1,3	2430
350	0,35	450	**1350**	1,35	2550
400	0,4	525	**1400**	1,4	2670
450	0,45	600	**1450**	1,45	2775
500	0,5	685	**1500**	1,5	2850
550	0,55	825	**1550**	1,55	2970
600	0,6	900	**1600**	1,6	3075
650	0,65	1050	**1650**	1,65	3225
700	0,7	1110	**1700**	1,7	3300
750	0,75	1220	**1750**	1,75	3440
800	0,8	1330	**1800**	1,8	3525
850	0,85	1450	**1850**	1,85	3780
900	0,9	1537	**1900**	1,9	3750
950	0,95	1650	**1950**	1,95	3835
1000	1	1750	**2000**	2	3935
1050	1,05	1875	**2500**	2,5	5000
1100	1,1	1950	**3000**	3	6075
1150	1,15	2100	**3500**	3,5	7130
1200	1,2	2200	**4000**	4	8180

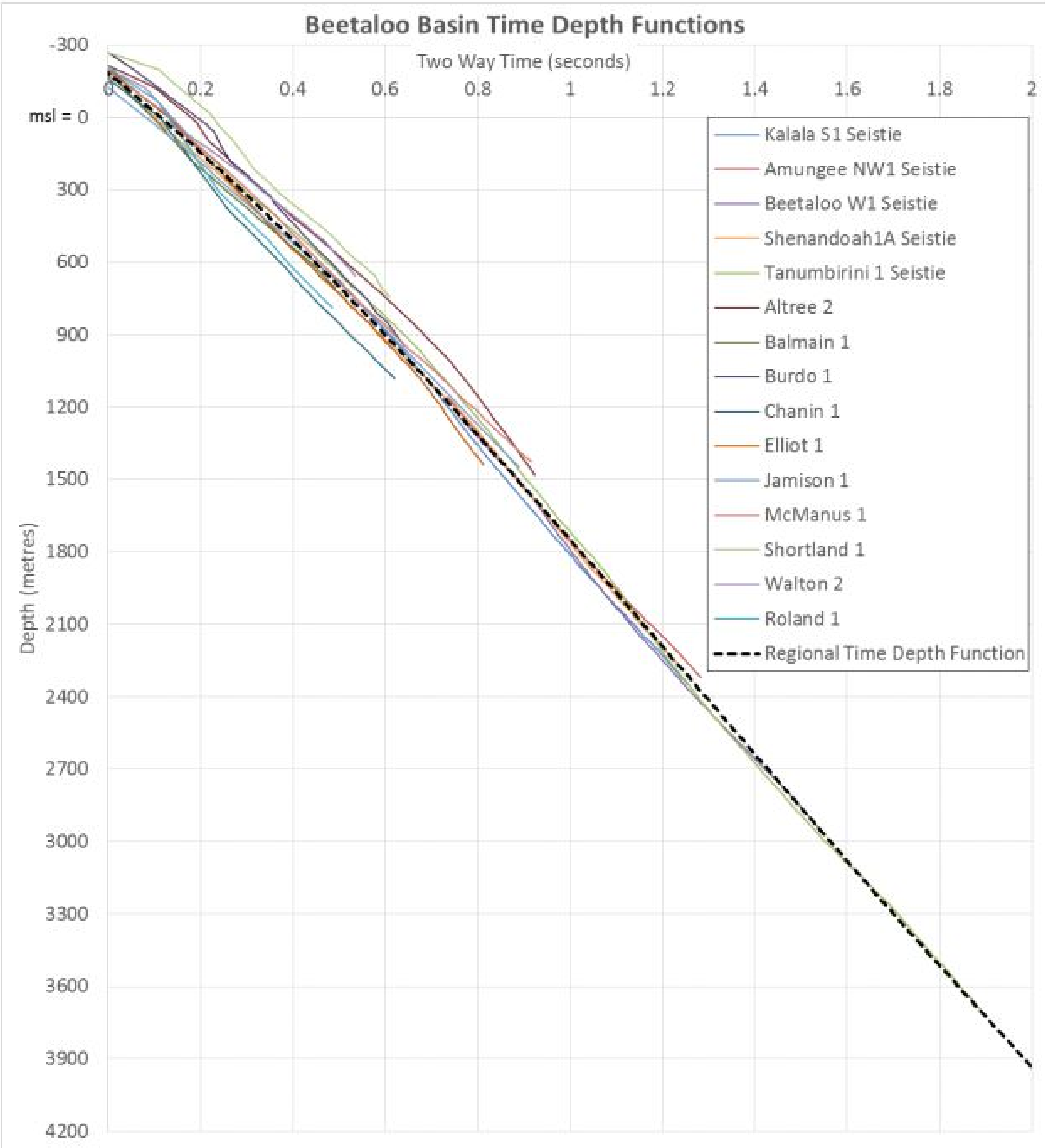


Figure B.1: Relevant well time to depth relationships for wells drilled in the Beetaloo sub–Basin and the regional time–depth trend that was used for a pseudo depth conversion of the 2D seismic data. Graph provided by Origin Energy [Origin Energy, 2017].

C

3D Horizon interpretation

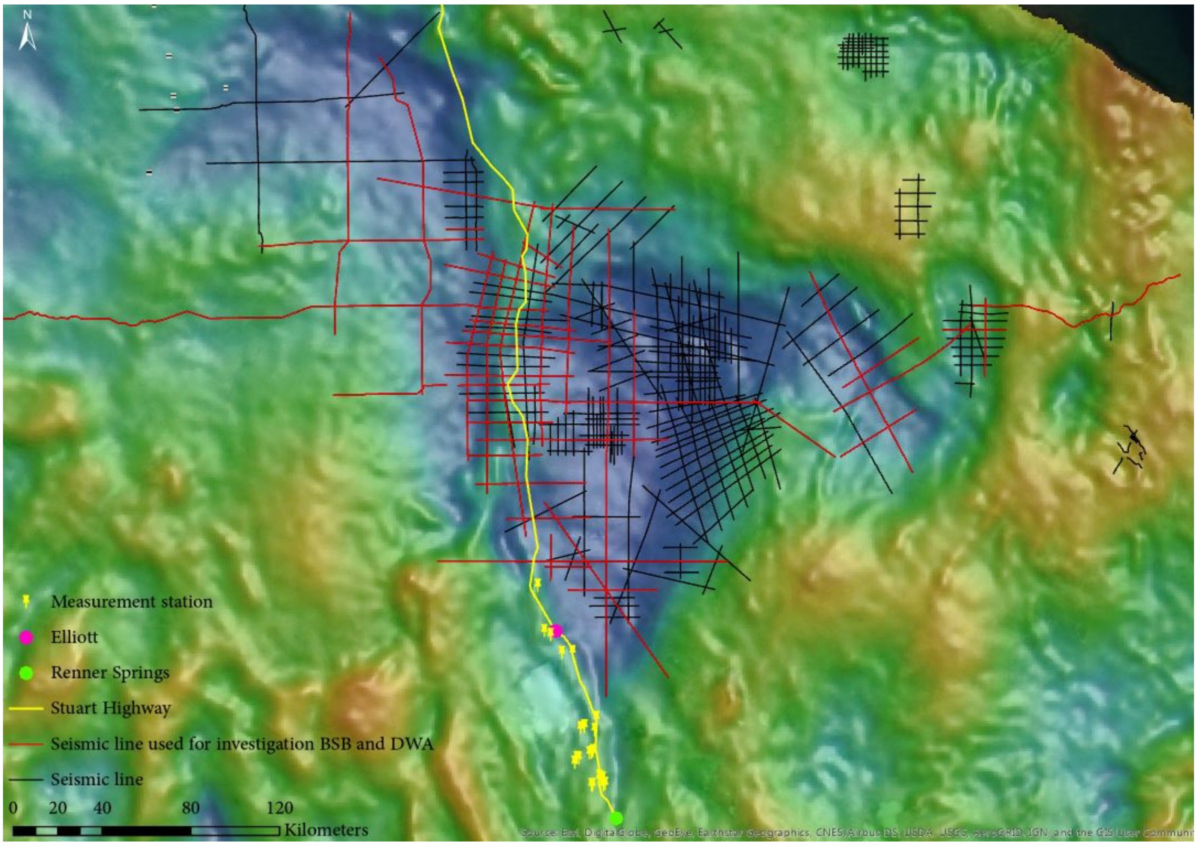


Figure C.1: Interpreting data from multiple sources: Seismic data in the Daly Waters Arch (seismic lines in red were used for the interpretation of formations in the Daly Waters Arch), outcrops in the Tomkinson Province. In this map, the topographical data is overlain with a gravity data map, so that the structure of the Daly Waters Arch in the Beetaloo sub–Basin is visible.

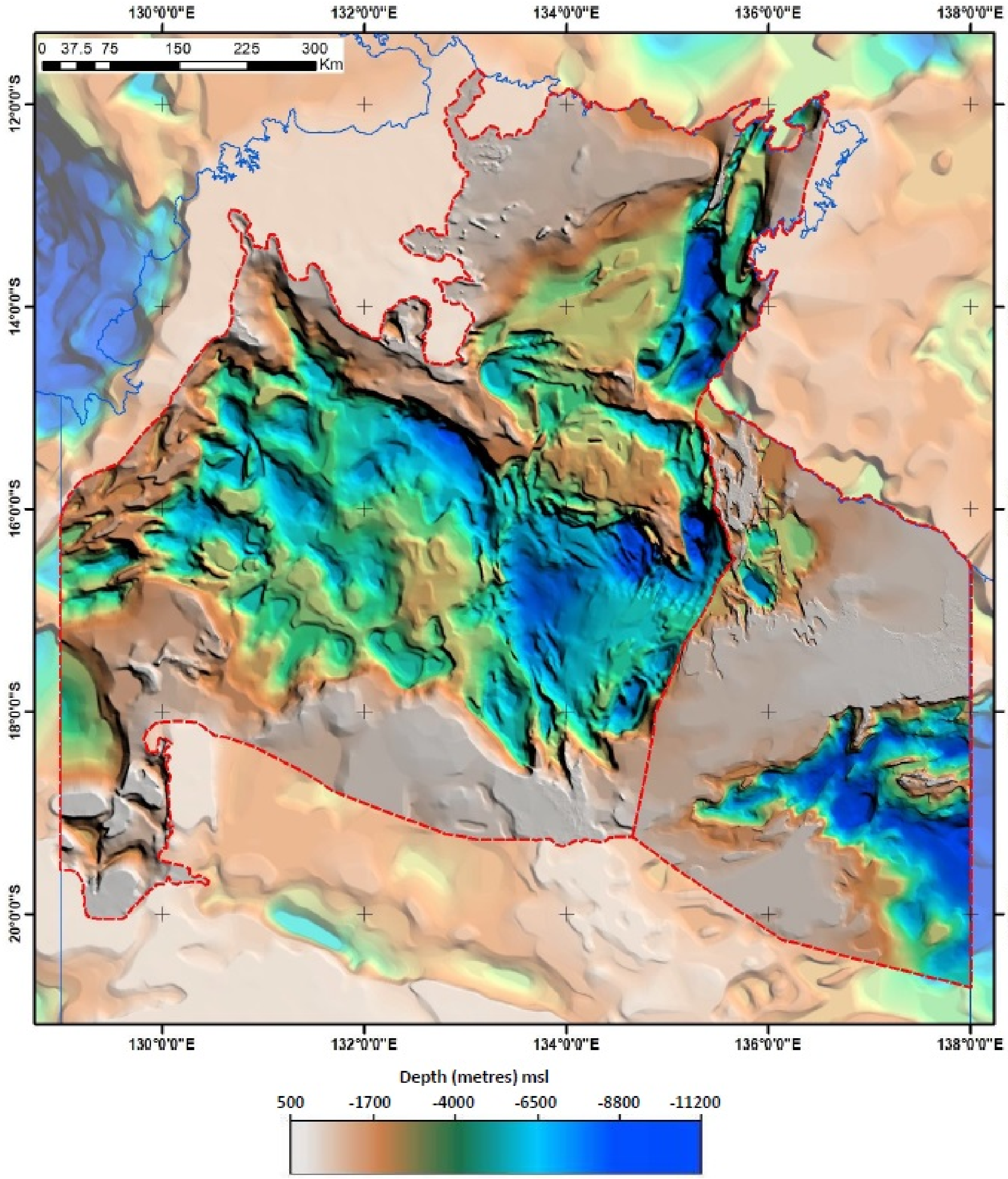


Figure C.2: The 2018 Greater McArthur Basin SEEBASE map [Frogtech Geoscience, 2018]. The red dashed line represents the outline of the area of interest, e.g. the extent of the Greater McArthur Basin. The map shows the depth of the base of the Redbank Package. Image retrieved from the SEEBASE report 2017 [Frogtech Geoscience, 2018].

Figure C.3: 3D map of the interpreted seismic lines, seen from the southwest.

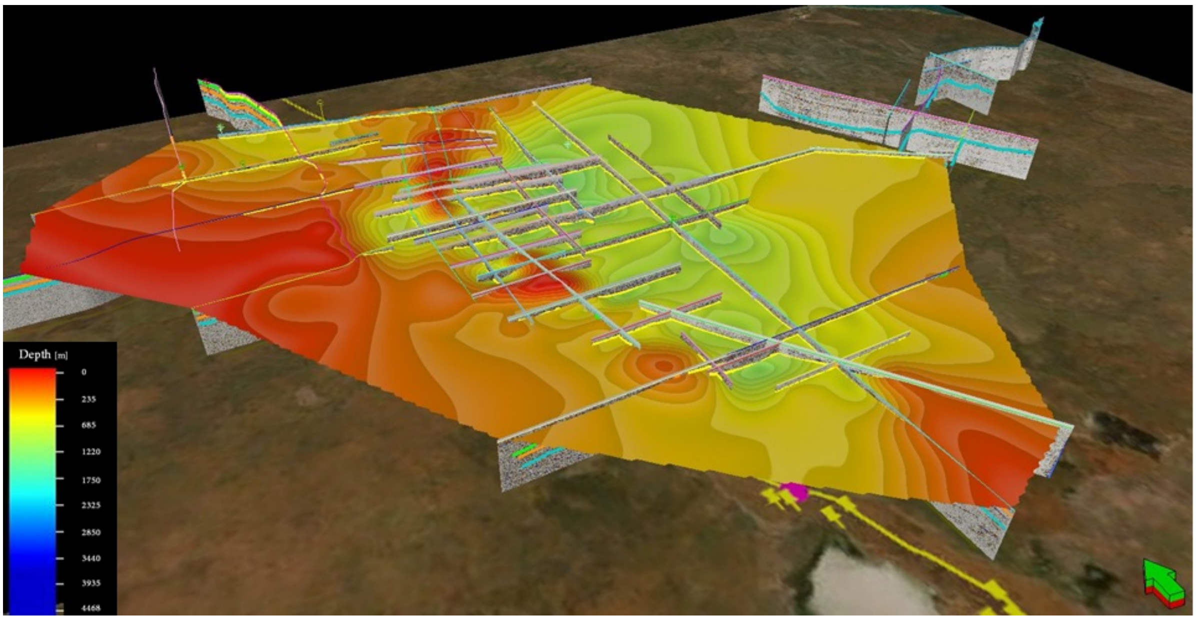


Figure C.4: 3D horizon interpretation of the Moroak Sandstone.

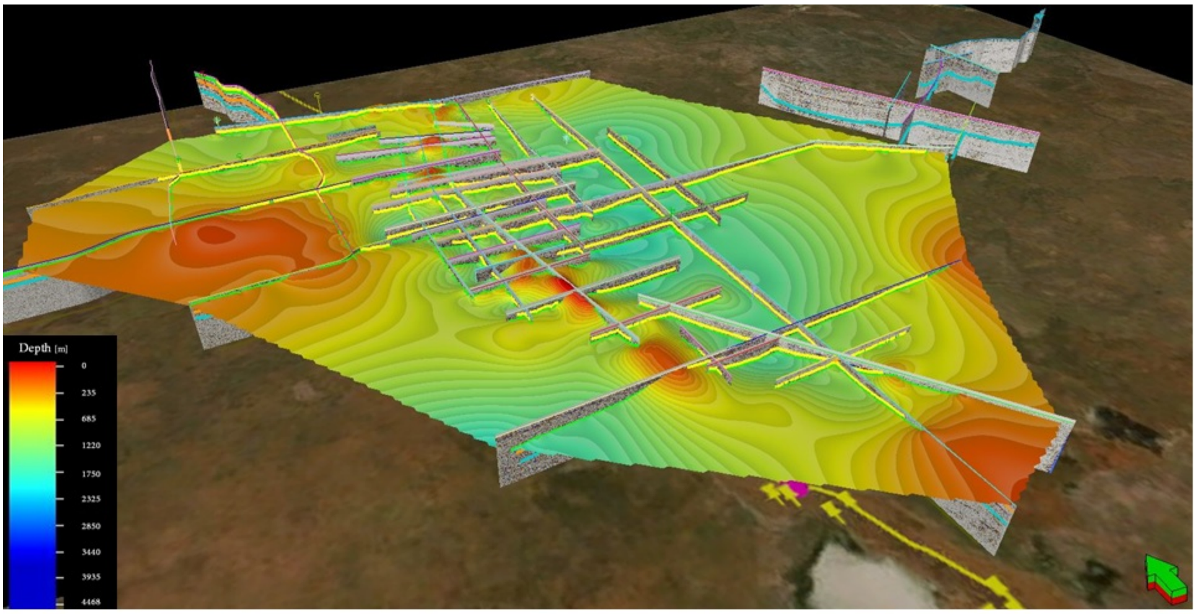


Figure C.5: 3D horizon interpretation of the Velkerri Formation.

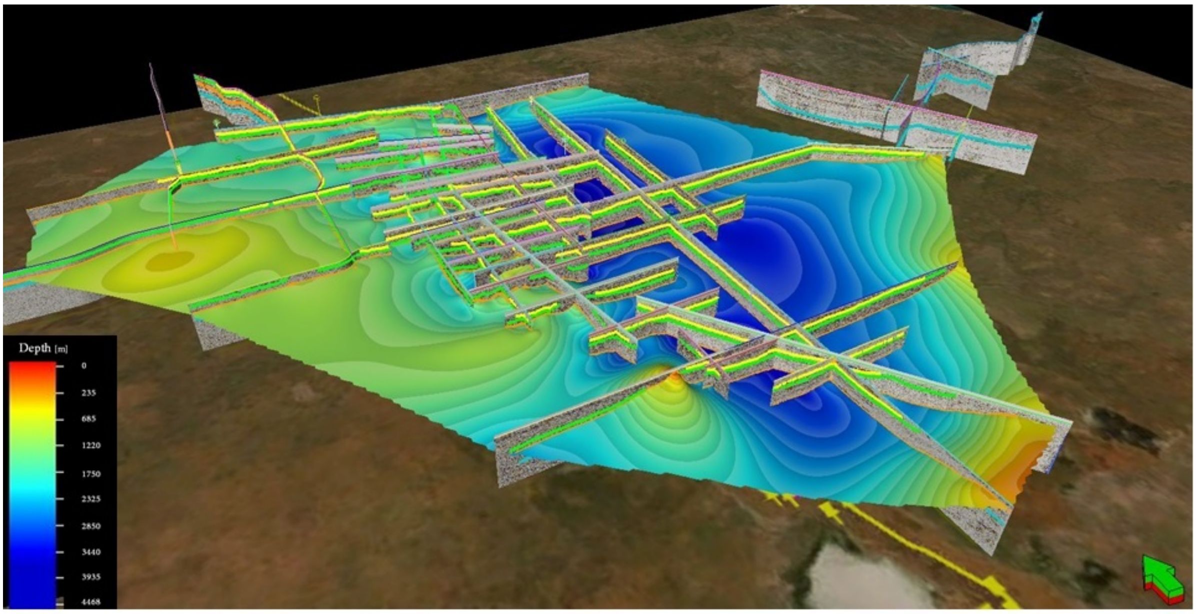


Figure C.6: 3D horizon interpretation of the Powell Formation.

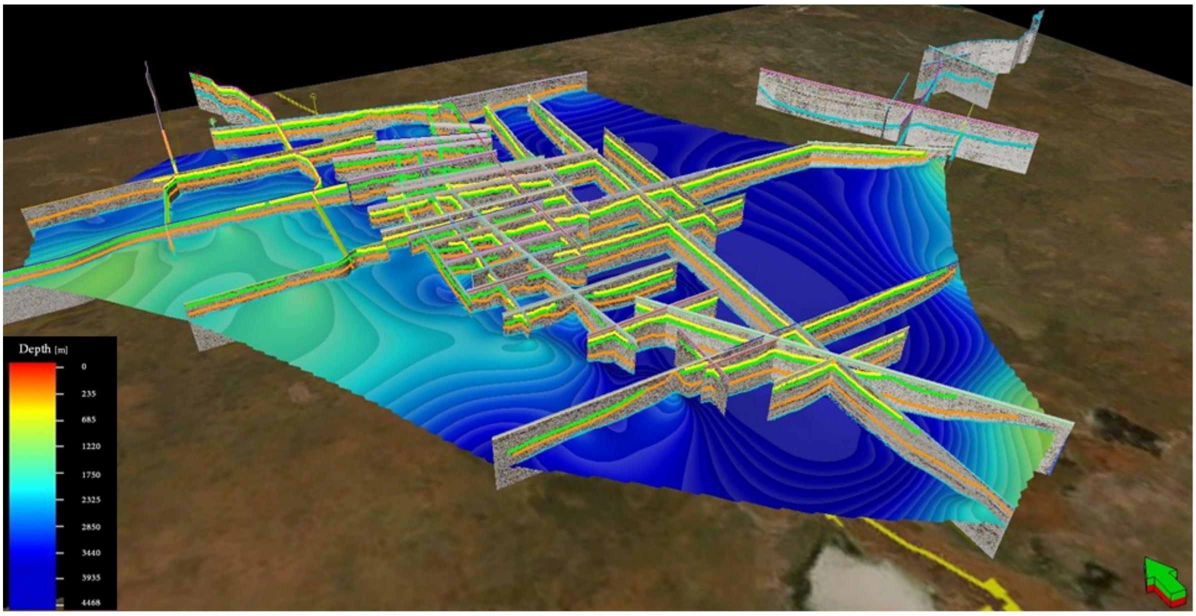


Figure C.7: 3D horizon interpretation of the undifferentiated Namerinni Group.

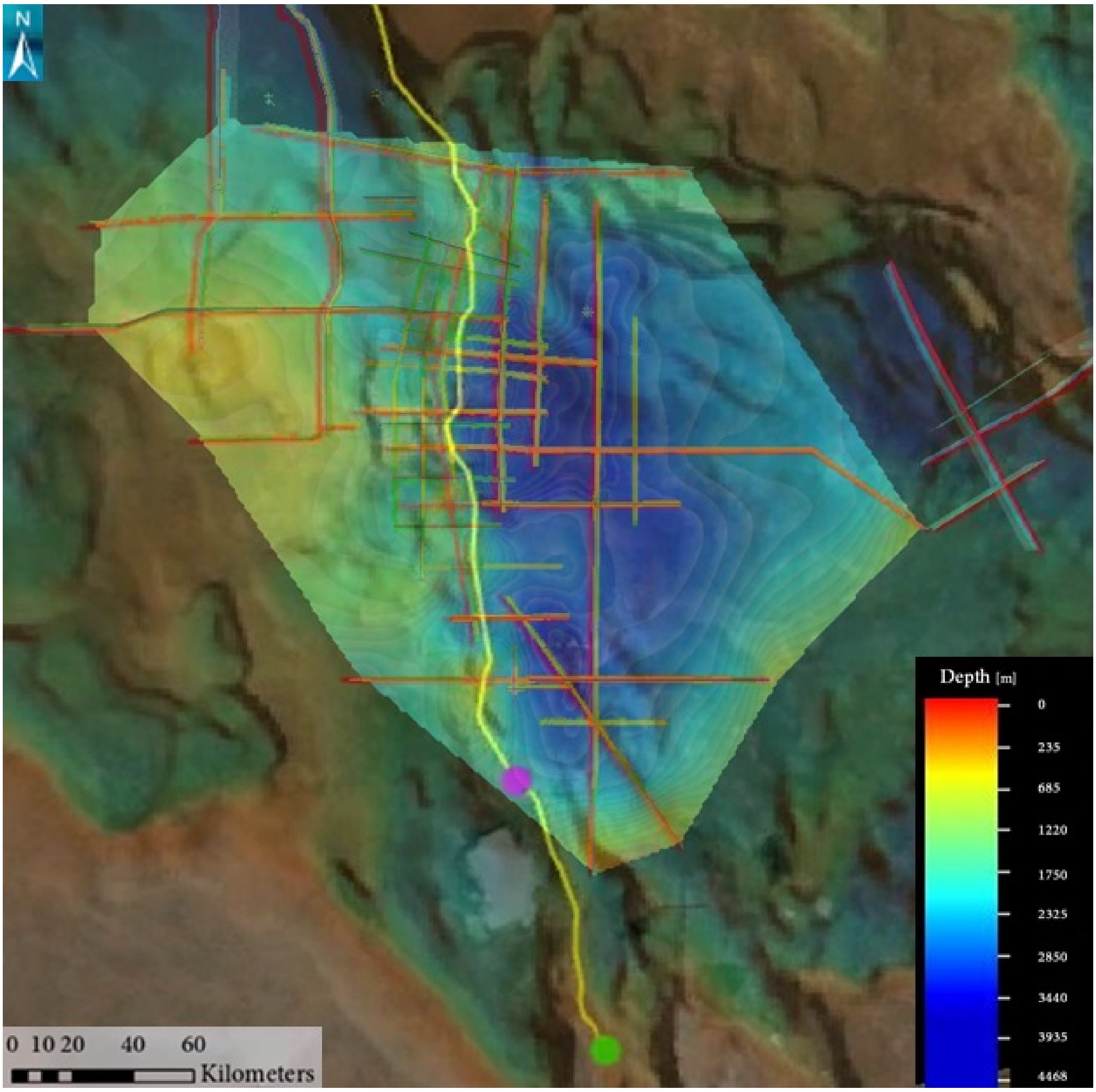


Figure C.8: The SEEBASE gravity map Frogtech Geoscience [2018] placed over the 3D deformation of the Powell Formation in the Beetaloo sub–Basin and the Daly Waters Arch.

D

Formations in wells

Table D.1: Depths of the formation tops in the wells in Figure D.1, used for seismic interpretation. Only the formation tops relevant for this study are displayed.

Formation Tops Depth [TVD, m]	Sever 1	Tarlee 1	Tarlee 2
Base Cambrian Unconformity	-	213,8	233,16
Hayfield Mudstone	-	213,8	233,16
Jamison Sst	-	373,83	327,29
McMinn Formation	151,5	483,72	430,05
Kyalla Fm	-	655,04	569,51
Moroak Sst	-	752,6	-
Upper Velkerri Fm	331,35	795,41	664,41
Middle Velkerri Fm	637,45	1039,86	867,41
Dolerite intrusion	757,78	-	-
Middle Velkerri Fm	839,97	-	-
Lower Velkerri Fm	917,22	1293,07	1084,73
Bessie Creek Sst	1166,96	-	-
Corcoran Fm	1227,64	-	-
Total depth	1259,86	1335,5	1180

Formation Tops Depth [TVD, m]	Tarlee 3	Birdum Creek 1	Walton 2
Base Cambrian Unconformity	372,9	149,4	-
Hayfield Mudstone	-	-	-
Jamison Sst	-	149,4	-
McMinn Formation	690,5	246,65	-
Kyalla Fm	690,5	728,07	-
Moroak Sst	872,3	977,51	-
Upper Velkerri Fm	1002,2	1095,42	-
Middle Velkerri Fm	1213,1	1381,39	259,6
Dolerite intrusion	1481	1406,47	844
Middle Velkerri Fm	1546,7	1506,96	-
Lower Velkerri Fm	1596,7	-	555,5
Bessie Creek Sst	-	-	969,7
Corcoran Fm	-	-	-

Table D.1 continued from previous page

Total depth	1650,6	1929,66	1014,45

Formation Tops Depth [TVD, m]	**McManus 1**	**Altree 2**	**Kalala South 1**
Base Cambrian Unconformity	-	-	-
Hayfield Mudstone	-	-	-
Jamison Sst	-	-	-
McMinn Formation	553	-	671
Kyalla Fm	553	-	671
Moroak Sst	668	320	1102,5
Upper Velkerri Fm	738	391,72	1600
Middle Velkerri Fm	1199	672	1818,5
Dolerite intrusion	-	2133	-
Middle Velkerri Fm	-	-	-
Lower Velkerri Fm	1550	948,23	2326
Bessie Creek Sst	-	1229,65	-
Corcoran Fm	-	1647,11	-
Total depth	1617	1699,85	2376

Formation Tops Depth [TVD, m]	**Chanin 1**	**Amungee NW 1H**	**Shenandoah 1A**
Base Cambrian Unconformity	-	-	-
Hayfield Mudstone	622,4	-	-
Jamison Sst	875	-	-
McMinn Formation	948	686,5	1257,4
Kyalla Fm	948	686,5	1257,4
Moroak Sst	1328	1087	1485,3
Upper Velkerri Fm	-	1424	1968,2
Middle Velkerri Fm	-	1835,4	2238,1
Dolerite intrusion	-	-	-
Middle Velkerri Fm	-	-	-
Lower Velkerri Fm	-	2326,1	-
Bessie Creek Sst	-	-	-
Corcoran Fm	-	-	-
Total Depth	1411	2162	2482,6

Formation Tops Depth [TVD, m]	**Balmain 1**	**Mason 1**	**Jamison 1**
Base Cambrian Unconformity	-	-	-
Hayfield Mudstone	404	472,3	-
Jamison Sst	854	876,5	-
McMinn Formation	938,5	973,7	968,8
Kyalla Fm	938,5	973,7	968,8
Moroak Sst	-	-	1714,32
Upper Velkerri Fm	-	-	-
Middle Velkerri Fm	-	-	-
Dolerite intrusion	-	-	-
Middle Velkerri Fm	-	-	-

Table D.1 continued from previous page

Lower Velkerri Fm	-	-	-
Bessie Creek Sst	-	-	-
Corcoran Fm	-	-	-
Total Depth	1050	1106	1766,85

Formation Tops Depth [TVD, m]	**Shortland 1**	**Beetaloo W1**	**Elliott 1**
Base Cambrian Unconformity	-	-	-
Hayfield Mudstone	490,6	-	-
Jamison Sst	891,3	-	524
McMinn Formation	981,9	748,38	664,73
Kyalla Fm	981,9	748,38	664,73
Moroak Sst	-	1535,3	1322,28
Upper Velkerri Fm	-	1987,3	-
Middle Velkerri Fm	-	2355,95	-
Dolerite intrusion	-	-	-
Middle Velkerri Fm	-	-	-
Lower Velkerri Fm	-	2908,51	-
Bessie Creek Sst	-	-	-
Corcoran Fm	-	-	-
Total Depth	1020	2927,65	1729,2

Formation Tops Depth [TVD, m]	**Hidden Valley S2**
Base Cambrian Unconformity	305
Undifferentiated Roper Group	305
Arnold Sst	319
Mainoru Fm	440
Gibb Member	606
Limmen Sst	644
Base Roper Unconformity	774

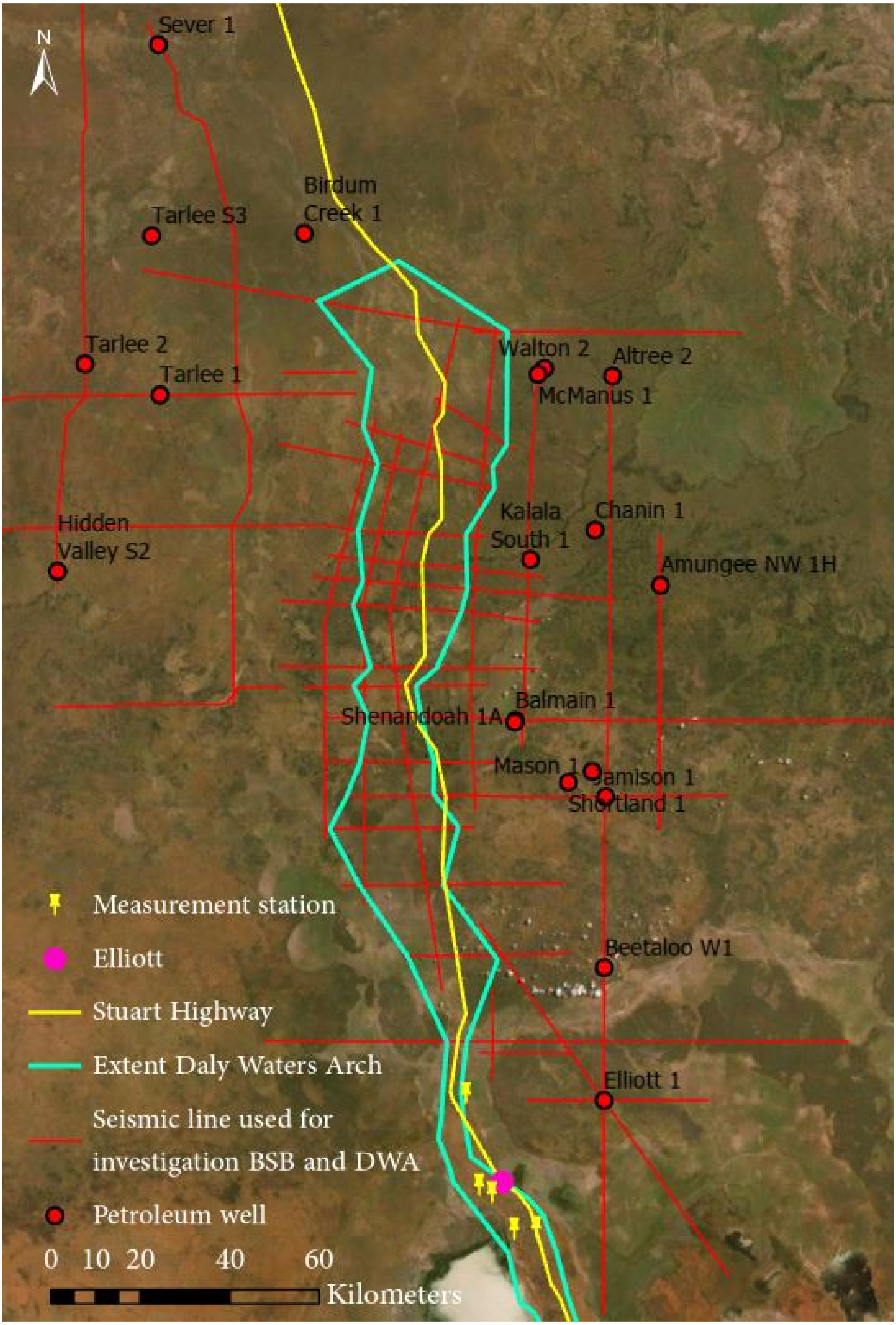


Figure D.1: Locations of the petroleum wells used for determination of formation tops in the subsurface.

E

Depth to Moho

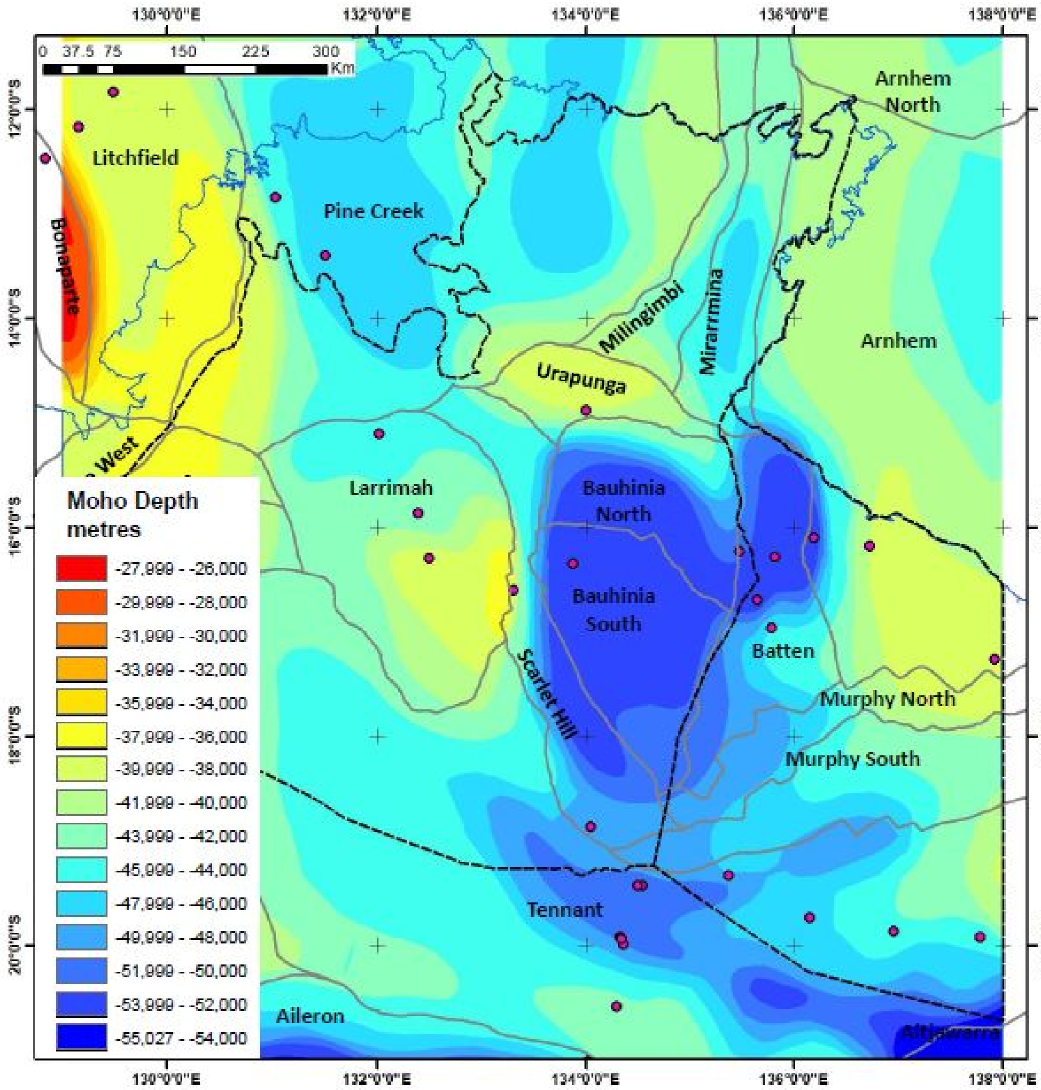


Figure E.1: In this image, the depth–to–MOHO data is overlain by the terrane boundaries in grey. The pink dots represent the control points that were used. Image from SEEBASE 2018 Frogtech Geoscience [2018].

F

Fracture pavement characteristics from drone imagery

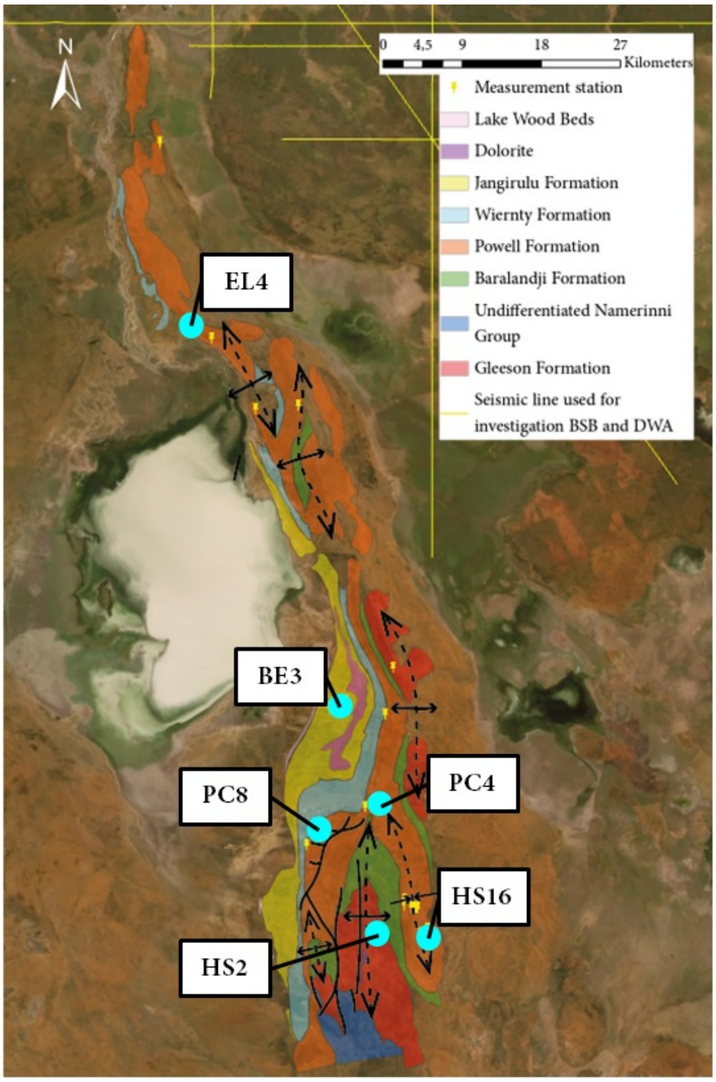


Figure F.1: Outcrops in the Tomkinson Province for which fracture characteristics have been calculated using FracPaQ software in Matlab.

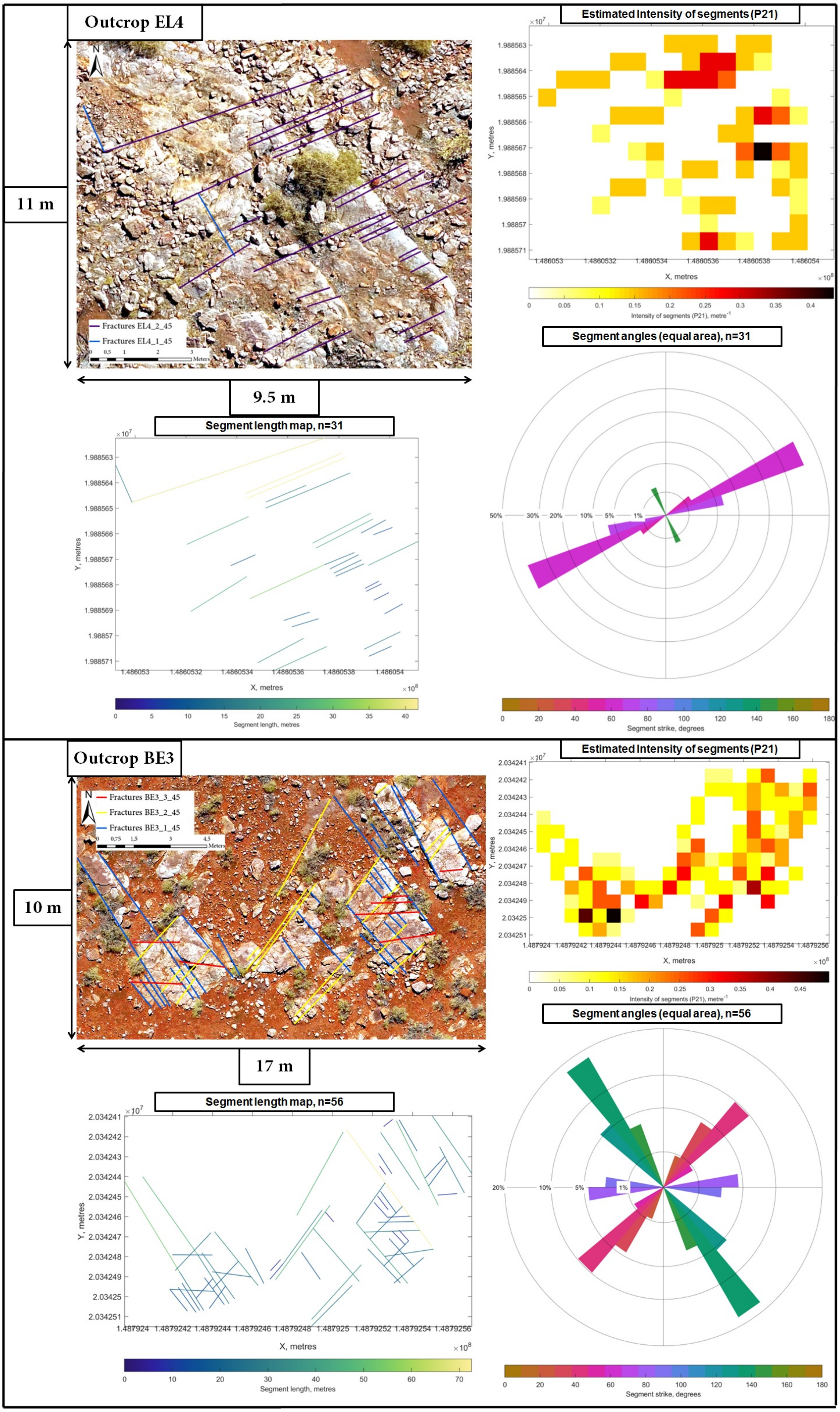


Figure F.2: Fracture characteristics calculated for fracture pavements at outcrops EL4 and BE3 in the Tomkinson Province using FracPaQ software in Matlab: top left) Drone image of the fracture pavement, including the scale of the pavement; top right) estimated intensity of the segments (P21) in m^{-1}; bottom left) fracture segments length in metres; bottom right) rose angle diagram for the strikes of the segments in degrees.

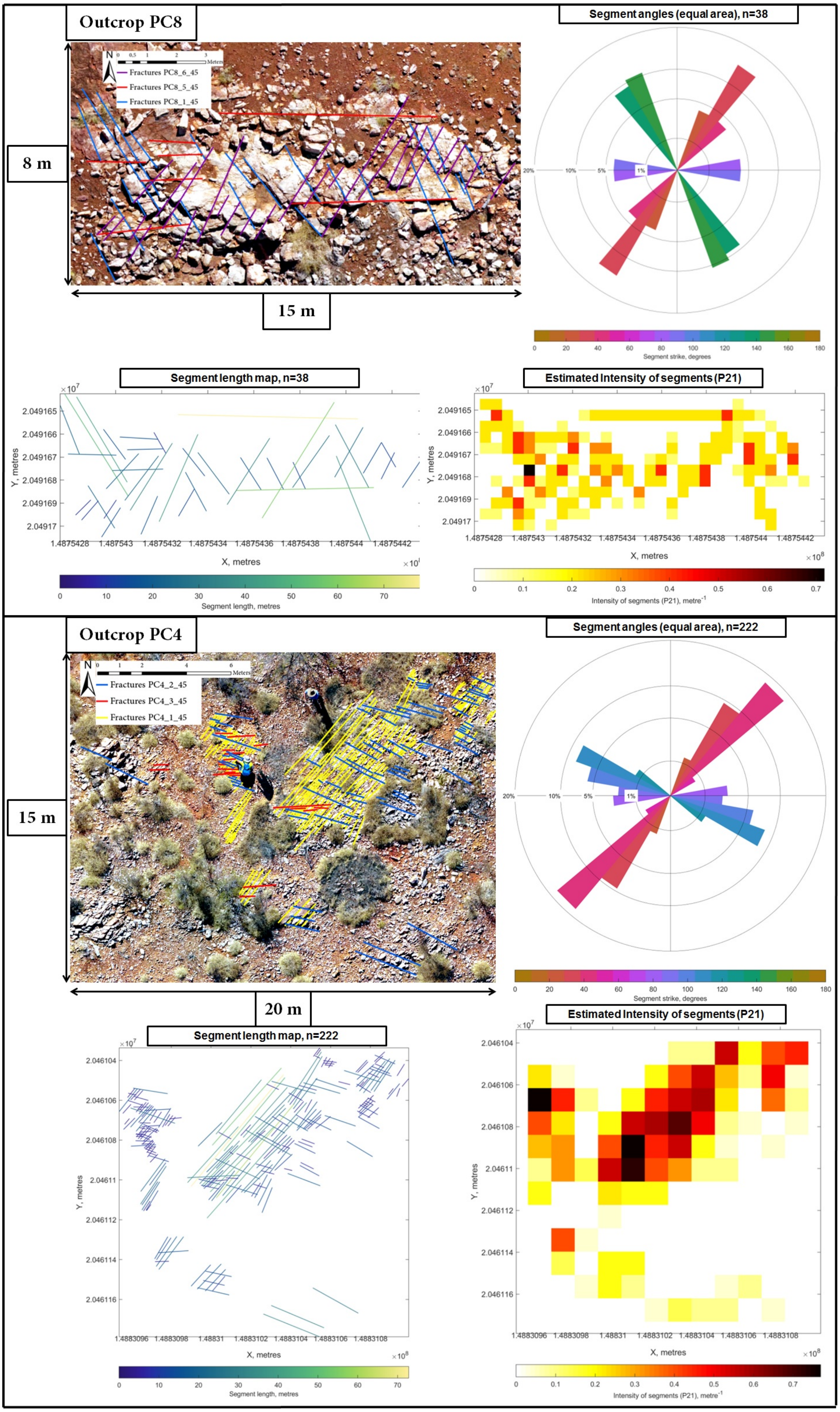


Figure F.3: Fracture characteristics calculated for fracture pavements at outcrops PC8 and PC4 in the Tomkinson Province using FracPaQ software in Matlab: top left) Drone image of the fracture pavement, including the scale of the pavement; top right) rose angle diagram for the strikes of the segments in degrees; bottom left) fracture segments length in metres; bottom right) estimated intensity of the segments (P21) in m^{-1}.

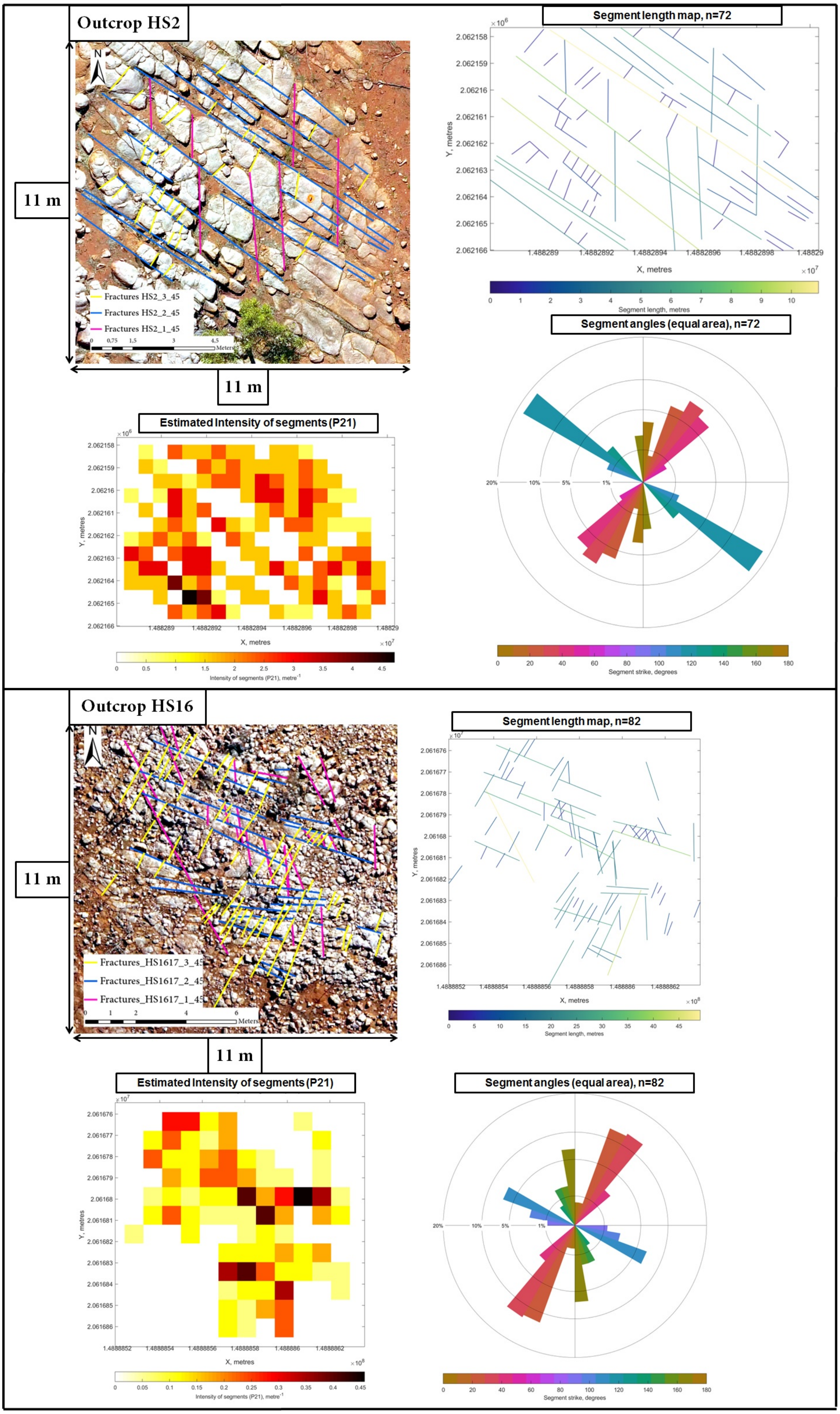


Figure F.4: Fracture characteristics calculated for fracture pavements at outcrops HS2 and HS16 in the Tomkinson Province using FracPaQ software in Matlab: top left) Drone image of the fracture pavement, including the scale of the pavement; top right) fracture segments length in metres; bottom left) estimated intensity of the segments (P21) in m^{-1}; bottom right) rose angle diagram for the strikes of the segments in degrees.

G

Interview Associate Professor Geothermal Engineering and Sciences – TU Delft **(P2)**

G.1. Interview protocol

Thursday, December 19th, 15.00-16.00h.
Faculty of Civil Engineering and Geosciences
Stevinweg 1, Delft

First of all, thank you very much for helping me with me research by answering interview questions. I explained the core of my research briefly via e–mail prior to this meeting, but I would like to explain some details now. In the recent history of gas production in The Netherlands, opposition and resistance was expressed towards the Dutch government. Resistance was expressed by strikes and a decrease in trust in the Dutch government. Currently, an energy transition takes place from economic activities based on fossil fuels towards the implementation of more sustainable energy production methods. One of these sustainable techniques is the production of geothermal energy from the Earth's subsurface to hear houses, buildings, greenhouses and maybe even for applications in the industrial sector.

This thesis project forms the final phase of a double degree MSc program, combining the two MSc projects Reservoir Geology and Science Communication. In this thesis, the following aspects will be discussed:

- Which technical aspects and uncertainties play a role in the implementation process of geothermal energy in The Netherlands?
- Are there similarities between the technical aspects and uncertainties of gas and geothermal energy production?
- Which technical aspects and uncertainties of gas production might lead to the same (negative) associations for geothermal energy production?
- How can the technical aspects and uncertainties of geothermal energy production in The Netherlands be communicated to the broader public during the decision–making processes?

Your expertise in the field of geothermal energy engineering can help me to describe the different technical aspects of geothermal energy, and provide insights in the technical uncertainties that guide this implementation process with respect to the general public. The data that is collected during this interview will only be used in my MSc thesis.

Is it okay for you if I record this interview with my mobile phone? The recorded part will be for myself only, so that I can re–play the interview when processing the data later on.

If you wish, the information retrieved from this interview can be anonymised in the report. If this is not necessary, is it okay for you if I use some of your quotes in the report? Would you like to receive a transcript of the interview? And would you like to read through the used quotes in the report before I hand it in at my supervisors and for publication of this report on the TU Delft Repository? If you change your mind after this interview has taken place, you can always send me an e–mail.

When my report is finished, I would like to send it to you. Of course, you will be very welcome to attend my thesis presentation when the research is finished. My thesis defence is scheduled for the end of March 2020.

In my research, the Dutch government is the problem owner and I will investigate the problem from the perspective of the broader public.

G.1.1. Expertise and discussion of technical aspects of geothermal energy

1. What is your scientific background and what is your experience in the field of geothermal engineering?
2. Which techniques are used to produce the water from the subsurface? Which materials and facilities are needed for the different types of geothermal energy?
3. To what extent are the techniques used for geothermal energy and gas production comparable? Is it likely that the techniques for fracking or other techniques that have a negative association will be used as a technique in geothermal energy production?
4. What are your ideas about the co–production of radioactive or chemical components during the production of geothermal energy? I have read that this risk is lower for geothermal energy, due to the rock that it is trapped in. What do you think about this?
5. Do you have ideas about the time it takes to re–heat the water that is pumped back into the reservoir?
6. Do you have ideas about the flow of water from the surrounding area? How is the pressure in the reservoir maintained to prevent compaction or subsidence?
7. In the case of deep geothermal energy, which seems to have the greatest potential for the industrial sector. Do you think this technique has potential in The Netherlands and why? Do you have ideas about how this hot water can be produced? (Difference in pressures and temperatures; steam to water?) What are the main uncertainties at this moment for deep geothermal energy production?

G.1.2. Geothermal energy as technique in the Dutch energy transition

1. How large is the potential of geothermal energy as energy source in the Dutch energy transition?
2. Who are, in your opinion, the stakeholders in the implementation process of geothermal energy in The Netherlands?

3. What is currently the technical uncertainty(-ies) or unknown(s) of the implementation of geothermal energy in The Netherlands? What are the aspects of geothermal energy production that we know the least of? For which uncertainties, more investigation is needed before implementation can take place?

4. Do you have an idea of where in The Netherlands deep geothermal energy can be or is implemented?

G.1.3. Communication around geothermal energy with the general public

1. Do you have ideas about how and when the unknown technical aspects of geothermal energy production can be communicated to a broader public?

2. What do you think can be a role for the scientists in the communication process around geothermal energy? In which communication process are you involved concerning the implementation of geothermal energy?

3. If techniques like fracking are needed to produce geothermal energy, do you have ideas about how and when these facts should be communicated?

4. Should the potential and techniques for deep geothermal energy be communicated to the broader public, or not? Why?

5. Which unknowns or uncertainties of geothermal energy might lead to opposition or a negative association in the future?

G.2. Interview transcript

For this interview, the *cursive* text is spoken by the researcher, the normal text are the words of the interviewee.

After a short introduction about myself and my research, the interview was started.

First of all, I am interested in your scientific background and your experience with geothermal engineering. Can you tell me something about that?

Not many people get trained in geothermal energy, because these things don't exist yet. I am a Civil Engineer and I did my PhD in radioactive waste disposal. This sounds different, but those are also thermal, hydraulic, mechanical processes in the ground. When you put it that way, it sounds just like geothermal energy. In general what you want to do in radioactive waste disposal, is to keep things cool. You want the heat to leave, but you also want to the water to move very slowly. Which is a bit opposite to geothermal where you want to get the heat out and you want the water typically to move fast. They are slightly different materials but the same principles and the same physics apply. So I did that for a PhD and then I moved on to more to shallow geothermal topics. Really shallow, like a hundred of meters. I worked a little bit on CO_2 sequestration. I sort of half managed or technically managed the big projects on geo–energy. I think there were 12 people working on that, and I was sort of looking after the scientific part of them. There was also underground coal gasification in South Wales, where I went to university. Big coal fields there were abundant, and we were looking at what we could do that was more environmental friendly that just digging it up. So we looked at those three things. And then I came to Delft in 2012, and did a whole lot of modelling, more on mechanics than on energy. I have been at a project here on energy piles, which is very shallow, ten's of meters, where you are combining foundations and energy transfer. And the base is basically that if you put a foundation in and you have already got a free hole in the ground, that if you put in a heat ex-changer then it is cheaper. And then, I was more involved in deep–geothermal energy.

And with deep you mean which depths?

Several kilometers. That was from about 2016, so relatively new.

Because now there are plans to drill a geothermal well in Delft?

Exactly, so I am managing the science part of that.

Because from what I read from theory is that not many people are trained in geothermal energy, and the techniques are pretty new. There are multiple types of geothermal energy production, is that true?

Correct. The thing is that there is no real definition. They have what we call 'shallow' geothermal energy, which is in The Netherlands up to 300 or 500 meters depth. That depends on who you ask about it. Another says that shallow geothermal continues to 1500 meter depth. Others say that it is really shallow, so anything in 10's to 100's of meters. All of them have a basis somewhere. The 500 meters boundary is where the Mining Law starts. Above 500 meters is for water, below the 500 meters depth there is oil and gas. Secondly, there are also different technologies. Closed–loop in shallow subsurface is most common, where water is located in soft sediments, which vary in shear strength. When you pump in water in an open–loop system, the rock starts to deform. In a closed loop, this does not happen. You seal the closed loop system, so it is safer to aquifers etc. As soon as you start going deeper, you do not get enough energy. The costs go up, so open loop is more effective then.

Deep geothermal energy is pretty new in The Netherlands, I read.

Yes, deeper than 3 km we know practically nothing. That is what they call the ultra–deep geothermal (**UDG**).

I read that UDG has the highest energy potential, but that you also have to look out for pressure differences, etc.

In the end, it depends on what temperature and pressure it is. So if you have 300 degrees under enough pressure, it is still water. But as soon as you come up with steam, it is very complicated indeed. Or you can keep the whole thing under pressure, there are a lot of opportunities.

But then you have to add pressure to it.

Well, you always have to pump.

Do you think UDG has potential for The Netherlands?

Yes, but in certain places. And it depends on what you use it for. If you look for example at the heat demand, around 75% are low temperatures, so households, greenhouses, etc. Space heating, basically. Industry have requirements for higher temperatures, but the demand is smaller. In the EBN Masterplan Geothermal they looked at the heat demand for different sectors.

When I see the images in that report, the images are in 2D as they are on paper. I am wondering if you know what happens in reality, so in 3D, behind and in front of the image? Do you know how well the subsurface around a well is monitored?

Around the well it is not, as it is very difficult to do that. We try to develop a few methods to make it more easy. As are some other people. We are proposing a electromagnetic geophysics method, where you can pick up different densities. This way you can image where the hot and cold water is. But, in general, you need to have electrodes at that level or even below and above, which is kind of expensive. TNO is proposing to do something with pulse-testing. What that is, is you basically put a pressure pulse and the speed waves travel through hot and cold water is different, so you can maybe say something about the subsurface.

A bit like seismic imaging?

Yes, it is basically seismic imaging.

You see these nice and simple images, but of course the reservoir does not look like that. There are more advanced reservoir simulation models. We are trying to develop those, where you put the realistic geology in, but then you can also look at different heterogeneities and uncertainties from logs, for example. So you take logs down from wells, and you have some more information. You see what is happening than. And then you can start to do probabilistic calculations, so you start by stating what you know, but there are lots of things you don't know. If you know some basic statistics, you then make realistic scenarios. And not just one, but maybe a hundred. They are all different, but they are all realistic. Then, you can run them all, so they are all between the boundaries of what you know and what you don't know. Then, you get more an idea of what is happening. But what is exactly true is not exactly monitored, mainly due to technical difficulties, such as the monitoring of the heat. Things like seismicity are better monitored, because it is easier.

And is that maybe also because people, especially in The Netherlands, are really keen on increased seismicity?

Yes, sure it is. And it is also easier to do. You put a seismometer somewhere near the surface, or you put it a hundred meters down because there, it is a bit quieter. The waves travel up and that's what you see. You see it immediately.

Do all types of geothermal energy production methods for the different depths use the same facilities and materials?

No. In general, the hotter you get, the deeper you get, the more equipment you need. There are higher pressures, higher temperatures, so you need different material. Now, we don't have any ultra-depth projects...

... Also not on the planning?

Well, there are seven projects, if I am correct, that are being funded by the government that start looking at UDG. So there was a Green Deal in ultra-deep geothermal, where they want to develop projects that specify what they know and what they don't know, what information they need, how to work out the different well designs, etc. I think, in the end, two or three of the most promising projects will be heavily subsidised by the government or paid for by the government to go ahead.

Money is one of the most limiting factors, I guess?

Yes, one of the tricky things always about most renewable energies, but specifically geothermal, is that all the money goes up front. All your capital costs compared to you operational costs, it is capital heavy. Whereas for a gas plant, that is not. At least, not anymore.

Is there any cooperation with gas companies or sharing of knowledge taking place?

Yes. Shell has just opened a geothermal company and the same is happening for other companies. They look at this, too. But also the service companies, like Baker Hughes, Schlumberger, etc., they are also planning their technologies to geothermal which means that the transfer of knowledge is happening. There are conferences dedicated to transferring knowledge from one to the other.

Do you have an idea of how big the risks are or ideas about the co-production of, for example, radioactive materials or chemical components?

There will be some radioactive elements but there are radioactive elements in this office as well. What will happen probably is that as you pump the water, the element will accumulate in the filters. You store them, actually. You have to be a little bit careful with that, but that are relatively standard working procedures. It depends on where you are, on what type of rock it is, etc. The more granitic, the more fractured rock types, that have a higher water content, have a higher chance of co-producing radioactive components. One of the issues with geothermal energy in The Netherlands, with the type of production that we do, is the water has quite a high gas content. That means you are co–producing gas, which is dissolved in the water. As the water is pumped up, the gas starts to come out of the water.

Which is something you do not want when you are producing hot water.

Well, it depends on your target. The greenhouse owners are delighted, because it has value. They burn the gas for extra heating or for electricity production and use the CO_2 for their crops. If they did not have this, they would have to buy CO_2, because it helps their plants grow faster. So for them, it is not a bad thing. It depends on how you operate your system, but the gas can be up to several ten's of percents of the energy of the total production. With gas, you can take out the gas and you multiply the amount of gas you get out of the ground by a constant and that is the energy you can get. With hot water, it depends how cold you can return it, so that is a bit more complicated. The more heat I can take out of the water, the more energy I get. If I can return it at 10 degrees, I would be happy.

Is there a limit to the temperature at which you can pump back the water into the reservoir? Because I can imagine that if you pump cold water into the reservoir, the rock starts to shrink and you fracture the rock. Is that a risk?

It is a possibility, whether it has a bad consequence or not. If you say risk, it is a possibility multiplied by a consequence. That is a separate thing. What you do get, is thermally induced stress changes. That can happen and it generally moves things towards the failure region. But, it does not mean it will make your rock fail.

There are possibilities to monitor that during the production phase?

In general, we don't. What we are going to try to do on the well here, is to we are going to try and put an acoustic vibro-optic cable cemented behind the casing through the reservoir. So we can actually listen to the well.

That is interesting. The well will be drilled diagonally from the campus towards the A13 highway, is that correct?

The idea is that it will start next to the heat power plant near the InHolland, and will go down and come over towards the highway.

For the shallow geothermal energy production, do you think there is any additional stimulation of the reservoir needed?

How shallow are you talking now?

Up to 4 km depth?

In general, we try to target reservoirs that do not need it. Below here, we are targeting the Delft sandstone, which has a very high permeability, considering it is at two km depth. That would be zero stimulation. You could start to stimulate areas that don't have such a good permeability. But then, you have to take your public relations into account, since you are fracking a bit.

Yes, that is where I wanted to go to. Because in 2015, the politics said 'We don't want fracking in The Netherlands for shale gas', and now there is a possibility we have to frack to come to water. I have the feeling that people are more okay with fracking for water, what do you think?

That is an interesting topic. They do frack for water now, not hot water but drinking water. That is not quite the same as fracking in shales. It is more gentle, but it is damaging the rock for more water flowing. So that is done. At least, there will be less fracking probably than... Fracking is a whole range of different techniques, and there are also other options. People talk about putting acids in the wells, to clean them and things. But if you put acids in in a certain way or even put them in under pressure and frack the rock a little bit, than you actually destroy some of the rock, without big pressure increases. Also, there is drilling, we call it laterals. That means drilling outwards to the rock, to also increase the permeability. There are lots of different ways. But if you think about a well and you think about the typical type of pressure distribution towards the well, so either an injection or production well, it is a logarithmic curve. So actually, if you damage just a bit of rock close to the well, you increase the permeability a lot. So you don't have to drill very far. Whereas often in shale gas, they have to frack more. With water, it is more continuous.

The wells for geothermal energy production are mainly vertical?

At the moment, yes. That is partly due to the value of the product. The amount of value you get from gas and from geothermal is different; for geothermal it is much, much lower.

Yesterday, I had a meeting with the head of the geothermal section of States Vision of Mines, and I asked him the same question. And he told me that for shale gas fracking, you do need a lot more fracks per well, and now I see what he meant.

Yes, shale is like a clay, so tiny permeabilities. But coming back to the temperature changes as well, there are at least concepts that seem to work to some degree, of using temperature changes to frack the rock slightly. When you inject water in the well, so you create changes in chemicals in the reservoir. You get a sort of skin, which means that it is harder to inject. In general, your injectability goes down over time. That means you either have to push harder to increase your pumping pressure, but that has limits. If you get too high, you cause a frack. And it is expensive. So what some people to to clean it, is to put some acid down and take all the stuff out. You could also potentially change the temperature, so temporally pump some hot water in and you could pump some very cold water in to crack and shift you rock. Creating some holes to move you stuff.

Do you work together with other stakeholders in this process?

A bit. We are not a real geothermal advocate. We want to find out how to do it the best, how to develop techniques. And if it is a good idea, someone else needs to apply it. So we are not like, in big clubs or with operators and things. We are a member of the Platform Geothermie. We also work on projects with EBN and other people.

And with 'we' you mean the section?

Yes, the university has a group here. And we also work with other people as well, it is a relatively practical scientific subject, so we often work with companies.

I think there is a lot of need for it, so people want to work with you?

Yes, that is true. So we do work together with lots of people. That is still a bit tricky, in communication as well. Because sometimes, it appears as if you work for big companies.

Yes, I recognise that from this research. Everyone has a bias, and I try to look objectively as much as possible. Sometimes it is hard to separate the risks from the techniques.

Yes, there are some big risks. You have not mentioned the seismicity too much, but for me, it is one of the most interesting science communication things about geothermal. Because it will cause seismicity.

On the same scale as gas production?

No, we think absolutely not. We think it will be several magnitudes lower. There are some significant differences and the main one is that the water that you pump out, you pump back in. Whereas in gas, they take it out and they do not replace it with anything. So that means your stresses take changes completely. So instead of having gas holding the reservoir up, you get a reservoir holding the reservoir up. So it ends up with much more stress.

Is that always true for geothermal energy? Is it always a closed circle?

It does not have to be.

And I can imagine that if you pump colder water back into your reservoir, it has a different density. Does that change anything?

The density is not that different. Only a few percents. That does not cause a risk. You cause a slightly different pressure, as you have a pressure gradient. You push the pressure in through one, and decrease it in the other, so the water flows. But it is nowhere near the amount that you would with say Groningen, for example.

Since your reservoir is open, it is in connection to other layers, probably. Is there also a risk of materials flowing back into your reservoir while you are still pumping up and have not put anything back?

When you start, the quantities of water that you have outside the reservoir are almost zero, compared to the amount of water that is in the reservoir. So you have got to have a buffer tank, but that can also be filled with something beforehand. So the amount of water that goes into the actual well itself is the difference, which is almost zero.

Geothermal projects are located closer to the Randstad, for example. Is the seismicity a big risk in that sense?

Well, oil and gas projects have also taken place here. Pijnacker for example, a big oil field. And Berkel. So yes, it could be closer. I would say the bigger risk, from personal point of view, is you have to distribute the heat. You have a hot water network, and that will leak occasionally. As any water network would. Then you get hot water coming out and not cold water. I would say that is a far bigger risk. There are lots of heat notworks operating. So it is not that it is new or over-risky in that sense. The temperatures are not like in New York, where you have steam pipes. It is liquid water, but still, it is not something you would want to have on your skin when walking through the city.

Because that network would be under the surface?

Yes. More or less, you can consider it as replacing the gas network. Or being next to the gas network, just a next pipe in the road.

In geothermal, you have to produce very close to where the heat demand is, right?

Well, moderately close. I think that might change. But it is not a very easy question. So for example, there is a lot of waste heat here in Rotterdam. They talk about piping it to Leiden, some ten's of km away, with about 2 to 3 percents of heat losses. That is rather small. It all depends on the size of the pipe. Most of the losses is really getting it from where the heat network finishes to the individual houses, because your pipes become much smaller. For the bigger pipes, it is not so much of an issue.

More for the communication part. In the end, I want to come up with some kind of advice for the Dutch Ministry of Economic Affairs an Climate Policy. Say, for example, worst case scenario: Some journalist from a newspaper who does not know anything about geothermal attends a meeting and hears the word fracking combined with geothermal energy. He thinks 'Okay, that is not something we want', and writes an article about it. If people start to worry then, do you think there is a way to anticipate on that in advance? And do you have ideas about how we can do that? When do we have to start communicating about the uncertainties that are still present in the geothermal energy production?

I would say, there is one step before. Which is the natural induced seismicity. If you talk about fracking, which is than really induced seismicity, then actually the one thing before is the standard seismicity that might occur when you change stresses. And it will occur, we should say. But the level at which it will occur is very small, we think. The science is relatively well-known of what causes it, so then actually we are pretty confident that it will be relatively small.

And with 'relative' you mean the frequency of small earthquakes happening, or the magnitudes at which these happen?

The magnitude, that would be very small.

So nothing compared to Groningen, for example?

No, nowhere near. Like several magnitudes lower. The biggest one in Groningen was 3.6, I believe. And I don't think almost any have been measured in geothermal projects in The Netherlands. It depends a bit on where you are. So the West Netherlands Basin ones, which have flow through the rock matrix and not fractured flow, it more or less means that the magnitudes will be below 1 or something. So with the instruments that the KNMI has, they are not even noticeable.

That says something as well.

Yes, one of our colleagues has done some extra monitoring, where they put 35 geo–phones around one project. So what you can then do, is to stack information. They measured, I think, one as 0.16. It is really hard to measure.

And even harder to feel as a person.

Yes, that is really impossible. Anything below 2, you can not feel. Unless you really expect it.

Then, the interesting thing which I am always curious about, is that this is something we know as scientists.

Yes, I think that is really, really difficult.

When do you have to inform people or when do you have to say nothing? That is a delicate balance, especially here in Holland, where activities are going to take place in people's backyards.

Yes, and there is this whole thing that it is not really your choice. If we drill a well here, it is gonna go over there. It is under lots of peoples property that is not ours.

Who's property is it? The state?

The underground? In the end, the state. You have to apply for a license.

Are you currently involved in those communication processes, with the state?

Not those. So I am a bit involved in the communication process then with our well. Of course, we are doing science, we are having it for heating and things like that. And we have a whole series of people that meet together. Because it is important to the university, to the companies involved, to science, so there is a lot of action on that. And there is also, let's say, annoyance of people that live close to the location. Drilling is also a little bit noisy. The problem with drilling is, of course, is that it will go on for 24 hours a day. Then, you have to insulate it so that people will not hear it.

Did you already start the process of informing people about that well in a more structured way?

People know about the well. It has been in the Delft Integral, it has been on the website, people have been sort of contacted that there will be a well. The specifics of there is gonna be a drill rig there, making an X amount of noise, how comfortable are you with that, has not yet began. And someone is being employed from February next year.

Employed by the university?

Yes.

That would be an interesting task.

Yes, I think that most students would be supportive. And so there are lots of students that live on the campus, and I think the fact that it is gonna be the energy source and that it is low–carbon, it is going to be a big research project, it is important for Delft to do it, and it puts Delft on a map, then it has quite a lot of positive push to it, which generally puts the negative things a bit further down. But we have to, of course, do that. I think some of the other researchers that have some vibrations will not be that happy. But of course, there is also the wind tunnel and things that makes some noise. But that does not run for 24 hours a day.

Do you know if the person that is going to do the communication around that process is already available for an interview?

I don't know, but there are two persons that you could talk to. One is the TU Delft program coordinator, that is trying to link all the different parts of geothermal at the TU Delft together. The second one is the head of corporate communication. We had a session with her just the other day, to talk about how we will frame this in the next kind of steps.

Do you have ideas about that?

Yes, I think the positives for the TU Delft and the surrounding area are really quite high. So I think, I mean, I don't think it is going to be too difficult in this case. The time that it is sort of annoying is quite short. We do have to do things, but I have the impression we don't have to do that much.

Because if you drill the well, it can produce for more than ten's of years?

Yes, for thirty maybe. But actually in production, do don't hear it, you don't see it.

I am also planning to visit one of the greenhouses near Delft, Ammerlaan, where geothermal energy is produced.

That is interesting, because Ammerlaan was one of the first ones to drill a well and of course, he is not a well designer. So in the end, he had some problems with his well, and he had to re–drill it. Re–drilling it, they had some problems.

I heard, during the interview at States Vision of Mines, that because of knowledge lacks from, for example people that run the greenhouses who want to drill a geothermal well, they often don't have the knowledge to know what they have to do.

When you talk to the greenhouse owner now, he probably has the most knowledge of anyone. I mean, he is a businessman. Growing flowers and other plants is technical so they are smart, technical people. But of course, the things you have from experience, they did not have. So some mistakes were made.

In terms of drilling, if you lived in Pijnacker, could you hear the drilling?

No, I don't think so. Haven't heard anything.

So, in conclusion. What do you think, if there would be one or two or three things that you would have to investigate more in geothermal energy?

I think induced seismicity is by far the biggest. I think people are afraid of Groningen, and I think there is some work to be done. So I think that is by far the biggest. The second is, if we really upscale geothermal wells, and of course in urban area, in the drilling period, there will be a whole bunch of annoyances. The rig is working 24 hours a day, it might cause some noise and vibrations, people see it, you have to bring materials to the site. Trucks, etc. To people, that would be a local issue for a relatively short period of time, for several months. And I think only then, other things might become an issue. Things like ÜDG or fracking, I think they are relatively longer-term issues.

And with longer terms you mean..?

I think the first projects might go ahead in, let's say, 3 to 5 and 10 years.

Yes, that is longer terms, but not like very far into the future. No, but those would be test projects, and then it might be another 5 to 10 years before another project is ahead. And then there might be some more issues, which I think is not really communication, but of how to split up the resource. So how do you get licences, etc. And of course there is the gas coming up, which is a technical problem. But it is also a political problem, because you are generating gas and it is a fossil fuel. So the very purist people that say 'zero-carbon', it does not satisfy them. You can of course pump it back into the ground.

Can you use your injection well for that?

Yes.

Or you can grow your own flowers and make a greenhouse.

We are considering two different things. One is we have a combined heat and power plant, so we might use some of the gas there. So instead getting gas from the grid, we use our own gas. So it is kind of a replacement, rather than new gas. Or the second thing is feeding it into the grid. So changing the gas composition to match the gas that you get of the gas grid, and put it in there. Then someone else will burn it, what actually is happening is that you are not importing that gas from Russia, for example.

In my research, I am trying to make a combination on certain aspects between geothermal energy and gas production. And the facilities are comparable, but not the same. I mean, the idea is the same, but the materials and facilities and ways of production are different, right?

Yes.

Next Monday, I have a meeting with someone from the ministry who is responsible for the policy and communication around gas production from small gas fields. We have Groningen, but that will be closed. Holland can not be without gas, so we still need the gas from smaller gas fields until we have other energy sources.

I wonder if they have geothermal as a gas source in mind. I suspect it has not been a major consideration for them.

Are there major differences or similarities in facilities and pumping methods between gas and geothermal production?

Gas, you don't really have to pump up. It just comes up. You don't have an injection well typically in gas production. Sometimes you do put water in a gas reservoir to enhance the recovery types. You have to separate water and gas. Because the gas well also has water in it. And water wells have gas in it.

If you have drilled your geothermal well, is it still visible as a well then at the surface?

The pump is in the ground, situated at around 800 meters depth. What you see above ground are some pipes and the typical type of Christmas tree, comparable to what you see at a gas production location. If you look up 'geothermal power plant' or anything, you get electricity plants, which have cooling towers and things, which are fairly different. Look for 'geothermal well' or anything. At the surface, some pipes will go into a building. Our pipes will go into the already existing power plant and then, there is a buffer tank. That means you can produce constantly during the day, and fill it at different times. First, it will go through a filter, then probably a gas separator, then basically a heat ex-changer, then another filter, and then it goes back into the ground. The heat ex-changers are 4 to 5 meters big, and the biggest structure you need. So nothing that you can not hide in a building.

Last question: Are there ideas about how long it takes for the cold water of how long it takes to be re–heated again?

Yes, the very short answer is: Much longer than your operational period. After a while, your reservoir is cold and then you should complete the project. Because if you wait for it to warm up again, it will be several hundred years, probably. So it is a conduction process, whereas in the heat ex-changer it is advection. Conduction takes a long time, since it depends on the conductivity. You could do two things. You could continue to operate it, since it is warmed up a little bit. For some applications, that is fine if there is a lower heat demand. Or you drill deeper, which I think is not reasonable since your well is all finished and completed and everything. Or you say the project is finished.

Do you also have geologists working on this project? Yes, we do.

In the concluding part of the interview, P2 provided some extra names that can be contacted for an interview at EBN (Head of Geothermal), Platform Geothermie, ENECO and Hydreco.

H

Semi–open coding – Code trees

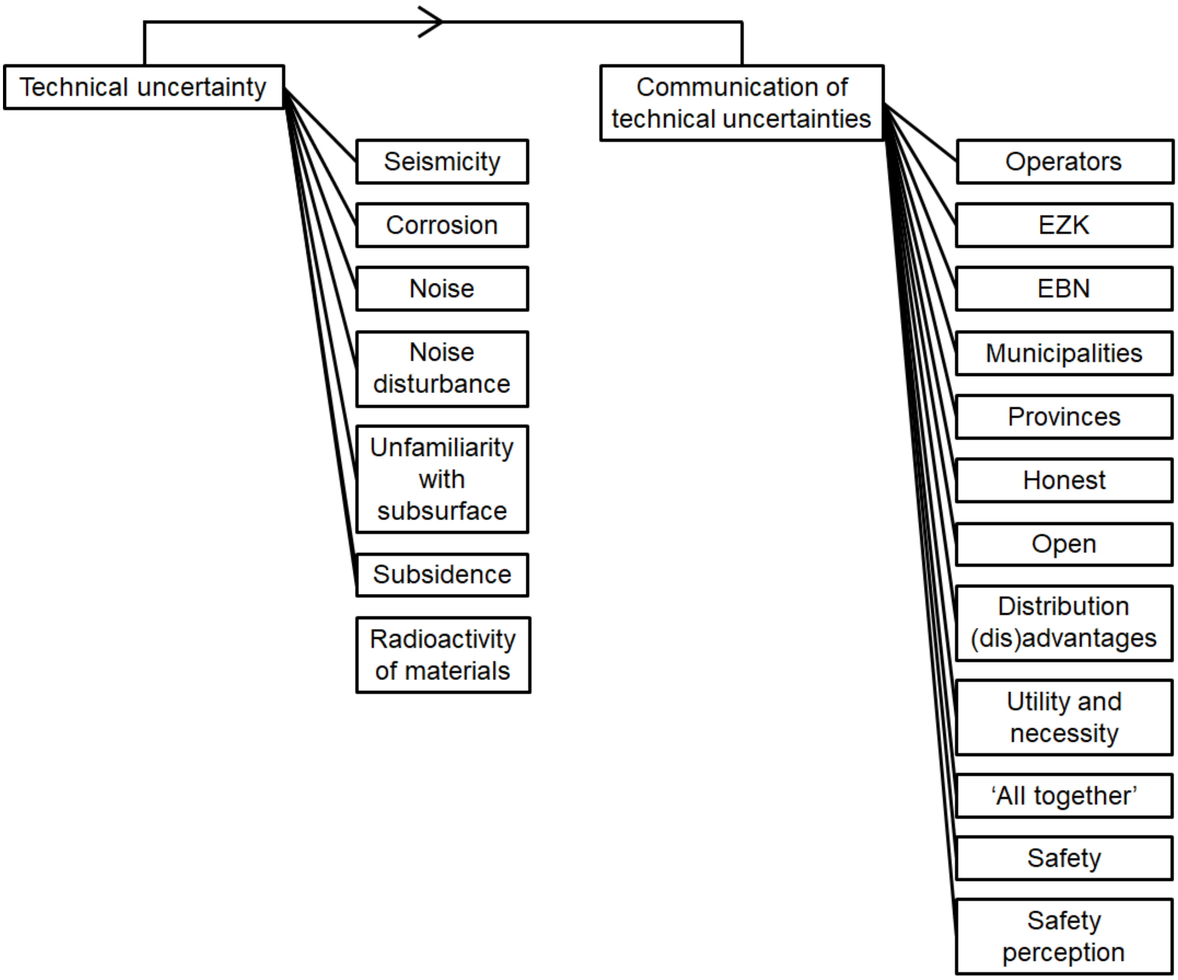


Figure H.1: Code tree obtained from interviews that was used as a starting point for the semi–open coding process.

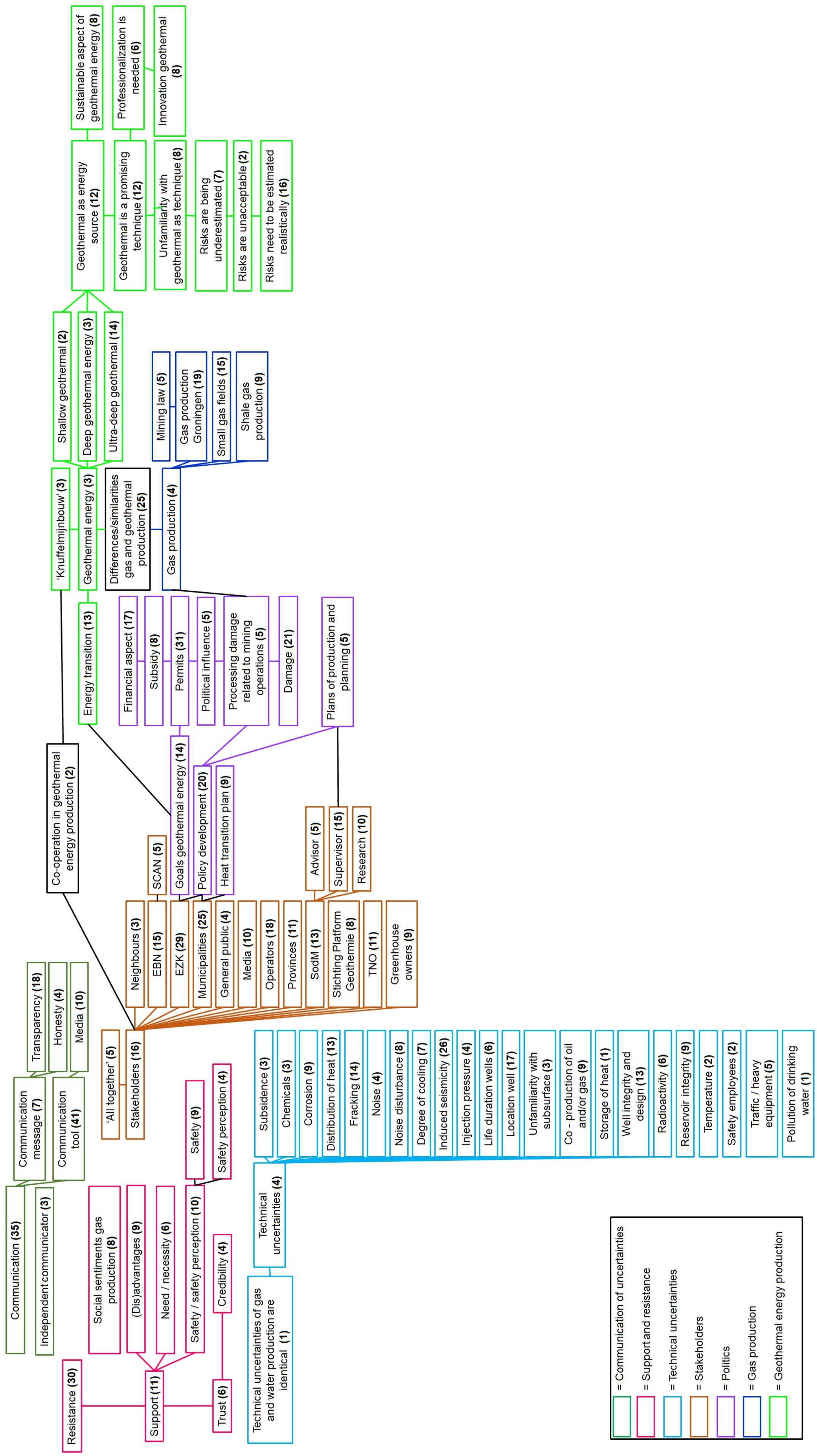


Figure H.2: Code tree that was finally used to doe the interviews. In **bold**, it is displayed how much a code was used in an interview. =

I

Public resistance to shale gas production in the Netherlands

SHALE gas is no longer an option for the energy mix in the Netherlands [Ministerie van Infrastructuur en Waterstaat, Ministerie van Economische Zaken en Klimaat, 2018]. Besides the production costs [CE Delft, 2015] – which are higher than the costs of producing conventional gas – and the possible effects on the environment, civil unrest was one of the reasons for the Dutch government to put a stop on all shale gas exploration activities in the Netherlands [Rijksoverheid].

Over the last decade, a debate about the production of shale gas has taken place in the Netherlands. In October 2009, the Dutch division of the British gas company Cuadrilla Resources Holding Limited (**Cuadrilla**) received a temporary exploration permit from the Dutch government [De Vries *et al.*, 2013], to explore the shale gas potential of the Dutch province of Noord–Brabant. The permission for these exploration activities was checked and approved by the Dutch organisations of TNO, 'State Supervision of Mines' (SodM) and the Mijnraad, which are all authorities that have a supervising or research function concerning mining activities. In 2010 and 2011, the opposition started to group itself from the populations of the communities of Haaren and Boxtel – the two communities that were assigned for the gas exploration activities. Later, a provincial environmental NGO and the environmental NGO of 'Milieudefensie' joined the opposition [Cuppen *et al.*, 2019]. The concerns that were announced were probably influenced by negative stories about the pollution to drinking water due to shale gas production in the United States and earthquakes induced by shale gas activities in the United Kingdom [De Vries *et al.*, 2013; Whitton *et al.*, 2017]. Also, the documentary 'Gasland' on the impact of shale gas exploration and production in the US (broadcasted in 2010) probably played a role in triggering public debate [Cuppen *et al.*, 2019]. A regional newspaper used the Dutch law to get public access to government information to find out which chemicals were used in fracking the rock. A Dutch bank filed an official complaint, arguing that tremors caused by the shale gas explorations could damage their nearby located data centre [Cuppen *et al.*, 2019]. A water company was worried about the quality of drinking water concerning the potential risk of aquifer contamination. This commotion alarmed the local and regional authorities and governments. Following the increasing resistance by the opposition and the growing concerns of local governments, the Dutch Minister of Economic Affairs and Climate Policy announced a moratorium on the exploration activities and promised not to allow exploration drills until the safety and security of the activities for the local people could be guaranteed.

In the document 'Structuurvisie Ondergrond' [Ministerie van Infrastructuur en Waterstaat, Ministerie van Economische Zaken en Klimaat, 2018], the Dutch government announced that the exploration and production of shale gas will be excluded from the areas that are covered in the report, which was practically all onshore and offshore areas of the Netherlands. So for the future, shale gas will not play a role in the Dutch energy mix.

J

Additional information and example questions communication approach

THIS appendix provides additional information and example questions that add to the communication approach as presented in Chapter 12. For each step in the communication approach, questions are listed that illustrate how the communication process can be started by the communicating parties. These question will need to be asked by the senders and the receivers themselves; there is no external communicator present in the conversation. The outcomes of these questions will need to be analysed and interpreted, but the outcomes of these questions and the actions they imply, were not in the scope of this research. The example questions or communication methods are all listed in a box. Questions that the initiators can ask themselves are boxed in dark blue, questions that can be posed by the public are boxed in red. Questions that the initiators and the public should ask both or together are boxed in purple.

J.1. Context and situation description

1. Regarding the stakeholders involved:
    - Which stakeholder groups are involved in the communication process?
    - Which of these stakeholder groups are the initiators of the geothermal project that will act in the communication process, and who of the local audience will perform as communicating actor?
    - Are there other stakeholder groups involved in the communication process? What is their role in the conversation and how are they addressed?
    - Which stakeholder group is responsible of the communication process?
    - Are communication experts involved or policy experts only?

2. Regarding the location of the communication process:
    - Where does the communication process take place?
    - Is the location the same for all different steps of the communication process?
    - Does each stakeholder group physically attend the conversation if meetings are organised?
    - How are the different communicating actors spatially divided over the room?

3. Regarding the link to the technical planning:
    - What does the technical timeline of the project look like?
    - Is there communication between the stakeholders of the technical process and the communication process?
    - At which stage of the technical planning will the communication process take place?

J.2. The sender and the receiver and their reference frame in the communication approach

To identify the level of knowledge of the initiators of a geothermal project, the following example questions can be asked amongst the initiators during the communication process:

- What is the economic and technical potential for geothermal energy implementation in this area?
- Which goals for geothermal energy production need to be met in this area?
- What are the technical uncertainties that are present in geothermal energy implementation? How were they classified/discovered?
- What is the interest for each stakeholder group in geothermal energy implementation?
- Where, when and how do the stakeholder groups find relevant information?
- Do all stakeholder groups have access to the information that is needed?
- Is the subsurface in the area used for other activities than geothermal energy production?
- What does the subsurface physically look like?

Example questions to determine the level of knowledge of the local public, are:

- To what extent does the public have access to relevant information?
- Which experience does the public have with mining operations in the area?
- Which experience does the public have with the other stakeholder groups that are involved in the communication process?
- To what extent did the public already form an opinion about the geothermal project? How was this opinion constructed?
- What is the pre–existing knowledge about the social perspective around gas production from Groningen, and, if present, what is the influence of this on the public acceptance on geothermal energy production?
- Does the public trust the sources of information that are used in the communication process?
- Which feelings / social sentiments are present amongst the local public?

To define the level of control of the initiators, the following questions can be answered:

- Do all stakeholder groups have an equal voice in the communication process?
- Which stakeholder group is in control of each part of the geothermal project?
- Is the to–be–communicated message more beneficial for one of the initiators?

Example questions that can be asked to determine the level of control of the local public are:

- To what extent is the public able to control its role in the process of geothermal energy production?
- How is the public able to make its own decisions during the process of geothermal energy implementation?
- How is the public able to express concerns, ideas, questions, etc. during the geothermal project?
- How can the public control the extent to which the communicator understands their message?
- What information sources does the public need to maintain a certain level of control?

Example questions to determine the base level of social acceptance by the public, are:

- What is the current level of social acceptance of geothermal energy implementation of the local public?
- How was this level of social acceptance obtained?
- How was this level of social acceptance investigated?
- Which of the three values of social acceptance has the most impact on the level of social acceptance in this case? Safety / safety perception, distribution advantages / disadvantages or utility / necessity?
- Which technical uncertainties influence the level of social acceptance positively? And which negatively? How was this difference investigated?
- How will the technical uncertainties be addressed? By who?

Bibliography

M. Ahmad and T.J. (compilers) Munson. Tomkinson Province. *Geology and mineral resources of the Northern Territory*, 1(5):16:1–16:27, 06 2013a.

M. Ahmad and T.J. (compilers) Munson. McArthur Basin. *Geology and mineral resources of the Northern Territory*, 1(5):15:1–15:72, 06 2013b.

M. Ahmad, J.N. Dunster, and T.J. Munson. The Stratigraphic Architecture, distribution and hydrocarbon potential of the organic rich Kyalla and Velkerri shales of the Upper Roper Group. *Geology and mineral resources of the Northern Territory*, 15(5):1–3, 2013.

Algemeen Handelsblad. Aardgas bij Groningen aangetroffen, 1955. URL `https://www.delpher.nl/nl/kranten/view?query=aardgas+groningen&facets%5Bperiode%5D%5B%5D=1%7C20e_eeuw%7C1950-1959%7C&facets%5Btype%5D%5B%5D=artikel&facets%5Bspatial%5D%5B%5D=Landelijk&page=1&coll=ddd&identifier=KBNRC01:000041637:mpeg21:a0020&resultsidentifier=KBNRC01:000041637:mpeg21:a0020`.

B. Amadei, W.Z. Savage, and H.S. Swolfs. Gravitational Stresses in Anisotropic Rock Masses. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, 24(1):5–14, 02 1987. doi: https://doi.org/10.1016/0148-9062(87)91227-7.

N.H. Anderson. Integration theory and attitude change. *Psychological Review*, 78(3):171–206, 1971. doi: https://doi.org/10.1037/h0030834.

M. Asif and T. Muneer. Energy supply, its demand and security issues for developed and emerging economies. *Renewable and Sustainable Energy Reviews*, 11(7):1388–1413, 03 2007.

Australian Bureau of Statistics. Consensus 2016 quickstats, 2016. URL `https://quickstats.censusdata.abs.gov.au/census_services/getproduct/census/2016/quickstat/1`.

Australian Bureau of Statistics. Estimates of aboriginal and torres strait islander australians, 2018. URL `https://www.abs.gov.au/ausstats/abs@.nsf/mf/3238.0.55.001`.

A. Baghbanan and L. Jing. Hydraulic properties of fractured rock masses with correlated fracture length and aperture. *International Journal of Rock Mechanics and Mining Sciences*, 44(5):704–719, 2007. doi: https://doi.org/10.1016/j.ijrmms.2006.11.001.

M.M. Bakema, C. Parra, and P. McCann. Analyzing the Social Lead-Up to a Human-Induced Disaster: The Gas Extraction-Earthquake Nexus in Groningen, The Netherlands. *Sustainability*, 10(10).

I.E. Bal, E. Smyrou, and E. Bulder. Liability and damage claim issues in induced earthquakes: Case of Groningen. *SECED - UK National Conference on Earthquake Engineering*, 1(1):1–10, 2019.

J. Bardon. Fracking exploration in nt to begin in 'coming days, if not weeks', 2019. URL `https://www.abc.net.au/news/2019-06-12/nt-fracking-exploration-could-begin-within-days-gas-wells/11204340`.

A.K. Baronas and M.R. Louis. Restoring a Sense of Control During Implementation: How User Involvement Leads to System Acceptance. *MIS Quarterly*, 12(1):111–124, 1988. doi: https://doi.org/10.2307/248811.

P. Betts, R. Armit, and L. Ailleres. Unravelling the McArthur Basin fault architecture and comparisons with the Mount Isa terrane. *PGN Geoscience Report 1/2014*, 1(1), 2015a.

P. Betts, R. Armit, and L. Ailleres. Potential-field interpretation mapping of the greater McArthur Basin. *PGN Geoscience Report 15/2014*, 15(1), 2015b.

K. Bisdom. Burial-related fracturing in sub-horizontal and folded reservoirs: Geometry, geomechanics and impact on permeability, 2016.

T.N. Blaikie, P.G. Betts, R.J. Armit, and L. Ailleres. The ca. 1740–1710 Ma Leichhardt Event: Inversion of a continental rift and revision of the tectonic evolution of the North Australian Craton. *Pre–Cambrian Research*, 292(1):75–92, 02 2017. doi: http://dx.doi.org/10.1016/j.precamres.2017.02.003.

D.H. Blake and R.W. Page. The Proterozoic Davenport Province, Central Australia: Regional Geology and Geochronology. *Precambrian Research*, 40–41(1):329–340, 1988.

P. Bordia, E. Hunt, N. Paulsen, D. Tourish, and N. DiFonzo. Uncertainty during organizational change: Is it all about control? *European Journal of Work and Organizational Psychology*, 13(3):345–365, 2007. doi: https://doi.org/10.1080/13594320444000128.

B. Bourbiaux, R. Basquet, M.C. Cacas, J.M. Daniel, and S. Sarda. An Integrated Workflow to Account for Multi-Scale Fractures in Reservoir Simulation Models: Implementation and Benefits. *Abu Dhabi International Petroleum Exhibition and Conference*, 10(1), 10 2002.

T.A.P. Boxem, J.G. Veldkamp, J.D.A.M. Van Wees, and *TNO*. Ultra–diepe geothermie: Overzicht, inzicht & to–do ondergrond, 2016.

D.E. Brashers. Communication and Uncertainty Management. *Journal of Communication*, 51(3):477–497, 2001. doi: https://doi.org/10.1111/j.1460-2466.2001.tb02892.x.

J. Breunese, H. Mijnlieff, and J. Lutgert. The life cycle of the Netherlands' natural gas exploration: 40 years after Groningen, where are we now? *Geological Society London, Petroleum Geology Conference Series*, 6(1):69–75, 2005. doi: https://doi.org/10.1144/0060069.

P.O. Bruna, T. Dhu, D. Revie, B. Smith, B. Lewis, and D. Close. The greater McArthur Basin 3D modelling project: Updates, developments and steps towards the future. *Annual Geoscience Exploration Seminar (AGES)*, AGES(2016):79–83, 2016.

P. Burnard. A method of analysing interview transcripts in qualitative research . *Nurse Education Today*, 11(1):461–466, 1991.

L. Byrnes, C. Brown, J. Foster, and L. Wagner. Australian renewable energy policy: Barriers and challenges. *Renewable Energy*, 60(1):711–721, 2013. doi: https://doi.org/10.1016/j.renene.2013.06.024.

P.A. Cawood and R.J. Korsch. Assembling Australia: Proterozoic building of a continent. *Precambrian Research*, 166(1):1–38, 2008. doi: https://doi.org/10.1016/j.precamres.2008.08.006.

CE Delft. Schaliegas in Nederland – Verkenning van de maatschappelijke effecten, 2015.

Centraal Bureau voor de Statistiek. Hernieuwbare energie in Nederland, 2013, 2014.

Centraal Bureau voor de Statistiek. Gemeentelijke indeling ongewijzigd in 2020, 2019. URL https://www.cbs.nl/nl-nl/nieuws/2019/53/gemeentelijke-indeling-ongewijzigd-in-2020.

Central Land Council. The history of the land rights act. URL https://www.clc.org.au/articles/info/the-history-of-the-land-rights-act/.

D.J. Clark, B.J. Hensen, and P.D. Kinny. Geochronological constraints for a two-stage history of the Albany–Fraser Orogen, Western Australia. *Precambrian Research*, 102(3/4), 2000.

D.I. Close, E.T. Baruch, C.M. Altmann, A.J. Cote, F.M. Mohinudeen, B. Richards, and S. Stonier. Unconventional gas potential in Proterozoic source rocks: Exploring the Beetaloo Sub-basin. *Annual Geoscience Exploration Seminar (AGES)*, AGES(2016):91–94, 2016.

A. Correljé and G.. Verbong. Transition from coal to gas: radical change of the Dutch gas system, 2004.

J.W. Cosgrove. The association of folds and fractures and the link between folding, fracturing and fluid flow during the evolution of a fold–thrust belt: a brief review. *Geological Society London Special Publications*, 421(1), 05 2015.

L. Cox. 'not safe, not wanted': is the end of nt fracking ban a taste of things to come?, 2018. URL https://www.theguardian.com/environment/2018/jun/18/not-safe-not-wanted-is-the-end-of-nt-fracking-ban-a-taste-of-things-to-come.

E. Cuppen, U. Pesch, S. Remmerswaal, and M. Taanman. Normative diversity, conflict and transition: Shale gas in the Netherlands. *Technological Forecasting and Social Change*, 145(1):165–175, 2019. doi: https://doi.org/10.1016/j.techfore.2016.11.004.

J. De Joode. De rol van gas in de Nederlandse energiehuishouding op de korte en lange termijn. *TPEdigitaal*, 9(2):79–91, 2015. doi: https://doi.org/10.1016/j.enpol.2012.04.010.

De Telegraaf. Aardgas gevonden bij boring in Slochteren, 1959. URL https://www.delpher.nl/nl/kranten/view?query=aardgas+groningen+&coll=ddd&page=1&facets%5Bperiode%5D%5B%5D=2%7C20e_eeuw%7C1950-1959%7C1959%7C&identifier=ddd:010615390:mpeg21:a0079&resultsidentifier=ddd:010615390:mpeg21:a0079.

De Telegraaf. Asser geograaf wijt aardbeving aan gaswinning, 1986. URL https://www.delpher.nl/nl/kranten/view?query=aardgas+groningen+van+der+sluis&coll=ddd&identifier=ddd:011207389:mpeg21:a0191&resultsidentifier=ddd:011207389:mpeg21:a0191.

A. De Vries, R. Van Est, and A. Van Waes. Samen winnen; Verbreding van schaliegasdiscussie en handvatten voor besluitvorming, 2013.

S.T. De Vries, L.L. Pryer, and N. Fry. Evolution of Neoarchaean and Proterozoic basins of Australia. *Precambrian Research*, 166(1–4):39–53, 2008. doi: https://doi.org/10.1016/j.precamres.2008.01.005.

A. Demirbas. Global Renewable Energy Projections. *Energy Sources, Part B: Economics, Planning and Policy*, 4(2), 2009.

J. Dirven, J. Rotmans, and A.P. Verkaik. Samenleving in transitie: Een vernieuwend gezichtspunt, 2002.

R. Domenech and A. Melguizo. Projecting Pension Expenditure in Spain: On Uncertainty, Communication and Transparency. *SSRN*, 1(1):707–730, 2008. doi: http://dx.doi.org/10.2139/ssrn.1997271.

A.M. Dowd, N. Boughen, P. Ashworth, and S. Carr-Cornish. Geothermal technology in Australia: Investigating social acceptance. *Energy Policy*, 39(10):6301–6307, 2011. doi: https://doi.org/10.1016/j.enpol.2011.07.029.

I.R. Duddy, P.F. Green, H.J. Gibson, and K.A. Hegarty. Regional palaeo-thermal episodes in northern Australia, 2004.

A. Dutkiewicz, H. Volk, J. Ridley, and S.C. George. Precambrian inclusion oils in the roper group: a review. *NTGS Proceedings*, 2(1), 2005.

EBN. Update Green Deal UDG: ontwikkeling ultradiepe geothermie, 2019. URL `https://www.ebn.nl/update-green-deal-udg-ontwikkeling-ultradiepe-geothermie/`.

Energie Beheer Nederland. Energie in Nederland, 2019. URL `https://www.ebn.nl/wp-content/uploads/2019/01/EBN_Infographic2019_14JAN19.pdf`.

B. Erdogan, M.L. Kraimer, and R.C. Liden. Procedural Justice as a Two-Dimensional Construct: An Examination in the Performance Appraisal Context. *The Journal of Applied Behavioral Science*, 37(2):205–222, 2001. doi: https://doi.org/10.1177/0021886301372004.

Europa Decentraal. Klimaatakkoord Parijs definitief, 2016. URL `https://europadecentraal.nl/klimaatakkoord-parijs-definitief/`.

European Commission. Paris Agreement, 2019. URL `https://ec.europa.eu/clima/policies/international/negotiations/paris_en`.

M.P. Fischer and P.B. Jackson. Stratigraphic controls on eformation patterns in fault-related folds: a detachment fold example from the Sierra Madre Oriental, northeast Mexico. *Journal of Structural Geology*, 21(1), 1999.

R. Folger and J. Bies. Managerial Responsibilities and Procedural Justice. *Employee Responsibilities and Rights Journal*, 2(2):79–90, 1989. doi: https://doi.org/10.1007/BF01384939.

R.W. Fri and M.L. Savitz. Rethinking energy innovation and social science. *Energy Research & Social Science*, 1(1):183–187, 2014. doi: https://doi.org/10.1016/j.erss.2014.03.010.

S.M. Friedman, S. Dunwoody, and C.L. Rogers. *Communicating Uncertainty: Media Coverage of New and Controversial Science*. Lawrence Erlbaum Associates, Inc., Mahwah, NJ, 1991.

Frogtech Geoscience. SEEBASE study and GIS for greater McArthur Basin. *Northern Territory Geological Survey, Digital Information Package DIP*, 17(1), 2018.

M. Frydman, F. Pacheco, J. Pastor, F.C. Canesin, J. Caniggia, and H. Davey. Comprehensive Determination of the Far-Field Earth Stresses for Rocks With Anisotropy in Tectonic Environment. *SPE Argentina Exploration and Production of Unconventional Resources Symposium, Buenos Aires, Argentina*, 1(1), 06 2016.

S. Fulton and A. Knapton. Beetaloo Basin Hydrogeological Assessment, 2015.

J.F.W. Gale, S.E. Laubach, J.E. Olson, P. Eichhubl, and A. Fall. Natural fractures in shale: A review and new observations. *AAPG Bulletin*, 98(11):2165–2216, 11 2014. doi: https://doi.org/10.1306/08121413151.

Gereformeerd Gezinsblad. Aardgasvondst bij Slochteren (Gr.), 1959. URL https://www.delpher.nl/nl/kranten/view?query=aardgas+groningen&facets%5Bperiode%5D%5B%5D=1%7C20e_eeuw%7C1950-1959%7C&facets%5Btype%5D%5B%5D=artikel&facets%5Bspatial%5D%5B%5D=Landelijk&page=13&coll=ddd&identifier=ddd:010626121:mpeg21:a0015&resultsidentifier=ddd:010626121:mpeg21:a0015.

A. Ghassemi and G. Suresh Kumar. Changes in fracture aperture and fluid pressure due to thermal stress and silica dissolution/precipitation induced by heat extraction from subsurface rocks. *Geothermics*, 36(2):115–140, 04 2007. doi: https://doi.org/10.1016/j.geothermics.2006.10.001ja.

A.M. Gholipour, J.W. Cosgrove, and M. Ala. New theoretical model for predicting and modelling fractures in folded fractured reservoirs. *Petroleum Geoscience*, 22(3):257–280, 06 2016. doi: https://doi.org/10.1144/petgeo2013-055.

D. Giles, L. Ailleres, D. Jeffries, P. Betts, and L. Gordon. Crustal architecture of basin inversion during the Proterozoic Isan Orogeny, Eastern Mount Isa Inlier, Australia. *Precambrian Research*, 148(1–2):67–84, 2006. doi: https://doi.org/10.1016/j.precamres.2006.03.002.

N.A. Gillespie and L. Mann. Transformational leadership and shared values: the building blocks of trust. *Journal of Managerial Psychology*, 19(6):588–607, 2004. doi: https://doi.org/10.1108/02683940410551507.

GPM Metals Inc. Australia – walker gossan project, 2019. URL https://www.gpmmetals.ca/projects/australia/.

S. Grainger, F. Mao, and W. Buytaert. Environmental data visualisation for non–scientific contexts: Literature review and design framework. *Environmental Modelling Software*, 85(1):299–318, 2016. doi: https://doi.org/10.1016/j.envsoft.2016.09.004.

D. Granberg. Social Judgment Theory. *Annals of the International Communication Association*, 6(1):304–329, 1982. doi: http://dx.doi.org/10.1080/23808985.1982.11678502.

J.O. Greene. A cognitive approach to human communication: An action assembly theory. *Communication Monographs*, 51(4):289–306, 1984. doi: https://doi.org/10.1080/03637758409390203.

M. Gross. Old Science Fiction, New Inspiration: Communicating Unknowns in the Utilization of Geothermal Energy. *Science Communication*, 35(6):810–818, 2013. doi: https://doi.org/10.1177/1075547012469184.

A. Grubler. Energy transitions research: Insights and cautionary tales. *Energy Policy*, 50(1):8–16, 2012. doi: https://doi.org/10.1016/j.enpol.2012.02.070.

R.L. Heath, S. Seshadri, and J. Lee. Risk Communication: A Two-Community Analysis of Proximity, Dread, Trust, Involvement, Uncertainty, Openness/Accessibility, and Knowledge on Support/Opposition Toward Chemical Companies. *Journal of Public Relations Research*, 10(1):35–56, 1998. doi: https://doi.org/10.1207/s1532754xjprr1001_02.

H.G. Heneman and D.P. Schwab. Evaluation of research on expectancy theory predictions of employee performance. *Psychological Bulletin*, 78(1):1–9, 1972. doi: https://doi.org/10.1037/h0033093.

M. Hoel and S. Kverndokk. Depletion of fossil fuels and the impacts of global warming. *Resource and Energy Economics*, 18(2):115–136, 06 1996. doi: https://doi.org/10.1016/0928-7655(96)00005-X.

T.W. Hoffman. Roper basin burial history modelling: Inferences for the timing of hydrocarbon generation. *AGES Proceedings*, 1(1), 2016.

M. Hook and X. Tang. Depletion of fossil fuels and anthropogenic climate change —- A review. *Energy Policy*, 52(1):797–809, 01 2013. doi: https://doi.org/10.1016/j.enpol.2012.10.046.

N.M.A. Huijts, C.J.H. Midden, and A.L. Meijnders. Social acceptance of carbon dioxide storage. *Energy Policy*, 35(5):2780–2789, 2007. doi: https://doi.org/10.1016/j.enpol.2006.12.007.

D.R. Hunter. *Precambrian of the Southern Hemisphere*. Elsevier, 1981.

K.J. Hussey, P.R. Beier, A.J. Crispe, N. Donnellan, and P.D. Kruse. Helen Springs SE 53–10 1:250 000 Geological Series. *Northern Territory Geological Survey*, 1(2), 2001.

Indian Scribes. 4 Rules of Verbatim Transcription, 2018. URL `https://www.indianscribes.com/4-rules-of-verbatim-transcription/`.

IPCC. Special report: global warming of 1.5 °, 2018. URL `https://www.ipcc.ch/sr15/chapter/spm/`.

IPCC. Global Warming of 1.5 degrees Celsius. *An IPCC Special Report on the impacts of global warming of 1.5 degrees Celsius above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty*, 2018.

M.J. Jackson, D.L. Scott, and D.J. Rawlings. Stratigraphic framework for the Leichhardt and Calvert Superbasins: Review and correlations of the pre– 1700 Ma successions between Mt Isa and McArthur River. *Australian Journal of Earth Sciences*, 47(3):381–403, 2000. doi: https://doi.org/10.1046/j.1440-0952.2000.00789.x.

A. Jarrett, S. MacFarlane, T. Palu, C. Boreham, L. Hall, D. Edwards, G. Cox, T. Munson, J. Brocks, L. Carr, and P. Henson. Source rock geochemistry and petroleum systems of the greater mcarthur basin and links to other northern australian proterozoic basins. *AGES Proceedings*, 1(1):92–105, 03 2019.

L.R. Jauch and K.L. Kraft. Strategic Management of Uncertainty. *Academy of Management Review*, 11(4):777–790, 1986. doi: https://doi.org/10.5465/amr.1986.4283934.

K. Jenkins, D. McCauley, R. Heffron, H. Stephan, and R. Rehner. Energy Justice: A conceptual review. *Energy Research and Social Science*, 11(1):174–182, 2016. doi: http://dx.doi.org/10.1016/j.erss.2015.10.004.

B.B. Johnson. Exploring dimensionality in the origins of hazard related trust. *Journal of Risk Research*, 2(4):325–354, 2011. doi: https://doi.org/10.1080/136698799376763.

B.B. Johnson and P. Slovic. Presenting Uncertainty in Health Risk Assessment: Initial Studies of Its Effects on Risk Perception and Trust. *Risk analysis*, 15(4):485–494, 1995. doi: https://doi.org/10.1111/j.1539-6924.1995.tb00341.x.

M.F. Kaplan and N.H. Anderson. Information integration theory and reinforcement theory as approaches to interpersonal attraction. *Journal of Personality and Social Psychology*, 28(3):301–312, 1973. doi: https://doi.org/10.1037/h0035112.

T. Kawahara. Intelligent Transcription System based on Spontaneous Speech Processing. *Second International Conference on Informatics Research for Development of Knowledge Society Infrastructure*, 1(1):1–9, 2007. doi: https://doi.org/10.1109/ICKS.2007.13.

R. Kemp and D. Loorbach. Dutch policies to Manage the Transition to Sustainable Energy, 2005.

R. Kemp and D. Loorbach. *Reflexive Governance for Sustainable Development*. Edward Elgar Publishing, Cheltenham, 2006.

Klimaatakkoord. Afspraken van het Klimaatakkoord, 2019a. URL https://www.klimaatakkoord.nl/klimaatakkoord.

Klimaatakkoord. Wat is het verschil tussen het Klimaatakkoord en het Energieakkoord?, 2019b. URL https://www.klimaatakkoord.nl/klimaatakkoord/vraag-en-antwoord/wat-is-het-verschil-tussen-het-klimaatakkoord-en-het-energieakkoord.

P. Kloprogge, J. Van der Sluijs, and A. Wardekker. Uncertainty Communnication – Issues and good practice, 2007.

M.A. Korsgaard, D.M. Schweiger, and H.J. Sapienza. Building Commitment, Attachment, and Trust in Strategic Decision-Making Teams: The Role of Procedural Justice. *Academy of Management Journal*, 38(1):60–84, 1995. doi: https://doi.org/10.5465/256728.

M.W. Kramer. *Managing Uncertainty in Organizational Communication*. Routledge, London, 2014.

L. Kramers, J.D. Van Wees, M.P.D. Pluymaekers, A. Kronimus, and T. Boxem. Direct heat resource assessment and subsurface information systems for geothermal aquifers; the Dutch perspective. *Netherlands Journal of Geosciences — Geologie en Mijnbouw*, 91(4): 637–649, 2012. doi: https://doi.org/10.1017/S0016774600000421.

E. Laes, L. Gorissen, and F. Nevens. A Comparison of Energy Transition Governance in Germany, The Netherlands and the United Kingdom. *Sustainability*, 6(1):1129–1152, 2014. doi: https://doi.org/10.3390/su6031129.

G. Lakoff. *Don't Think of an Elephant!: Know Your Values and Frame the Debate : the Essential Guide for Progressives*. Chelsea Green Publishing Company, Vermont, 2004.

J. Lamarche, A. Chabani, and B.D.M. Gauthier. Dimensional threshold for fracture linkage and hooking. *Journal of Structural Geology*, 108(1), 2018.

Leeuwarder Courant. Groningen vraagt: Waar blijft ons aardgas?, 1953. URL https://www.delpher.nl/nl/kranten/view?query=aardgas+groningen&facets%5Bperiode%5D%5B%5D=1%7C20e_eeuw%7C1950-1959%7C&page=1&coll=ddd&identifier=ddd:010613605:mpeg21:a0108&resultsidentifier=ddd:010613605:mpeg21:a0108.

S.W. Littlejohn and K.A. Foss. *Theories of Human Communication*. Wadsworth, Boston,, 2008.

L. Liu, T. Bouman, G. Perlaviciute, and L. Steg. Effects of trust and public participation on acceptability of renewable energy projects in the Netherlands and China. *Elsevier Energy Research Social Science*, 53(1):137–144, 2019. doi: https://doi.org/10.1016/j.erss.2019.03.006.

Lock the Gate Alliance. Lock the Gate – Stop fracking in the NT, 2019. URL https://www.lockthegate.org.au/.

D. Loorbach and J. Rotmans. Managing transitions for sustainable development. *Understanding Industrial Transformation: Views from different Desciplines*, 1(1):187–206, 2006. doi: https://doi.org/10.1007/1-4020-4418-6_10.

L. Loorbach. Transition Management for Sustainable Development: A Prescriptive, Complexity-Based Governance Framework. *Governance: an international journal of Policy, Administration and Institutions*, 23(1):161–183, 2009. doi: https://doi.org/10.1111/j.1468-0491.2009.01471.x.

Q. Ma, L. Luo, R.Z. Wang, and G. Sauce. A review on transportation of heat energy over long distance: Exploratory development. *Renewable and Sustainable Energy Reviews*, 13(6–7):1532–1540, 2009. doi: https://doi.org/10.1016/j.rser.2008.10.004.

A.H. Maslow. *Motivation and Personality*. Harper and Row, New York, 1954.

K.A. McComas. Defining Moments in Risk Communication Research: 1996–2005. *Journal of Health Communication*, 11(1):75–91, 2006. doi: https://doi.org/10.1080/10810730500461091.

Ministerie van Infrastructuur en Waterstaat, Ministerie van Economische Zaken en Klimaat. Structuurvisie Ondergrond, 2018.

M.G. Morgan. Characterizing and Dealing With Uncertainty: Insights from the Integrated Assessment of Climate Change. *Integrated Assessment*, 4(1):46–55, 2003.

M. Mulder and P. Perey. Gas production and earthquakes in Groningen: reflection on economic and social consequences. *Policy Papers*, 3(1):1–74, 2018.

T.J. Munson. Sedimentary characterisation of the Wilton package, greater McArthur Basin, Northern Territory. *NTGS Record*, 3(1), 2016a.

T.J. Munson. Sedimentary characterisation and correlation of the Wilton package, greater McArthur Basin. *Annual Geoscience Exploration Seminar (AGES)*, AGES(2016):4, 2016b.

T.J. Munson, J.M. Thompson, I. Zhukova, S. Meffre, E.E. Beyer, J.D. Woodhead, and J.A. Whelan. Summary of results. NTGS laser ablation ICP–MS U–Pb and Lu–Hf geochronology project: Roper Group (McArthur Basin), overlying ungrouped units (Beetaloo Subbasin), Renner Group (Tomkinson Province), and Tijunna Group (Birrindudu Basin). *NTGS Record*, 7(1), 2018.

R. Murray Berndt. *Australian Aboriginal Religion, Parts 1–4*. Brill Archive, 1974.

J.S. Myers, R.D. Shaw, and I.M. Tyler. Tectonic evolution of Proterozoic Australia. *Tectonics*, 15(6):1431–1446, 1996.

I. Mynatt, S. Seyum, and D.D. Pollard. Fracture initiation, development, and reactivation in folded sedimentary rocks at Raplee Ridge, UT. *Journal of Structural Geology*, 31(10):1100–1113, 10 2009. doi: https://doi.org/10.1016/j.jsg.2009.06.003.

F. Ndamani and T. Watanabe. Farmers' Perceptions about Adaptation Practices to Climate Change and Barriers to Adaptation: A Micro-Level Study in Ghana. *Water*, 7(9):4593–4604, 2015. doi: https://doi.org/10.3390/w7094593.

Northern Territory Government. What is hydraulic fracturing?, 2019. URL `https://hydraulicfracturing.nt.gov.au/about`.

F.R. Oomkes. *Communicatieleer: een inleiding (Communication studies: an introduction)*. Boom Lemma, Den Haag, 2013.

Origin Energy. Amungee NW-1H – Velkerri B Shale Pool. Results of Evaluation of the Discovery and Preliminary Estimate of Petroleum in Place. *Amungee NW-1H Discovery Report*, 1(1), 2017.

B. Peerlings. Holistically improving screening decisions under uncertainty in aircraft conceptual design and technology assessment: Insights on bottom-up uncertainty quantification and propagation and integrated socio-technical group decision making, 2019.

R.E. Petty and J.T. Cacioppo. The Elaboration Likelihood Model of Persuasion. *Communication and Persuasion*, 1(1):1–24, 1986. doi: https://doi.org/10.1007/978-1-4612-4964-1_1.

N. Pinet. Far–field effects of Appalachian orogenesis: A view from the craton. *Geology*, 44 (2):83–86, 02 2016. doi: http://dx.doi.org/10.1130/G37356.1.

K. Popovski. Political and public acceptance of geothermal energy. *Geothermal Traning Programme, short course*, 1(1):31–41, 2003.

N. Pragt. Geological history and fracture network characterization in unconventional reservoirs of the McArthur Basin (NT Australia), 2018.

M. Provoost, L. Albeda, B. Godschalk, B. Van der Werff, and F. Schoof. Geothermal Energy Use, Country Update for The Netherlands. *European Geothermal Congress*, 1(1):1–8, 2019.

M.A. Randal and K.G. Smith. Beetaloo SE 53–5 1:250 000 Geological Series. *Northern Territory Geological Survey*, 1(1), 1969.

M.A. Randal, M.C. Brown, W.J. Perry, and S.K. Skwarko. Daly Waters SE 53–1 1:250 000 Geological Series. *Northern Territory Geological Survey*, 1(1), 1969a.

M.A. Randal, M.C. Brown, and K.G. Smith. Beetaloo SE 53–6 1:250 000 Geological Series. *Northern Territory Geological Survey*, 1(1), 1969b.

D.J. Rawlings. Stratigraphic resolution of a multiphase intracratonic basin system: The McArthur Basin, northern Australia. *Australian Journal of Earth Sciences: An International Geoscience Journal of the Geological Society of Australia*, 46(5), 1999.

D.J. Rawlings, R. Korsch, B. Goleby, G. Gibson, D. Johnstone, and M. Barlow. The 2002 Southern McArthur Basin Seismic Reflection Survey. *Geoscience Australia*, 17(1), 2004.

D. Revie. Unconventional petroleum resources of the Roper Group, McArthur Basin. *NTGS Record*, 2(1):1–70, 01 2017. doi: https://doi.org/10.1016/j.precamres.2017.10.025.

S. Riad. Of mergers and cultures: "What happened to shared values and joint assumptions?". *Journal of Organizational Change Management*, 20(1):26–43, 2007. doi: https://doi.org/10.1108/09534810710715261.

Rijksdienst voor Ondernemend Nederland. Australia – walker gossan project, 2019. URL `https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/duurzame-energie-opwekken/aardgasvrij/aan-de-slag-met-aardgasvrij/transitievisie-warmte-en-wijkuitvoeringsplan`.

Rijksoverheid. Geen winning van schaliegas in Nederland. URL `https://www.rijksoverheid.nl/onderwerpen/schaliegas/schaliegas-in-nederland`.

Rijksoverheid. Kabinet: einde aan gaswinning in Groningen, 2018. URL `https://www.rijksoverheid.nl/actueel/nieuws/2018/03/29/kabinet-einde-aan-gaswinning-in-groningen`.

Rijksoverheid. Geen extra gaswinning kleine gasvelden vanwege eerder sluiten Groningenveld, 2019a. URL `https://www.rijksoverheid.nl/onderwerpen/gaswinning-uit-kleine-gasvelden/nieuws/2019/10/04/geen-extra-gaswinning-kleine-gasvelden-vanwege-eerder-sluiten-groningenveld`.

Rijksoverheid. Ontstaan Klimaatbeleid, 2019b. URL `https://www.rijksoverheid.nl/onderwerpen/klimaatverandering/klimaatbeleid/ontstaan-klimaatbeleid`.

R.G. Roberts, R. Jones, N.A. Spooner, M.J. Head, A.S. Murray, and Smith M.A. The human colonisation of Australia: optical dates of 53,000 and 60,000 years bracket human arrival at Deaf Adder Gorge, Northern Territory. *Quaternary Science Reviews*, 13(5–7):403–684, 1994. doi: https://doi.org/10.1016/0277-3791(94)90080-9.

M.M. Roksandic. The Tectonics and Evolution of the Hudson Bay Region. *Sedimentary Basins and Basin-Forming Mechanisms*, 12(1), 1987.

A.M. Rosso-Ceron and V. Kafarov. Barriers to social acceptance of renewable energy systems in Colombia. *Current Opinion in Chemical Engineering*, 10(1):103–110, 2015. doi: https://doi.org/10.1016/j.coche.2015.08.003.

J. Rotmans and R. Kemp. Managing Societal Transitions: Dilemmas and Uncertainties: The Dutch energy case-study. *OECD Workshop on the Benefits of Climate Policy: Improving Information for Policy Makers* , 1(1):1–31, 2003.

J. Rotmans, R. Kemp, and M. Van Asselt. More evolution than revolution: Transition management in public policy. *Foresight*, 3(1):15–31, 2001. doi: https://doi.org/10.1108/14636680110803003.

D.M. Rousseau, S.B. Sitkin, R.S. Burt, and C. Camerer. Not So Different After All: A Cross-Discipline View Of Trust. *Academy of Management Review*, 23(3):393–404, 1998. doi: https://doi.org/10.5465/amr.1998.926617.

K.E. Rowan. Goals, Obstacles, and Strategies in Risk Communication: A Problem-Solving Approach to Improving Communication About Risks. *Journal of Applied Communication Research*, 19(4):300–329, 1991. doi: https://doi.org/10.1080/00909889109365311.

R. Russell-Jonas. Role of shale gas as a bridge fuel is overstated. *Financial Times*, 1(1).

A. Safari, N. Das, O. Langhelle, J. Roy, and M. Assadi. Natural gas: A transition fuel for sustainable energy system transformation? *Energy Science and Engineering*, 1(1):1075–1094, 2019. doi: http://dx.doi.org/10.1002/ese3.380.

D.J. Sanderson and C.W. Nixon. The use of topology in fracture network characterization. *Journal of Structural Geology*, 72(1):55–66, 01 2015. doi: http://dx.doi.org/10.1016/j.jsg.2015.01.005.

A. Scheidel and A.H. Sorman. Energy transitions and the global land rush: Ultimate drivers and persistent consequences. *Renewable and Sustainable Energy Reviews*, 45(1):565–573, 2015. doi: https://doi.org/10.1016/j.gloenvcha.2011.12.005.

F. Schoof, M. Van der Hout, J. Van Zanten, and J.W. Van Hoogstraten. Masterplan Aardwarmte in Nederland, 2018.

SER. Wat is het Energieakkoord?, 2013. URL `https://www.ser.nl/nl/thema/energie-en-duurzaamheid/energieakkoord/wat`.

M. Sheridan, D. Rhodri Johns, and H.D. Johnson. The Stratigraphic Architecture, distribution and hydrocarbon potential of the organic rich Kyalla and Velkerri shales of the Upper Roper Group. *AEGC Sydney, Australia*, 1(1):1–4, 2018.

J.N. Sheth. Psychology of Innovaton Resistance: The less developed concept. *Marketing*, 4(1):273–282, 1981.

M. Silverman and T. Ahlbrandt. Mesoproterozoic Unconventional Plays in the Beetaloo Basin, Australia: The World's Oldest Petroleum Systems. *AAPG International Conference and Exhibition*, 1(1), 2011.

P.M.M. Simoes and M. Esposito. Improving change management: how communication nature influences resistance to change. *Journal of Management Development*, 33(4):324–341, 2014. doi: http://dx.doi.org/10.1108/JMD-05-2012-0058.

A. Skukauskaite. Transparency in Transcribing: Making Visible Theoretical Bases Impacting Knowledge Construction from Open-Ended Interview Records . *Forum: Qualitative Social Research*, 13(1/14):1–32, 2012. doi: http://doi.org/10.17169/fqs-13.1.1532.

J.G. Smetana and N.E. Adler. Fishbein's Value x Expectancy Model: An Examination of Some Assumptions. *Personality and Social Psychology Bulletin*, 6(1):89–96, 1980. doi: https://doi.org/10.1177/014616728061013.

B.K. Sovacool and M.H. Dworkin. Energy Justice: Conceptual Insights and Practical Applications. *Applied Energy*, 142(1):435–444, 2015. doi: https://doi.org/10.1016/j.apenergy.2015.01.002.

G.P.T. Spampinato, P.G. Betts, L. Ailleres, and R.J. Armit. Structural architecture of the southern Mount Isa terrane in Queensland inferred from magnetic and gravity data. *Precambrian Research*, 269(1):261–280, 10 2015. doi: https://doi.org/10.1016/j.precamres.2015.08.017.

Staatstoezicht op de Mijnen. Oliewinning en gaswinning. URL `https://www.sodm.nl/onderwerpen/oliewinning-en-gaswinning`.

Staatstoezicht op de Mijnen. Staat van de Sector Geothermie: Ook aardwarmte moet veilig gewonnen worden, 2017. URL `https://www.sodm.nl/actueel/nieuws/2017/07/13/staat-van-de-sector-geothermie-ook-aardwarmte-moet-veilig-gewonnen-worden`.

B.J. Stephenson, A. Koopman, H. Hillgartner, H. McQuillan, S. Bourne, J. Noad, and K. Rawnsley. Structural and stratigraphic controls on fold-related fracturing in the Zagros Mountain, Iran: Implications for reservoir development. *Geological Society London Special Publications*, 270(1), 2007.

E. Stephenson, A. Doukas, and K. Shaw. Greenwashing gas: Might a 'transition fuel' label legitimize carbon-intensive natural gas development? *Energy Policy*, 46(1):452–459, 2012. doi: https://doi.org/10.1016/j.enpol.2012.04.010.

Stichting Platform Geothermie. Veelgestelde vragen aardwarmte, 2019. URL `https://geothermie.nl/index.php/nl/geothermie-aardwarmte/veelgestelde-vragen`.

E.K. Stigka, J.A. Paravantis, and G.K. Mihalalakakou. Social acceptance of renewable energy sources: A review of contingent valuation applications. *Renewable and Sustainable Energy Reviews*, 32(1):100–106, 2014. doi: https://doi.org/10.1016/j.rser.2013.12.026.

H.L. Stuckey. The first step in Data Analysis: Transcribing and managing qualitative research data. *Journal of Social Health and Diabetes*, 2(1):6–8, 2014. doi: http://dx.doi.org/10.4103/2321-0656.120254.

The Scientific Inquiry into Hydraulic Fracturing in the Northern Territory. About shale gas, 2016. URL `https://frackinginquiry.nt.gov.au/about-shale-gas#top`.

The Scientific Inquiry into Hydraulic Fracturing in the Northern Territory. Final report, 2018.

The Scientific Inquiry into Hydraulic Fracturing in the Northern Territory. Home page, 2019a. URL https://frackinginquiry.nt.gov.au/.

The Scientific Inquiry into Hydraulic Fracturing in the Northern Territory. Action items, 2019b. URL https://hydraulicfracturing.nt.gov.au/action-items.

ThermoGIS. The Geothermal Family, 2019. URL https://www.thermogis.nl/en/geothermal-family.

TNO. Aardgas, condensaat en aardolie. URL https://www.geologievannederland.nl/ondergrond/afzettingen-en-delfstoffen/aardgas-en-aardolie.

TNO & EBN. Play-based portfoliobenadering, eerste inzicht in zes voordelen voor veilig en verantwoord, kosteneffectief versnellen van geothermie, 2018.

TNO, Geologische Dienst Nederland. Groningen gasveld, 2019. URL https://www.nlog.nl/groningen-gasveld.

B. Trench. Towards an Analytical Framework of Science Communication Models. *Communicaitng Science in Social Contexts*, 1(1):229–135, 2008. doi: https://doi.org/10.1016/j.renene.2017.07.090.

Trouw. Groningen gaat over op aardgas, 1955. URL https://www.delpher.nl/nl/kranten/view?query=aardgas+groningen&facets%5Bperiode%5D%5B%5D=1%7C20e_eeuw%7C1950-1959%7C&facets%5Btype%5D%5B%5D=artikel&facets%5Bspatial%5D%5B%5D=Landelijk&page=1&coll=ddd&identifier=ABCDDD:010819867:mpeg21:a0105&resultsidentifier=ABCDDD:010819867:mpeg21:a0105.

Trouw. Bijna drie miljoen voor overschakeling op aardgas, 1959. URL https://www.delpher.nl/nl/kranten/view?query=aardgas+groningen+&facets%5Bperiode%5D%5B%5D=2%7C20e_eeuw%7C1950-1959%7C1959%7C&page=1&coll=ddd&identifier=ABCDDD:010817444:mpeg21:a0087&resultsidentifier=ABCDDD:010817444:mpeg21:a0087.

Trouw. Hoge raad geeft urgenda gelijk, overheid moet meer doen tegen broeikasgassen, 2019. URL https://www.trouw.nl/binnenland/hoge-raad-geeft-urgenda-gelijk-overheid-moet-meer-doen-tegen-broeikasgassen~b053

Tweede Kamer der Staten – Generaal. De nederlandse democratie, 2020. URL https://www.tweedekamer.nl/zo_werkt_de_kamer/de_nederlandse_democratie.

P. Upham, C. Oltra, and A. Boso. Towards a cross-paradigmatic framework of the social acceptance of energy systems. *Energy Research Social Science*, 8(1):100–112, 2015. doi: https://doi.org/10.1016/j.erss.2015.05.003.

M.B.A. Van Asselt. *Perspectives on Uncertainty and Risk*. Kluwer Academic Publishers, New York, USA, 2000.

M. Van Bruggen. Communication in the earthquake region in the province of Groningen: An evaluation by the residents, 2015.

A.M. Van der Bles, S. Van der Linden, A.L.J. Freeman, and D.J. Spiegelhalter. The effects of communicating uncertainty on public trust in facts and numbers. *Proceeding of the National Academy of Sciences of the United Sates of America*, 117(14):7672–7683, 2020. doi: https://doi.org/10.1073/pnas.1913678117.

K. Van der Hoorn and H. De Pater. Stimulatie in Ultradiepe Geothermie, een Verkenning, 2016.

N. Van der Voort and F. Vanclay. Social impacts of earthquakes caused by gas extraction in the Province of Groningen, The Netherlands. *Environmental Impact Assessment Review*, 50(1):1–15, 2015. doi: https://doi.org/10.1016/j.eiar.2014.08.008.

E.V. Van Heekeren and M. Koenders. The Netherlands Country Update on Geothermal Energy. *Proceedings World Geothermal Congress*, 1(1):1–7, 2010.

M.H. Van Meurs. *Een beeld van een provincie: Groningen in de twintigste eeuw*. Uitgeverij Van Gorcum, 2006.

K. Van Thienen-Visser and J.N. Breunese. Induced seismicity of the Groningen gas field: History and recent developments. *The Leading Edge*, 34(6):664–671, 2015. doi: https://doi.org/10.1190/tle34060664.1.

M. Visser, L.T.M. Willems, and H. Ribbens. Een kwestie van contact; communicatie en veranderbereidheid. *Tijdschrift voor Management en Organisatie*, 59(2):7–24, 2005. doi: https://hdl.handle.net/2066/46791.

J.H.L. Voncken. Ontstaansgeschiedenis van de Steenkolenwinning in Nederland. *Stichting Geologische Activiteiten (GEA)*, 4(1):112–115, 2009.

B.P. Wade, D.E. Kelsey, M Hand, and K.M. Barovich. The Musgrave Province: Stitching north, west and south Australia. *Precambrian Research*, 166(1–4):370–386, 10 2008. doi: https://doi.org/10.1016/j.precamres.2007.05.007.

W.E. Walker, P. Harremoes, J. Rotmans, J.P. Van der Sluijs, M.B.A. Van Asselt, P. Janssen, and M.P. Krayer von Krauss. Defining Uncertainty: A Conceptual Basis for Uncertainty Management in Model-Based Decision Support. *Integrated Assessment*, 4(1):5–17, 2003. doi: http://dx.doi.org/10.1076/iaij.4.1.5.16466.

J.A. Wardekker, J.P. Van der Sluijs, P.H.M. Janssen, P. Kloprogge, and A.C. Petersen. Uncertainty communication in environmental assessments: views from the Dutch science-policy interface. *Environmental Science & Policy*, 11(7):627–641, 2008. doi: https://doi.org/10.1016/j.envsci.2008.05.005.

Healy D. Watkins, H., C.E. Bond, and R.W.H. Butler. Implications of heterogeneous fracture distribution on reservoir quality; an analogue from the Torridon Group sandstone, Moine Thrust Belt, NW Scotland. *Journal of Structural Geology*, 108(1):180–197, 03 2018. doi: https://doi.org/10.1016/j.jsg.2017.06.002.

C. Wehrmann and A.M. Dijkstra. The process of communicating science, 2018.

S.A. Wheeler. The barriers to further adoption of organic farming and genetic engineering in Australia: views of agricultural professionals and their information sources. *Renewable Agriculture and Food Systems*, 23(2):161–170, 2008. doi: https://doi.org/10.1017/S1742170507002128.

J. Whitton, K. Brasier, I. Charnley-Parry, and M. Cotton. Shale gas governance in the United Kingdom and the United States: Opportunities for public participation and the implications for social justice. *Energy Research & Social Science*, 26(1):11–22, 2017. doi: https://doi.org/10.1016/j.erss.2017.01.015.

E.D. Wiebes. Gaswinning uit de kleine velden in de energietransitie, 2018.

A. Wiek, C. Binder, and R.W. Scholz. Functions of scenarios in transition processes. *Futures*, 38(7):740–766, 2006. doi: https://doi.org/10.1016/j.futures.2005.12.003.

Y. Wiener. Forms of Value Systems: Focus on Organizational Effectiveness and Cultural Change and Maintenance. *Academy of Management Review*, 13(4):534–545, 1988. doi: https://doi.org/10.5465/amr.1988.4307410.

S.J. Wilkins. Fracture intensity from geomechanical models: application to the Blue Forest 3D survey, Green River Basin, Wyoming, USA. *Geological Society London Special Publications*, 292(1), 2007.

D.T. Wilson, H.L. Mathews, and J.W. Harvey. An Empirical Test of the Fishbein Behavioral Intention Model. *Journal of Consumer Research*, 1(4):39–48, 1975. doi: https://doi.org/10.1086/208606.

M. Wolsink. Planning of renewables schemes: Deliberative and fair decision-making on landscape issues instead of reproachful accusations of non-cooperation. *Energy Policy*, 35(5):2692–2704, 2007. doi: https://doi.org/10.1016/j.enpol.2006.12.002.

R. Wurstenhagen, M. Wolsink, and M.J. Burer. Social acceptance of renewable energy innovation: An introduction to the concept. *Energy Policy*, 35(1):2683–2691, 2007. doi: https://doi.org/10.1016/j.enpol.2006.12.001.

B. Yang, T.M. Smith, A.S. Collins, T.J. Munson, B. Schoemaker, D. Nicholls, G. Cox, J. Farkas, and S. Glorie. Spatial and temporal variation in detrital zircon age provenance of the hydrocarbon-bearing upper Roper Group, Beetaloo Sub-basin, Northern Territory, Australia. *Precambrian Research*, 204(1):140–155, 01 2018. doi: https://doi.org/10.1016/j.precamres.2017.10.025.

M. Yazdanpanah, N. Komendantova, and R. Shafiei Ardestani. Governance of energy transition in Iran: Investigating public acceptance and willingness to use renewable energy sources through socio-psychological model. *Global Environmental Change*, 22(3):588–595, 2012. doi: https://doi.org/10.1016/j.rser.2015.02.002.

B. Young, S. Huq, and I. Burton. Climate adaptation: Risk, uncertainty and decision–making, 2003.

C. Zeeb, E. Gomez-Rivaz, P.D. Bons, and P. Blum. Evaluation of sampling methods for fracture network characterization using outcrops. *AAPG Bulletin*, 97(9), 2013.

A. Zhang and K. Moffat. A balancing act: The role of benefits, impacts and confidence in governance in predicting acceptance of mining in Australia. *Resources Policy*, 44.