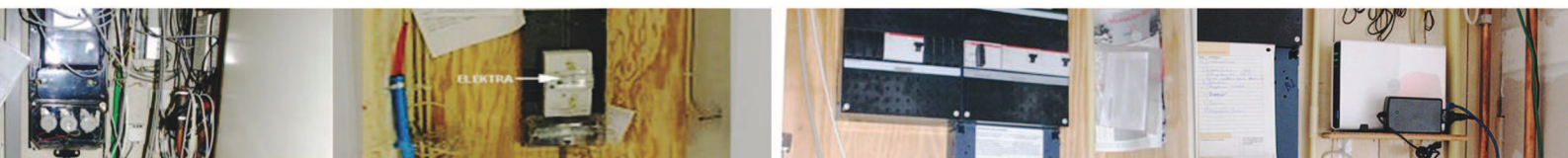




Keeping Connection



A comparative case study on
reliability in vital infrastructures



Guus van de Schouw
Master Thesis Report
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Keeping Connection

A comparative case study on reliability in vital infrastructures

In partial fulfillment of the requirements for the degree of
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Guus van de Schouw
Student number 1093177

Delft University of Technology
Faculty of Technology, Policy and Management
Master Systems Engineering, Policy Analysis and Management
Section Economics of Infrastructures

Gas Transport Services B.V.
Market Monitoring (LTM)

Graduation Committee:
Prof. dr. J.P.M. Groenewegen
Dr. A.F. Correljé
Dr. M.L.C. de Bruijne
Ir. S. de Jong



Preface

This report is the final result of a graduation project and completes the Systems Engineering, Policy Analysis and Management Master of the faculty of Technology, Policy and Management at Delft University of Technology. The study took place from April 2009 through February 2010 and was commissioned by Gas Transport Services B.V., the transmission systems operator of the Dutch gas infrastructure and a full subsidiary of N.V. Nederlandse Gasunie. Next to this report, a scientific paper was written as part of the deliverables of the graduation project. This paper, titled "Reliability and efficiency in transmission networks: a wicked trade-off", is included in this report as a separate appendix.

Writing this thesis report has been a valuable experience, not just for the project itself, but also for the insight and respect I gained for scientific research. Never will I think lightly again about just writing a report, knowing all the work that can be hidden behind those words. I would like to thank the graduation committee for giving me both the freedom and the guidance to experience this. Prof.dr. John Groenewegen, for chairing the committee. First supervisor Dr. Aad Correljé, for making the project possible and the valuable discussions on conceptualization. Second supervisor Dr. Mark de Bruijne, for always being available at the shortest notice, his contributions to the methodology and his meticulous reading. My external supervisors at GTS, ir. Sybren de Jong and ir. Maurice Vos for the continuous feedback and discussions, that helped to constantly sharpen and broaden my view. This would not have been possible without the freedom I got for my research, while also being a part of the Market Monitoring department.

I would also like to thank the interviewees at GTS, TenneT and Energiekamer for their time and cooperation. These interviews uncovered and validated information that was of vital importance to the research. My fellow students at GTS, Wilma Huitema and Ebel Kremer, for both the topical and non-topical discussions. My family and friends, for their continuous support and relativation of the proverbial last hurdle.

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Summary

The functioning of vital infrastructures, such as energy and telecommunications infrastructure, is key to societal and economic security and well-being in modern society. The reliability of these infrastructures is thus of paramount importance. Transmission system operators (TSOs) fulfill a central role in achieving this reliability, by maintaining, operating and developing the transmission networks that form the backbone of the infrastructure. However, the TSOs have to achieve this in changing conditions and with increasing uncertainties; vital infrastructures are faced with rapidly changing market conditions and regulations, especially given the ongoing liberalization process in the European Union. Furthermore, they not only have to maintain reliability, but also other values like affordability, accessibility and sustainability.

To ensure an adequate level of reliability, while also remaining efficient and profitable in a changing environment, TSOs need to continuously reevaluate their planning and investment decision making methods. To be able to do this, they need insight in the trade-off between reliability and efficiency and the different investment options to improve reliability. In this research, we aim to add to that insight by comparing three vital Dutch infrastructures (the gas infrastructure, the electricity infrastructure and the fixed line telecommunications infrastructure) using an analytical framework based on the ISO31000 Risk Management standard. By using risk management, we create a generic framework that explicitly deals with uncertainty. We focus on three elements in the risk management process: context, assessment and treatment. The study consists of a comparative case study, based on literature review and interviews with TSOs and regulators.

The context has been described along a set of factors, that have been categorized as either technical, economic or institutional. The final set of 12 factors is considered to be as parsimonious, relevant and complete as possible, to give a structured and efficient overview of the different infrastructures. From analyzing the context it follows that the infrastructures are very different, but often have striking similarities on individual context factors and experience similar developments, such as internationalization and institutional fragmentation. This fact enables us to analyze the particular influence of these factors on the assessment and treatment of reliability. This final set of factors thus forms a strong basis for the rest of the analysis.

Reliability is neither a simple nor an unambiguous concept for multiple reasons. First, we can identify different levels of reliability. Second, reliability risks can occur on different timescales and in different parts of the supply chain. Third, in vital infrastructures the public interest in reliability has a large influence on the perception of reliability. Finally, the discussion on reliability is often embedded in a specific infrastructure. To compare the assessment of reliability in different infrastructures, we have to deal with these complexities. Therefore, we have developed a new conceptual model that identifies different levels and dimensions of reliability and also is generic enough to be applied to all analyzed infrastructures. The assessment of reliability in gas and electricity infrastructure shows strong similarities, while in telecommunications infrastructure the assessment is radically different as a result of rapid technological developments and strong differentiation in services offered.

When analyzing the treatment of reliability, it becomes clear that individual treatment options are very infrastructure specific and comparing them is difficult and of limited use. Therefore, four high-level treatment strategies have been identified, which can be compared between infrastructures. These four treatment strategies are investing in larger infrastructures, investing in smarter infrastructures, supply responsiveness and demand responsiveness. The dominant strategies of the TSO in gas infrastructure are investing in larger infrastruc-

tures and supply responsiveness; in electricity infrastructure it is supply responsiveness and in telecommunications infrastructure it is investing in larger and smarter infrastructures. Demand responsiveness is important, but not a central strategy for TSOs, because they deal with aggregated traffic flows and have no direct contracts with consumers in which to include incentives for demand responsiveness.

The trade-off between reliability and efficiency is sometimes mistakenly simplified and over rationalized in the discussion between regulators and regulated TSOs. Considering that the costs of reliability risks and the investment costs to reduce these risks can be estimated, it is contended that this trade-off can be analytically optimized. However, given the multidimensionality and subjectivity of reliability and the complexity of transmission networks, this optimization is most likely false and extremely difficult. In an infrastructure where different stakeholders have different perceptions and requirements for reliability, which also change over time and as a result of incidents, an adequate level of reliability can only be determined in a political, rather than an analytical, process.

Another concern is that fragmented regulatory oversight and the decoupling of public values, can lead to conflicting interventions and suboptimal decisions by the TSO. Especially when the regulation of a specific value is very stringent compared to other values (e.g. efficiency by price regulation) and the regulated TSO has only specific responsibilities and capabilities, the risk exists that the scope of the TSO is narrowed only to those responsibilities and capabilities, instead of developing and encouraging new solutions. To avoid this, regulation should be more holistic and should address conflicts between different public values instead of decoupling them.

To achieve an adequate trade-off between reliability and efficiency, while dealing with institutional fragmentation and uncertainty, TSOs should employ more proactive mechanisms to efficiently and effectively utilize existing and future transport capacity. Especially the gas infrastructure lacks such mechanisms, e.g. an efficient capacity allocation mechanism. Also, while we have shown that analytically optimizing the trade-off between efficiency and reliability produces no sensible results, TSOs still need a way to determine and achieve an adequate level of reliability. Considering the political and complex nature of reliability, it is necessary to develop instruments to achieve long-term reliability in cooperation with other stakeholders.

Contents

Preface	i
Summary	iii
Table of Contents	v
List of Figures	vii
List of Tables	ix
List of Acronyms	xi
1 Introduction	1
1.1 Research objective	2
1.2 Research goal	4
1.3 Research framework and questions	5
1.4 Structure of the report	6
2 Issue exploration	7
2.1 Transport infrastructure paradigm	7
2.1.1 Transmission networks	8
2.2 Public interest of reliability	9
2.3 Dealing with reliability	11
2.4 Conceptualizing reliability	12
2.4.1 Reliability in energy infrastructures	12
2.4.2 Reliability in telecommunications infrastructures	13
2.4.3 A new conceptual model of reliability	15
3 Methodology	17
3.1 Research characteristics	17
3.2 Research framework	17
3.2.1 Exploring issue, reviewing literature and conducting interviews	18
3.2.2 Create and adapt analytical framework	19
3.2.3 Case studies	21
3.2.4 Cross-case analysis	23
4 Case I: The Dutch gas infrastructure	27
4.1 Introduction	27
4.2 Gas infrastructure paradigm	28
4.3 Infrastructure context	29
4.3.1 Technical context	29
4.3.2 Economic context	33
4.3.3 Institutional context	37
4.4 Assessment of reliability	40
4.5 Treatment	42
4.5.1 Current practice	42
4.5.2 Future trends	44

5	Case II: The Dutch electricity infrastructure	47
5.1	Introduction	47
5.2	Electricity infrastructure paradigm	48
5.3	Infrastructure context	49
5.3.1	Technical context	49
5.3.2	Economic context	52
5.3.3	Institutional context	54
5.4	Assessment of reliability	56
5.5	Treatment	60
5.5.1	Current practice	60
5.5.2	Future trends	61
6	Case III: The Dutch telecommunications infrastructure	63
6.1	Introduction	63
6.2	Telecommunications infrastructure paradigm	64
6.2.1	A changing infrastructure	64
6.2.2	The "new" paradigm	65
6.3	Infrastructure context	68
6.3.1	Technical context	68
6.3.2	Economic context	70
6.3.3	Institutional context	72
6.4	Assessment of reliability	73
6.5	Treatment	76
6.5.1	Existing practice	76
6.5.2	Future trends	77
7	Cross-case analysis	79
7.1	Comparison of cases	79
7.1.1	Context	79
7.1.2	Assessment	83
7.1.3	Treatment	85
7.2	Discussion	87
7.2.1	The complexity of reliability	87
7.2.2	Relating reliability and network capacity	91
7.2.3	Price regulation of transmission networks	92
7.3	Dealing with reliability in vital infrastructures	93
8	Conclusion and reflection	97
8.1	Conclusions	97
8.2	Implications	98
8.3	Reflection	99
8.3.1	On methodology and research process	99
8.3.2	On interviews	100
8.3.3	On results	100
8.3.4	On generalisation	101
8.3.5	Further research	101
	Bibliography	103
	A Scientific Paper	111

List of Figures

1.1	Theoretical optimum of reliability	3
1.2	Zone of adequacy for reliability	3
1.3	ISO31000 risk management process	5
2.1	Transport infrastructure paradigm	8
2.2	The general QoS model and the ITU/ETSI approach	14
3.1	Research framework	18
3.2	Analytical framework	20
3.3	Characterization of vital infrastructures	23
3.4	Treatment options contributing to multiple strategies	25
4.1	The gas infrastructure paradigm	29
4.2	Balancing regime	31
4.3	Hourly gas use of residential consumers at different temperatures	32
4.4	Production flexibility in North-West Europe	33
4.5	Gas quality related to origin of gas supply	34
4.6	Monthly trade volumes on the TTF 2003-2008	35
4.7	Composition of the retail gas price	37
5.1	The electricity infrastructure paradigm	49
5.2	Average monthly electricity usage in the Netherlands 1995-2008	52
5.3	Composition of the retail electricity price	54
5.4	Interruptions in the Dutch grid in 2002	57
5.5	Comparison of electricity reliability in Europe	59
6.1	The telecommunications infrastructure paradigm	66
6.2	Current PSTN structure	67
6.3	Daily traffic pattern AMS-IX	70
6.4	All-IP network structure	77
7.1	Feasibility of treatment strategies	87
7.2	Zone of adequacy as a result of the complexity of reliability	90
7.3	Zone of adequacy as a result of uncertain investment costs	92
7.4	Zone of adequacy for transmission networks	95

List of Tables

2.1	Criteria for hardness of public values	11
2.2	Levels of reliability	15
2.3	Dimensions of reliability	16
3.1	List of interviewees	19
3.2	Context factors	24
4.1	Supply flexibility of different sources	32
4.2	Quality indicators gas infrastructure	40
5.1	X-factors TenneT per regulation period.	55
5.2	Quality indicators electricity infrastructure	57
6.1	Old layer model of telecommunications infrastructure	65
6.2	New layer model of telecommunications infrastructure	65
6.3	Value of bits: approximate price per megabyte of various services	70
6.4	Relevance of quality parameters	74
7.1	Technical context	80
7.2	Economic context	81
7.3	Institutional context	82
7.4	Assessment of reliability	84
7.5	Treatment options gas infrastructure	88
7.6	Treatment options electricity infrastructure	88
7.7	Treatment options telecommunications infrastructure	88

List of Acronyms

AC	Alternating Current
ADSL	Asynchronous Digital Subscriber Line
AMS-IX	Amsterdam Internet Exchange
APX	Amsterdam Power Exchange
CAIDI	Customer Average Interruption Duration Index
CEPS	Center of European Policy Studies
CBS	Statistics Netherlands
CHP	Combined Heat and Power
CIEP	Clingendael International Energy Programme
DSO	Distribution System Operator
EHV	Extra High Voltage
ENTSO-E	European Network of Transmission System Operators
FACTS	Flexible Alternating Current Transmissions Systems
GTS	Gas Transport Services B.V.
HV	High Voltage
HVDC	High Voltage Direct Current
IEA	International Energy Agency
IP	Internet Protocol
ISP	Internet Service Provider
IT	Information Technology
KPN	Royal KPN Netherlands N.V.
LLU	Local Loop Unbundling
LNG	Liquified Natural Gas
LV	Low Voltage
MDF	Main Distribution Frame
MV	Midlevel Voltage
OAPEC	Organization of Arab Petroleum Exporting Countries
ONP	Open Network Provision

PRP	Programme Responsible Party
PSTN	Public Switched Telephone Network
PTT	Postal and Telecommunications Services
RF	Radio Frequency
RPI-X	Price-cap Regulation
QoS	Quality of Service
RRP	Regulating and Reserve Power
SAIDI	System Average Interruption Duration Index
SAIFI	Customer Average Interruption Frequency Index
SDF	Street Distribution Frame
SEP	Cooperation of Electricity Producing Companies
SEPAM	Systems Engineering, Policy Analysis and Management
SLA	Service Level Agreement
SOLR	Supplier of Last Resort
SoS	Security of Supply
TCP	Transmission Control Protocol
TTF	Title Transfer Facility
TSO	Transmission System Operator
VoIP	Voice over Internet Protocol

Chapter 1

Introduction

The functioning of infrastructures is crucial in today's modern society; the continuous supply of energy, telecommunication services and clean drinking water is a prerequisite for the continued development and stability of nations. Because these infrastructures are key to societal and economic security and well-being, they are regarded as vital infrastructures whose reliability is of the utmost importance. The failure of a vital infrastructure can have one or more of the following effects (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2005, p. 3):

- Economic or social disruption on an (inter)national level.
- A large number of direct and/or indirect casualties.
- A long term disruption, with a long recovery period without real alternatives during recovery.

In the Western European region, the risk of infrastructure failure is compounded by two developments; the growing interdependency of infrastructures and the growing vulnerability of society to failures of these infrastructures. Infrastructures become more and more inter-dependent, both across national boundaries and between different types of infrastructure:

- A failure of the gas infrastructure can have a direct impact on the electricity infrastructure, as gas-powered power plants will have to be shut off, and in turn a failure of the electricity infrastructure can lead to a shutdown of the electrically powered trains of the rail infrastructure.
- The failure of a large power generation plant in France will have direct implications for the electricity infrastructure in the Netherlands.

This growing interdependence increases the importance of infrastructure reliability, because a failure might cause a cascading effect of failures in other infrastructures (le Gras, 2007; Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2005; Luijck et al., 2003). Additionally, the vulnerability to infrastructure failures has increased together with the technological development in Western Europe. This unexpected effect is described as the *vulnerability paradox* by Steetskamp and van Wijk (1994); the more reliable infrastructures are in a given country, the harder a disruption in these infrastructures will affect the country. This can be explained due to the fact that people are not confronted with disruptions on a regular basis, and thus are less prepared and resilient when an actual disruption occurs. For example, in less developed countries people often stock candles and back-up heaters to deal with interruptions of the electricity supply; a practice uncommon in more developed countries. Moreover, technological developments have led to a higher penetration of equipment dependent on certain infrastructures, most notable electrical and telecommunications equipment. This higher level of penetration increases the risk of disruptions even further and causes a *double vulnerability paradox* (Steetskamp and van Wijk, 1994, p. 10).

Even during the current economic crisis, the majority of forecasts project a continuing demand growth in most infrastructures over the coming 20 years. As a result, investments

in new infrastructure and/or more efficient use of the existing infrastructure are necessary to continue meeting the quality and reliability standards required from these infrastructures. However, these investments are faced with large uncertainties; infrastructures are faced with rapidly changing market conditions and regulations, especially given the ongoing liberalization and unbundling process in the European Union. Also, reliability is just one of the many values at stake in infrastructures. Other values like affordability, accessibility and sustainability also play an important role in the decision process. A future change in perception can suddenly influence the prioritization and valuation of these values.

Transmission system operators (TSOs) fulfill a central role in infrastructures. By developing, maintaining and operating the national transmission networks, they enable the delivery of products and services from source to destination. This requires sophisticated planning and investment decision making; often these practices are proven and tested, having been developed based on decades of experience. In a changing environment however, transmission system operators have to deal with the uncertainties described above, and as a result will have to reevaluate their planning and investment decision making methods.

1.1 Research objective

This master thesis study was performed as part of a larger research project at the Market Monitoring department (LTM) of the Transport Services unit at Gas Transport Services B.V. (GTS), the national transmission system operator of the Dutch gas network. GTS is responsible for the management, operation and development of the gas transmission system in the Netherlands. GTS's mission is the independent provision and implementation of gas transmission services for the benefit of a properly functioning liberalized gas market both within and outside the Netherlands. Their priorities are safety, reliability, security of supply, customer focus, cost-consciousness and professionalism (GTS, 2009b). The focus of the larger research project is on how GTS can develop the gas transmission network through economically sound investments, while also ensuring the affordability and reliability¹ of the gas transmission network and the functioning of the natural gas commodity market.

At the root of this problem is an assumed trade-off between higher investment costs on the one side and higher damage costs, caused by increasing supply interruption risks and imperfect market functioning, on the other side. If society invests more to increase reliability (in the form of transport capacity, emergency backup facilities or other solutions), gas shortages and supply interruptions will occur less frequently. This can also be reversed; when fewer investments are made, the risk of shortages and interruptions will increase. The risk of supply interruptions and the associated damage costs are assumed to be decreasing with increasing investments, but the marginal decrease will become smaller if more is invested. Based on these assumptions it is asserted that a socially optimal investment level exists where the total social costs are minimized and that investing more or less than this optimal amount is not desirable (see Figure 1.1). However, several other considerations come into play here.

First, there is the aim to stimulate market forces in the liberalized gas market, which requires the availability of free transport capacity on the market. Additional transport capacity enables market parties to flexibly source natural gas from locations where the natural gas is cheapest, driving down the average cost of natural gas on the market. Considering the fact that transport costs typically form just a fraction of the price paid for natural gas, increasing the transport capacity can have a significant lowering effect on the total product cost. This might lead to a higher optimal investment level than that derived from a pure cost perspective, because a higher level of capacity is needed to allow for arbitrage. To address the complexity of the research project, the problem is thus divided into several smaller research problems. This particular study focuses on the consideration of reliability in investment and planning decisions and thus deals less with the consideration of market functioning.

¹ The term reliability has been defined in many, slightly different ways throughout literature. While we will discuss the concept of reliability in much more detail in Chapter 2, we offer a short explanation here to avoid confusion. Reliability means that the good/service is delivered from the supplier to the user at an acceptable price and quality with a minimal amount of interruptions. An increasing level of reliability reduces the risk of supply interruptions. A supply interruption is defined as the unexpected unavailability of the product or service to the end-user.

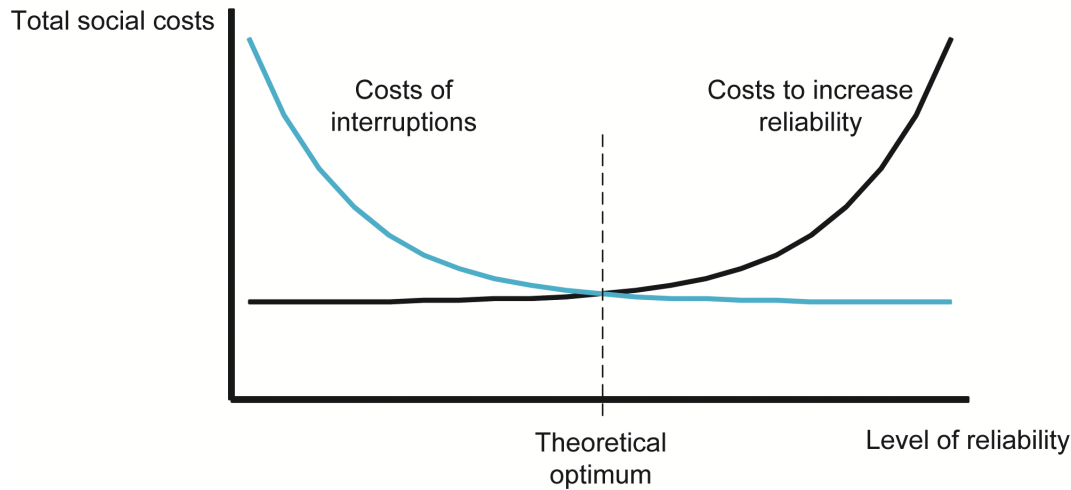


Figure 1.1: Theoretical optimum of reliability

Source: based on National Economic Research Associates (2002), Figure 3.1, p. 10

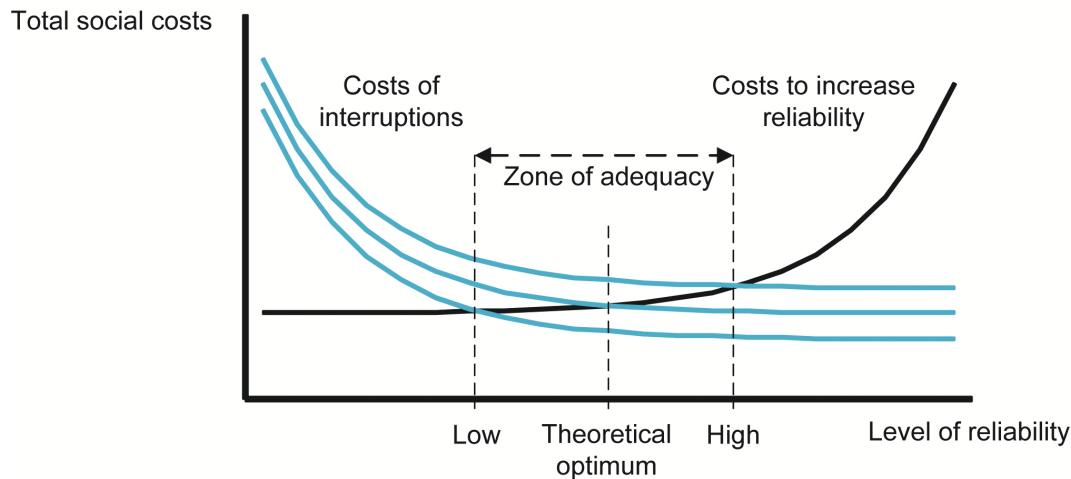


Figure 1.2: Zone of adequacy for reliability

Source: based on National Economic Research Associates (2002), Figure 3.2, p. 12

This of course does not mean we ignore the latter consideration, especially considering the interactions that inevitably occur in a system as complex as the gas network.

Second, based on Figure 1.1, it might be tempting to think that the cost curves can be determined easily. In reality, the different costs are very hard to determine, because they are influenced by a large number of factors, many of which have not even been properly determined yet. And a perfect distinction between internal and external costs (i.e. private and social costs) is hard to make, because the effects of supply interruptions can both be direct and indirect and can manifest themselves on different timescales (i.e. long-term rising prices or sudden price volatility) (Costantini and Gracceva, 2004). The effect of the uncertainty and ambiguity of costs is illustrated in Figure 1.2, where three different cost curves for interruptions are indicated.

The differences between these costs curves can have several causes, such as differences in the valuation of reliability by different stakeholders or under- or overestimation of the cost by the researcher. As a result, the costs can only be determined as a range of estimates. As long as the level of reliability lies within these estimates and the different cost curves are relatively flat, the social costs of "sub-optimality" are relatively limited. The level of reliability can thus be considered to be within a "zone of adequacy" (National Economic

Research Associates, 2002, p. 13).

The goal of the research project for GTS is to gain insight into this zone of adequacy compared to the current state of the infrastructure, considering a large variety in investment options (GTS, 2008a). In this research project we consider these investment options from a risk management perspective. They are treatment options available to transmission system operators, which can increase reliability. Of course, a number of these options have already been recognized and are already employed in the current gas infrastructure to increase reliability. However, we assume that these options were not always deliberately designed for the specific purpose of increasing reliability, but developed over time as a result of the context created by the company itself, market forces and the government. The current design and implementation of these options is thus assumed to be more the result of path-dependency than deliberate design.

Therefore, it is expected that in different infrastructures different options have emerged based on their respective context. By making a comparative analysis of multiple infrastructures, an increased understanding can be achieved of the effects of supply interruptions and options to reduce the risk of these interruptions, which can help transmission system operators in further developing their planning and investment decisions. In this research, the natural gas, electricity and telecommunications infrastructures in the Netherlands have been analyzed. This infrastructure overarching approach can also lead to creative insights, which might not be realized when the research is confined to one specific infrastructure. This project aims to identify how the context of an infrastructure influences both the assessment of reliability and the feasibility of treatment options available to transmission system operators in that infrastructure.

1.2 Research goal

The goal of the research is to make both a practical and a theoretical contribution. The practical contribution is to identify the feasibility of treatment options for transmission system operators to increase reliability. The theoretical contribution is twofold: the development of an analytical comparative framework, which enables comparison between infrastructures and a contribution to the knowledge about reliability in network infrastructures.

By identifying the feasibility of treatment options in different infrastructures, this research helps transmission system operators to further develop their planning and investment decisions. Refinement of these decisions is crucial to business success because of the typical characteristics of network infrastructures: sunk costs, long lead times and capital intensity. Thus ill-advised planning and investment decisions can lead to irreversible losses as they cannot be easily revised at a later stage. This is also important to society as a whole, as these additional incurred costs are most likely to be passed on to the public; especially in regulated, government-owned infrastructures like the electricity and gas transmission infrastructures.

The analytical comparative framework can be used as a starting point for multiple studies. It can be used by transmission system operators to analyze their current investment and planning decisions and identify promising options to increase reliability. It can be used by policy makers and regulators to gain insight in the differences and similarities between infrastructures, enabling them to design effective and made-to-fit policies. In academia it can be extended to additional cases within the infrastructures analyzed in this study or adapted for a comparative analysis with wholly new infrastructures.

Reliability is regarded as a central issue in infrastructures. However, the term is only loosely defined in literature and many other comparable terms like continuity, security of supply and adequacy are used to describe roughly the same issue, making reliability an overused and misunderstood concept (Helm, 2002). These conceptual issues make it difficult to clearly and precisely describe the problem at hand, as the concept is frequently discussed in an intuitive and non-systematic way (Luciani, 2004; de Joode and Touber, 2008). This becomes an even larger issue if we try to compare multiple infrastructures; the number of terms used and the different interpretations of these terms increase according to the number of infrastructures analyzed. In energy infrastructures the term security of supply (SoS) is especially prominent, while in telecommunications the term quality of service (QoS) is dominant. These terms have a lot in common, but their nuances make a direct comparison

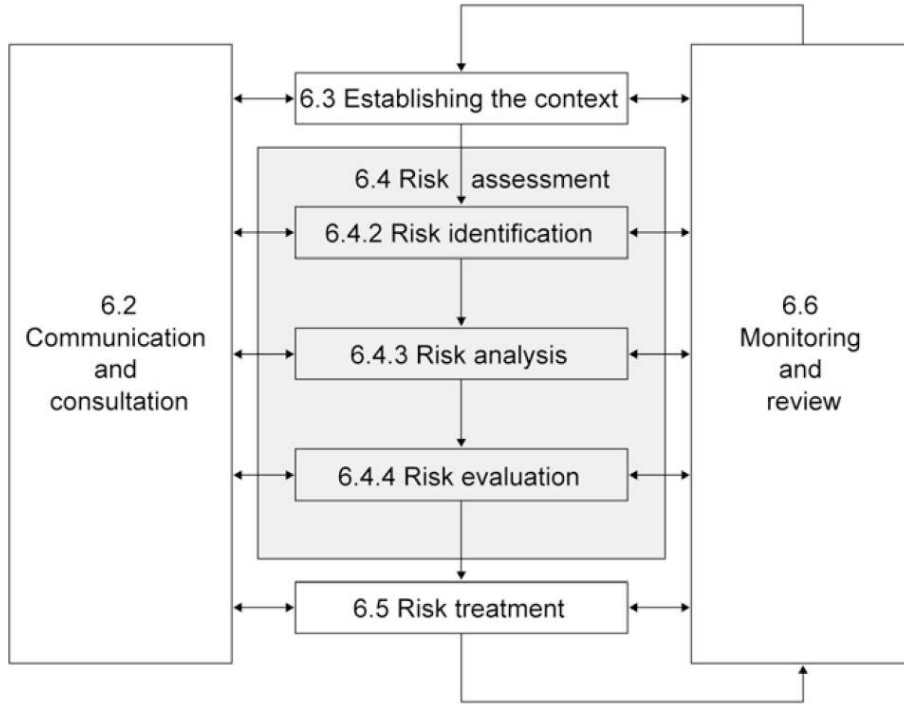


Figure 1.3: ISO31000 risk management process
Source: ISO (2009), Figure 3, p. 8

troublesome. By choosing an infrastructure overarching approach and developing a more infrastructure independent definition of reliability, this research aims to contribute to a more structured debate on reliability in infrastructures.

1.3 Research framework and questions

The main research question follows directly from the research objective:

"How does the difference in context between network infrastructures influence the assessment of reliability in that infrastructure and the feasibility of treatment options available to transmission system operators in that infrastructure?"

The research is structured around an analytical framework which was developed during the study and which will be discussed in more detail in chapter 3. This analytical framework is an adaptation of the official ISO31000 risk management process, which is depicted in figure 1.3. Using the ISO31000 risk management process as a starting point for this research is attractive because it is a widely accepted standard, both professionally and academically, and it is generic and not specific to any industry or sector (ISO, 2009). This makes it especially suitable for this research which is considered with a comparison between infrastructures. In this study we will focus on three steps in the risk management process: establishing the context, risk assessment and risk treatment. As can be seen, this does not comprise the whole risk management process. This decision is based on the limited time and resources available in the project and the fact that the excluded activities are outside the scope of analysis. The activities of “communication and consultation” and “monitoring and review” are more concerned with implementation in organization-specific contexts and processes and are thus outside the scope of this research, which focuses on the comparison between different infrastructures.

The following research questions have been derived from the main research question to enable a structured analysis. A more thorough discussion of these questions and the research process is provided in chapter 3.

1. *"How can reliability be defined and operationalized in network infrastructures?"* At the root of a good comparison between infrastructures is a clear and generic definition of reliability. While supply interruptions can occur in any infrastructure, the concepts are traditionally defined for a certain infrastructure in particular. To make a well founded decision on which aspects of reliability to incorporate in the comparative analysis, first the concept of reliability should be defined as thoroughly and unambiguously as possible.
2. *"What are the most important factors determining the context of network infrastructures?"* To make a comprehensive analysis of the different infrastructures possible, the context should be described in a systematic way. One way to do this is to describe the context in terms of factors. This description also allows an analysis of the influence of the context on both the assessment of reliability and the feasibility of treatment options available to transmission system operators in that infrastructure. This question corresponds to the "Establishing the context" step in the risk management process.
3. *"What is the influence of the context factors on the assessment of reliability in network infrastructures?"* The context influences the assessment of reliability in a given infrastructure. This assessment not only determines the necessity for improvement but also the perception about reliability in a given infrastructure. This question corresponds to the "Risk assessment" step in the risk management process.
4. *"What are the most important options for transmission system operators to improve reliability in network infrastructures?"* Several options to improve reliability exist, for example de Joode and Toubert (2008, p. 42) describe eleven options to improve the short-term reliability in gas infrastructures. However, not all these options are applicable to transmission system operators as they have only certain instruments and responsibilities in the total infrastructure. A clear and structured identification of the options available to transmission system operators is necessary for a good comparison between infrastructures. This question corresponds to the "Risk treatment" step in the risk management process.
5. *"What is the influence of the context factors on the feasibility of options to improve reliability?"* The context can influence the feasibility of options to improve reliability in different ways. For example, in electricity networks large scale energy storage is often considered prohibitively expensive and thus an infeasible option. Also differences in the tasks and functions of transmission system operators (e.g. due to the level of unbundling in a given infrastructure) may restrict the options available to a certain transmission system operator. By examining how the factors (defined in research question 2) influence the options (defined in research question 4), a clear analysis of the feasibility of options in a certain infrastructure can be made.

1.4 Structure of the report

Chapter 2 discusses the exploration of the research problem; it reflects on the concept of reliability in infrastructures and describes the risk management process in more detail. Chapter 3 is concerned with the methodology, explaining the research process and the research strategies used. It also describes the development of the analytical framework from the official risk management framework. Chapters 4 through 6 present the case studies that were performed. Chapter 7 then combines these case studies into a comparative analysis, and discusses general considerations in response to the research questions. Finally, Chapter 8 presents the conclusions and implications of the research and reflects on the research project.

Chapter 2

Issue exploration

This chapter explores the concept of reliability in infrastructures. It discusses the difficulties surrounding the determination and assessment of reliability in complex network infrastructures and presents the method chosen in this research to address these difficulties. The aim of this chapter is to integrate the infrastructure specific discussions on reliability into one overarching concept and to operationalize this concept for transmission system operators within the separate infrastructures.

First, in §2.1 we discuss some general features of transport infrastructures and transmission networks in particular. In §2.2, we will discuss the public interest issues attached to reliability in infrastructures and the consequences this has for dealing with reliability issues. In §2.3 we will argue for the selection of the conceptual risk management framework to analyze reliability in this research. In §2.4, an infrastructure overarching conceptual model of reliability is developed, based on the theoretical discussions on reliability in the separate infrastructures.

2.1 Transport infrastructure paradigm

Although the infrastructures that are analyzed in this research are very diverse and complex, their structures exhibit some strong similarities. These general features are represented in the transport infrastructure paradigm (see Figure 2.1), which is introduced here. The paradigm distinguishes some of the most important characteristics of the physical infrastructure and the institutional environment.

The physical infrastructure can be characterized by a supply chain consisting of four segments; supply, transmission, distribution and consumption. Transmission networks typically transport large quantities over long distances from a small number of suppliers to a small number of customers, most notably large industrial complexes and distribution companies. Distribution networks on the other hand typically transport small quantities over small distances to a large number of dispersed consumers.

Three typical forms of supply can be distinguished: producers, which create the product; storages, which store the product to supply it at a later time, and imports. The transport through the networks is arranged by network users, which conclude contracts with both suppliers and consumers of the product and contract transport services (e.g. capacity sales and balancing) from the network operators. Thus, two essential markets can be distinguished within the transmission infrastructure; the product market and the transmission market. The network operators manage, operate and develop the transmission and distribution networks to ensure reliable and efficient transport of the product. They also play an important role in balancing supply and demand in the network. The consumers can typically be divided in three categories; large consumers, small consumers and export.

Of course, this paradigm is a strong simplification of the actual infrastructures and ignores some infrastructure specific characteristics. For example, in telecommunications there is no single product market. However, the paradigm provides a good starting point for the individual case studies as well as a good comparative framework. In the case studies, the framework will be adapted and further extended to fit the analyzed infrastructure.

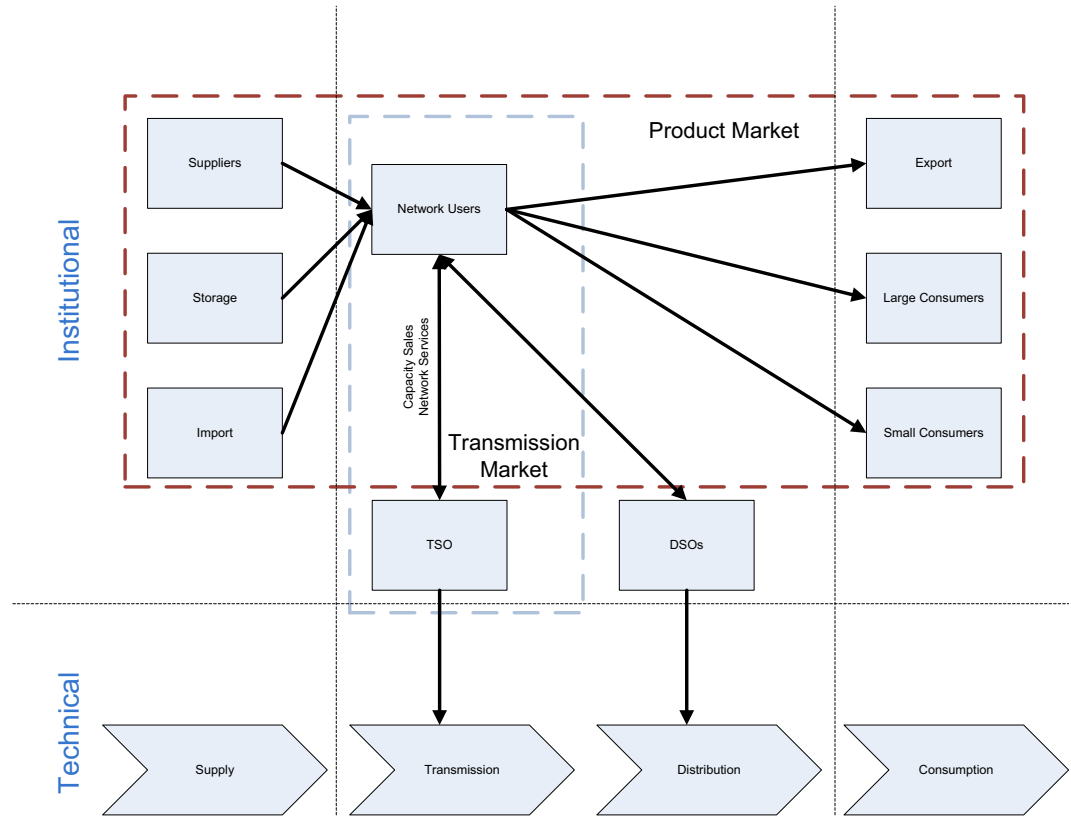


Figure 2.1: Transport infrastructure paradigm

Source: based on de Vries (2007)

2.1.1 Transmission networks

The focus of this research is on a particular part of transport infrastructures, namely on the transmission networks and the transmission system operators that develop, maintain and operate them. These transmission networks have some typical characteristics and design principles that are recognizable in almost all infrastructures. By discussing these early in the analysis, we stimulate a structured analysis and avoid repetition and overlap in the case studies as much as possible.

Transmission network characteristics

- Transmission networks transport large, aggregated volumes.
- Transmission networks have a limited number of large connections, often not directly connected to the consumer.
- Transmission networks are coupled to neighboring transmission networks.
- Transmission is regarded as a commodity, with limited added value compared to the transported product (e.g. gas, electricity or data).

Design principles

As the backbone of the national infrastructure and the connection to foreign infrastructures, transmission networks fulfill a central role in infrastructure reliability. Thus the reliability of these networks has to be extremely high. Commonly, transmission networks may only fail very infrequently and for very short periods of time. The allowed total failure time is often restricted to minutes per year, resulting in reliability requirements of 99,99% or above. Therefore transmission networks often have a very risk-averse design, which is reflected in the following design principles:

- Resilient network structures like meshed, ring or star configurations, which ensure the possibility to reroute flows if network components fail.
- High redundancy; transmission networks are designed to fulfill at least the N-1 criterion.¹ Distribution networks typically have lower reliability and redundancy requirements and do not have to fulfill this criterion.
- The investments are lumpy and discrete with long lead times, which requires initial over dimensioning to achieve reliability in the long-term.
- The investments are based on reliability criteria that are applied in network studies and design. These design reliability criteria are typically more strict than the operational reliability criteria that the TSO imposes during operation (Perez-Arriaga and Smeers, 2003). In turn, these operational reliability criteria are more strict than can be expected from a direct trade-off between investments costs and interruption costs.
- Because TSOs often do not have direct contracts with consumers, there is uncertainty and limited control over future network demand and flows. To anticipate this uncertainty, networks are typically over dimensioned.

2.2 Public interest of reliability

In the introduction, we stressed the importance of well functioning infrastructures for society as a whole. As a result the public interest of reliability in network infrastructures is large, which has important implications for the perception of reliability. For a good analysis of reliability it is thus necessary to have a clear overview of the public interest issues in a certain infrastructure. In this research we focus on two important aspects of public interest, namely public good and public value characteristics.

Public good characteristics

Public goods represent a form of market failure, as public goods will not be produced in adequate amounts by private markets. When reliability exhibits a strong public good character, the risk thus exists that the level of reliability provided is inadequate. This has been witnessed in several airlines, railways and electricity, where a focus on cost-cutting instead of *reliability*, has led to decreasing *reliability* levels (Luciani, 2004). In economics, a public good is defined as a good that has the following two characteristics:

- Non-excludability; when the good is provided to one consumer, other consumers cannot be excluded from access to the good.
- Non-rivalry; consumption of the good by one party does not reduce its availability to another party.

Because of these characteristics, a "pure" public good exhibits strong externalities; it has an impact on parties not directly involved in paying for the good. A classic example is a dike, where everybody behind the dike is protected from flooding, regardless if they paid for the construction of the dike. Thus, the public good character stimulates free riding; profiting from the provision of a good without contributing to the cost of its production. This is especially true in networks, where a large share of the reliability is an intrinsic characteristic of a network as a whole and is thus provided to all users.

However, an important network externality which contrasts with the notion of reliability as a public good is congestion. Because the capacity of a network is a limited resource, there is rivalry between users of the network; when the total demand exceeds the capacity of the network, the reliability decreases. It is important to determine the public good character of reliability in the different infrastructures, as this determines for an important part how well reliability can be provided by the market.

¹ A network fulfills the N-1 criterion if the failing of a random network element does not pose unacceptable limitations for the functioning of the network (D'Te, 2006, p. 12). The actual implementation of the criterion depends on the interpretation by stakeholders.

To make the importance of the public good characteristics of reliability clear, we provide one example. The impacts of a supply interruption differ per user and as a result not everyone values reliability equally. This could be addressed by consumer priority, where reliability is allocated to certain consumers at the costs of other consumers. For instance, consumers and traders may elect to accept a lower level of reliability in exchange for a lower price through interruptible contracts². Conversely, a certain group of consumers can also be protected from supply interruptions by government regulation, because they are considered extra vulnerable.

However, this separation might cause concerns when reliability is intrinsic to the network and thus largely a public good as described above; when a party which contracts interruptible supply does not financially contribute to the reliability, but essentially never experiences interruptions due to the high intrinsic level of reliability, they free-ride on the parties that do not contract interruptible capacity and thus pay a higher price. This can even create a moral hazard, where a party concludes interruptible contracts, while it cannot reasonably be disconnected. This has occurred in the UK, where some hospitals and care homes concluded interruptible gas contracts, sometimes even without arranging proper backup facilities, while interruptions could cause loss of life (DTI, 2006b, p. 5).

Public value characteristics

A public value is considered something that is valuable to a collective and thus has to be protected. Unlike for public goods, there does not exist a clear and unambiguous definition of public values in literature. For clarity, in this study we refer to the description of substantive public values provided in (de Bruijn and Dicke, 2006). A substantive public value has the following characteristics:

- There is a collectivity that can benefit from the protection of this value.
- There is an idea that the state is, directly or indirectly, responsible for safeguarding this value.

As all three infrastructures that are discussed in this research were public utilities before liberalization, both these characteristics have been considered as prominent and reliability was thus a clear public value. However, the characteristic of government responsibility has changed as a result of liberalization and privatization. In the gas and electricity infrastructures, the transport networks are still publicly owned monopolies, so the government still has responsibility towards reliability. In the telecommunications infrastructure however, the public switched telephony network (PSTN) has been privatized and competing communications networks with their own network operators (i.e. the RTV cable network and mobile networks) have been established, limiting government responsibility towards reliability.

As there are always costs associated with the protection of a value, a trade-off has to be made between different values. As public values are often ambiguous and hard to quantify, they are often considered soft values. In decision processes, soft values often tend to be sacrificed in favor of more hard values, as those show up more clearly in short-term results. It is thus important to determine how hard the value of reliability is in the analyzed infrastructures. Steenhuisen et al. (2009) provide a list of five criteria that influence the hardness of a value (see Table 2.1).

While the hardness of values can change dramatically when an incident occurs and they become politicized, it is useful to determine the relative hardness of reliability in the different infrastructures as this gives a good insight into the perception of the value of reliability. We will analyze the public interest issues in more detail in the individual case studies.

² Contracts that can be interrupted if there is a lack of supply or transport capacity (congestion).

Table 2.1: Criteria for hardness of public values

Criterion	Impact on hardness
Visibility	The more visible the problem and the current state of the value are, the harder the value.
Ability to Operationalize	The more the value is quantifiable and represented in norms, the harder the value.
Enforceability	The better a value is enforceable, the harder the value.
Immediacy	The sooner neglect of the value leads to problems, the harder the value.
Contestedness	The more consensus there is about the need and priority of the value, the harder the value.

Source: based on Steenhuisen et al. (2009), Box 1, p. 9

2.3 Dealing with reliability

Before we can continue conceptualizing reliability, we should consider an appropriate approach to address reliability issues. This will guide the choice of conceptualization: Which aspects are considered part of the analyzed system and which are part of the environment? Which central ideas are important enough to elaborate further and which can be considered peripheral? In this section we will discuss two different approaches to address reliability issues.

In literature, reliability is often directly associated with the risk of supply interruptions (e.g. in (de Nooij et al., 2007)). Intuitively, reliability and the risk of supply interruptions can be seen as two sides of the same medal, where reducing risks will increase reliability and vice versa. If we choose this narrow intuitive approach, we arrive at an economic trade-off between the cost of supply risks and the costs to reduce these risks. However, the same simplicity that makes this approach attractive, severely limits its scope and ability to deal with the intricacies of complex network infrastructures.

Another approach is proposed by the Center of European Policy Studies (CEPS) in their Insuring against Disruptions of Energy Supply (INDES) project, where security of supply is defined as a more active measure that (Egenhofer and Legge, 2001, p. 3):

“exists of a variety of approaches aimed at insuring against supply risks. Security of supply [thus] becomes a cost-effective risk management strategy of governments, firms and consumers.”

This active approach seems highly applicable in this research, as one of the aims of this research is to identify actual treatment options available to transmission system operators. Defining reliability as a risk management strategy enables us to identify and categorize treatment options in a structured way, by using and extending an existing and proven risk management framework. As argued in the introduction, we apply the ISO31000 risk management process as a starting point for this research, because it is a widely accepted standard, both professionally and academically, and it is generic and not specific to any industry or sector (ISO, 2009).

Furthermore, it allows us to include the influence of the technical, economic and institutional context on reliability and to deal with the uncertainty and multi-dimensionality of reliability. Unlike the economic trade-off, which conceptualizes reliability as a cost factor that can be exchanged, treated or mitigated just like any other cost factor, this can help us create a more comprehensive set of decision options (Renn, 1998). This makes it especially suitable for this research, which is considered with a comparison between infrastructures. To be able to answer the research questions, the risk management process was adapted in a new analytical framework, which will be discussed in chapter 3.

2.4 Conceptualizing reliability

To enable a good comparison between infrastructures, a clearly defined and generally applicable conceptual model of reliability should be developed. In this way, similarities and differences between infrastructures can be identified and analyzed in a structured and effective way. This conceptualization is achieved by analyzing and combining theoretical notions on reliability in the different infrastructures.

2.4.1 Reliability in energy infrastructures

Research on reliability in energy infrastructures, like oil, gas and electricity has a long history. As a result, an extensive and specific vocabulary has evolved to describe aspects of reliability in energy infrastructures. The central term used in energy infrastructures for these issues is security of supply³. This is a direct reflection of the first confrontation with the issue; the abrupt stop of *supply* sources. The term originally came into vogue after the first oil crisis in 1973. The oil embargo of the Organization of Arab Petroleum Exporting Countries (OAPEC) made Europe and the United States aware that the dependence on remote and unreliable countries threatened the vital continuous supply of oil. This led to the establishment of the International Energy Agency (IEA) in 1974, an organization dedicated to responding to the risk of physical disruptions in the supply of oil.

In the following decades the concept of security of supply was extended to different energy infrastructures, like electricity and gas (Bielecki, 2002). Also the scope of the concept was widened from interruptions of supply sources alone, to also include network security and market functioning. This makes the concept of security of supply a complex one; this section aims to refine the most important aspects of security of supply.

Price and availability

Traditionally, energy markets are characterized by geographically separated production and consumption; large-scale production plants produce the energy which then has to be distributed to a large consumer base. Therefore, the physical availability and price of the good at the place of consumption are traditionally seen as the main constituent parts of security of supply (Checchi et al., 2009; Jamasb and Pollitt, 2008; Egenhofer et al., 2004). These two constituents are tightly linked together, as is clearly illustrated from the definition of energy supply security by the European Commission (European Commission, 2000, p. 2):

“Energy supply security must be geared to ensuring...the proper functioning of the economy, the uninterrupted physical availability...at a price which is affordable...while respecting environmental concerns...Security of supply does not seek to maximize energy self-sufficiency or to minimize dependence, but aims to reduce the risks linked to such dependence”

This link between availability and price is evidenced by the fact that there always is a sufficiently high price where supply would meet demand, because consumers would no longer be able to pay for supply. However, given the importance of infrastructures, this would affect the economy in such a negative way, that one could not possibly call this security of supply, which means to maintain a stable supply at a reasonable price to avoid market distortions (OECD/IEA, 1995; Bohi and Toman, 1996). Thus security of supply also implies that the price of the good should be affordable, stable and predictable (Checchi et al., 2009; Helm, 2002; Jepma, 2004; Luciani, 2004). On the other hand the price also limits the maximum attainable level of security of supply, as the costs of reducing the risk of supply interruptions increase with the level of security. Thus absolute security of supply, defined by Neumann (2003) as “a state without any disruption or delay of delivery due to endogenous or exogenous influences” is neither attainable nor desirable.

³ To stay true to the sources and avoid confusion about terminology, we refer to security of supply instead of reliability in this section

Reliability and time

Reliability is not a static aspect that is stable in time; that the network functions now, says little how it will function in case of calamities or in the far future. This *notion* has spawned many different distinctive notions and even more terminology in literature. For clarity, we give a short overview of some of these terms, before we define the terminology we will use in the rest of this report. An often made distinction is that between short-term and long-term security. The short-term security of supply is mostly described as the ability to meet the total demand during operation. This is evidenced in literature by the use of terms like continuity (Egenhofer and Legge, 2001) and reliability (Joskow, 2005; von Hirschhausen, 2006). On the other hand, the long-term security of supply is described mainly in terms of adequacy (Egenhofer and Legge, 2001; IEA, 2002; Stern, 2002; Joskow, 2005) and relates to the certainty that enough production and transmission capacity will be available to meet demand in the long term. Another distinction is made between the concepts of operational and strategic security (Stern, 2002; Egenhofer et al., 2004). This distinction is closely related to the cause of the interruption risk (i.e. extreme weather, calamities or a lack of investment).

However, the definition of these concepts is complex and contradictory throughout literature. In this research the approach of CIEP is adopted because in this approach both the time dimension and the source of the risk are integrated into one classification (Correljé, 2010). The CIEP approach distinguishes between operational, strategic and long-term reliability:

- Operational reliability relates to the ability to meet demand under normal operation procedures (including extreme weather).
- Strategic reliability relates to the ability to withstand calamities (such as the failure of critical supply sources or transport routes) affecting the infrastructure.
- Long-term reliability relates to adequate developments to meet demand in the long-term.

Reliability and the value chain

Besides distinguishing reliability based on the cause and time, the distinction can also be made on the basis of the segment which is critical for (the lack of) reliability. In literature on energy infrastructures often a distinction is made between the reliability related to physical supply of the good and the reliability related to the adequacy of investment in infrastructure (i.e. in (Helm, 2002; von Hirschhausen, 2006; Jamasb and Pollitt, 2008; de Joode and Touber, 2008)).

In most network infrastructures we can distinguish three principal segments in the value chain: the production segment, the transport segment and the demand segment. Because of the technical, economic and institutional differences between these segments, they can have very different implications for reliability. For this reason we will develop this distinction further in the conceptualization.

2.4.2 Reliability in telecommunications infrastructures

As a fellow network infrastructure, the telecommunications infrastructure shares a lot of characteristics with energy infrastructures. However, there is one difference of critical importance. Unlike in energy infrastructures, where the main function is the delivery of a physical good, the main function of telecommunications infrastructures is to enable communication between users connected to the infrastructure. Thus the distinction between suppliers and consumers is not as clear cut as in energy infrastructures; an user can be a producer and consumer of information at the same time. This capability to exchange information through a telecommunications medium is considered a service, provided to a customer by a service provider. This service has to have a certain quality to satisfy the needs and expectations of the users. So when we discuss reliability in telecommunications infrastructures we do not talk about security of supply, but rather about the quality of service (QoS).

Quality is defined in ISO8402⁴ as "the totality of characteristics of an entity that bear on its ability to satisfy stated and implied needs" (ISO, 1994) The term quality of service is

⁴ International standard on Quality Management and Quality Ensurance

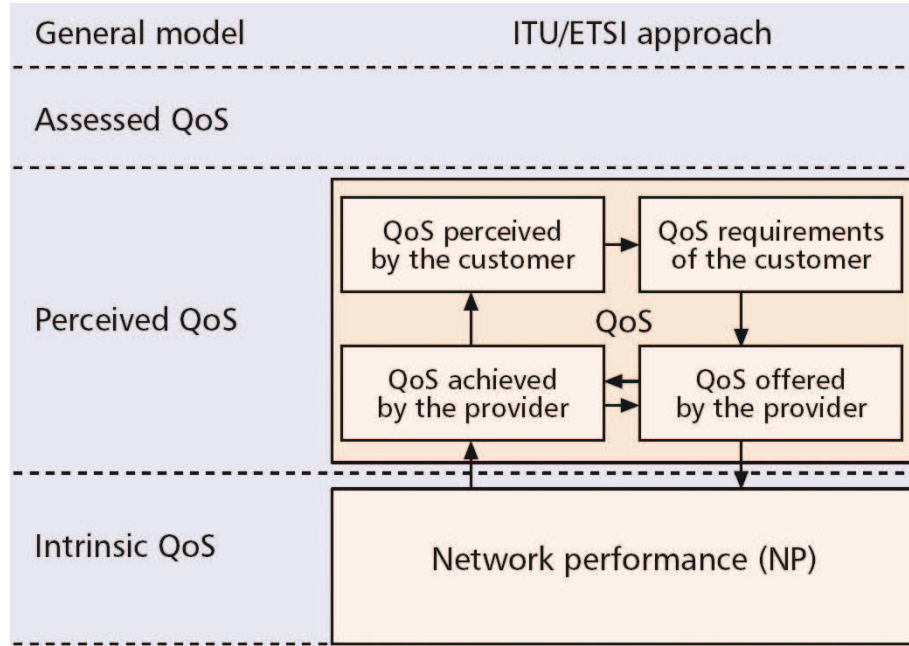


Figure 2.2: The general QoS model and the ITU/ETSI approach
Source: Gozdecki et al. (2003), Figure 1, p. 154

inherently broad, with parties having multiple different notions of the term and distinguishing multiple different characteristics that constitute the overall quality. In this section we will describe these notions and characteristics.

Notions of Quality of Service

In (Hardy, 2001) three notions of QoS are defined: intrinsic, perceived and assessed QoS (see Figure 2.2). Intrinsic QoS relates to service quality determined by technical aspects; thus it depends on the design of the transport network and the provisioning and quality of network access and components. It is often directly associated with network performance.

Perceived QoS relates to the quality experienced by the user; it is influenced by the observed performance compared to the user's expectations. This makes perceived QoS subjective and personal; even when the intrinsic quality provided to users is the same, the perceived QoS might differ between users. Perceived QoS also is influenced by the agreements, contracts and conventions between providers and customers, as is visualized in Figure 2.2.

Assessed QoS only becomes visible when an user decides to continue using a service or not. Because the most influential organizations in telecommunications terminology standardization (i.e. ITU/ETSI) do not explicitly deal with assessed QoS (Gozdecki et al., 2003) and the issue of service discontinuation is outside the scope of this research, we will not elaborate on assessed QoS in this research.

Characteristics of Quality of Service

Both the intrinsic and perceived QoS in a network can be described by a set of parameters. The intrinsic QoS parameters describe how individual packets pass through the network and are directly related to the network architecture. Some of most used parameters, which are applicable to a broad range of different services, are (Gozdecki et al., 2003):

- The bit-rate (flow) of data transfer
- The delay of data transfer in the network
- Jitter, or the variations in delay between individual packets

Table 2.2: Levels of reliability

Level	Description	Determination by
3	Perceived Quality	Behaviour of Actors
2	Intrinsic Quality	Measurable intrinsic quality parameters
1	Dependability	Frequency and severity of interruptions

- Packet loss rate, the ratio of undelivered packets to sent ones
- Unidirectional or bidirectional traffic
- Guaranteed or statistical QoS⁵

The parameters to describe perceived QoS are more difficult to define, because they do not only depend on the technical characteristics of the network but also on the specific environment and processes surrounding the service. Therefore defining general usable parameters for perceived QoS is an intensive and difficult process, which can even be an unfruitful approach, given the subjectivity of perceived quality. The inherent multidimensionality of QoS makes it a more complex phenomenon than reliability in energy infrastructures; apart from the actual delivery of the service, also the quality of the service can differ significantly.⁶ This makes it harder to assess QoS, but also greatly increases the opportunities to determine and offer different levels of QoS, which enables differentiation between services. To allow for this differentiation while keeping QoS intelligible for customers, contracts for telecommunications services often include a Service Level Agreement (SLA), which is an agreement on levels of service characteristics and the associated set of metrics, negotiated between a customer and the service provider.

2.4.3 A new conceptual model of reliability

So, now that we have introduced the concept in reliability in the different infrastructures, what does that mean for the transmission system operators in these infrastructures? Which aspects of reliability are general enough to be determined in all analyzed infrastructures, but specific enough to focus on the responsibilities and capabilities of a transmission system operator? Which relate directly to the research problem addressed in this study and which do not? Here we develop an integrated approach to reliability, which is appropriate for this research.

First, we distinguish three levels of reliability (see Table 2.2): dependability, intrinsic quality and perceived quality. Dependability, the first level of reliability, refers directly to the continuity of supply and frequency of interruption. In analyses of energy infrastructures, this is often the only level of reliability that is considered. But in this analysis, such an approach would be too narrow. Therefore, we introduce two more levels of reliability. The intrinsic quality refers to technical quality aspects of the service/good and thus can be determined by analyzing measurable quality parameters. Finally, we distinguish perceived quality, or how actors experience the offered quality. As we discussed before, perceived quality is highly subjective and not easily measured in generally usable parameters. Therefore, when analyzing perceived quality in this research, we will have to look at the actual behaviour of actors to deduce information about the perception of quality.

A second conceptual model brings together the notions of operational, strategic and long-term reliability and the segments of the value chain. This is an extension of the typology given by the Clingendael International Energy Programme (CIEP), which did not explicitly include the demand segment in the typology. Table 2.3 displays this conceptual model and illustrates that every combination results in different requirements for reliability.

⁵ Statistical QoS is based on expected levels of QoS and depends on the actual situation of the network. For example the QoS can be lower in case of congestion or equipment failure. By offering statistical QoS, the service provider can optimize the usage of his resources.

⁶ Of course the delivery of electricity and gas is also characterized by clear quality requirements. However these requirements are fixed; there is only one or a few set qualities.

Table 2.3: Dimensions of reliability

	Operational	Strategic	Long-term
Supply	Supply available to meet both the defined peak daily demand and to supply during a severe period or winter.	Ability to meet firm demand in the event of severe disruption to a principal supply source.	Supply available to cover the future projected demand.
Transport	Capacity to transport gas to meet defined peak daily demand.	Network capacity sufficient to meet peak firm demand in the event of defined loss of infrastructure.	Network expansion designed to meet the anticipated demand growth.
Demand	Demand able to adjust to scarcity signals of supply or transport capacity.	Adequate demand reduction measures in place to mitigate supply or transport failures.	Stable demand and reliable prices to enable investments in supply and transport.

Source: based on Correljé (2010)

How do these conceptualizations help us in conducting our research? First of all, they help us link reliability to the responsibilities, tasks and qualities of transmission system operators in a structured way. In all infrastructures, the technical quality of the network components and architecture is central to the functioning of the infrastructure. The dependability and intrinsic quality is thus of paramount importance to the reliability of the infrastructure. Also, the perceived quality of the network is important, as it puts constraints on the acceptable and allowable levels of reliability and has a major impact on the trade-off between price and reliability of the infrastructure. While the transmission system operator is the main responsible for the intrinsic quality of the network, it has relatively little influence on the perceived quality of the network as it is often has no direct contracts with the end user, and so cannot manage the expectations and agreements with the end user.⁷ This means that the perceived quality must mostly be seen as an external influence for a transmission system operator.

In this research, the focus is on reliability considerations in long-term planning and investment decisions. As a result the focus is more on the strategic and long-term reliability, than on the operational reliability. However, it is well possible that long-term planning and investment decisions influence the operational processes and/or that the operational reliability plays an important role in the current planning and investment decision process.

The main responsibility of TSOs is the coordination of transport through the transmission networks; they provide enough capacity to meet the transport demands and operate the network in an efficient way. On the other hand the supply and demand conditions are mainly outside the control and duties of the transmission system operator (with some exceptions, e.g. the public service obligation of the gas transmission system operator to ensure gas delivery to small consumers when the average daily temperature is below -9 °C (GTS, 2009b)). This means that the majority of planning and investments decisions by transmission system operators relate to the transport segment. However, the transmission system operator can also facilitate changes in the supply and demand segments to influence reliability, e.g. by providing more information about its network. The analysis of these segments can thus also provide interesting options for transmission system operators.

⁷ End users (in particular small consumers) often have an all-in contract with an energy supplier or internet service provider, which includes payment for the usage of transmission and distribution networks

Chapter 3

Methodology

This chapter describes the characteristics of the research and the research framework used. The research framework identifies among others the research approach employed, the steps performed in the research and the structure of the analysis.

3.1 Research characteristics

The research performed is clearly *explorative*; by making an untested comparison between different infrastructures, it attempts to identify concepts and relations within an analytical framework. It relies on an *iteration* of reviewing literature and conducting interviews, continuously diverging and converging, until a satisfying result is obtained. While the expected results of the research were assessed beforehand to ensure that the research project was feasible, the scope of these results has changed significantly during the research because new information necessitated refinement of the initial problem analysis.

Because of the complexity of the research subjects, complex and vital infrastructures, the research is also necessarily *qualitative*. The technological, economic and institutional differences between infrastructures and the complexity of the relations make quantification both extremely demanding and too simplistic. Given the long lifetime of infrastructures and the heavily changing context during this lifetime, the issues are longitudinal and changing over time and any relations are strongly influenced by the context. Thus there are only a few direct cause-and-effect relations that can be distinguished, as most cause-and-effect relations are heavily grounded in a context that is hard to determine and/or control. Therefore these relations are better referred to as "causal tendencies" (Sobh and Perry, 2006, p. 1200), relations that can be contested and ambiguous and thus are not suitable for quantification.

The research is also inherently *interpretative*; from the selection of cases, through the identifying of concept of relations to the interpretation, all decisions are to some degree influenced by the skills, position and perception of the researcher. Also, while the research subjects are constantly changing, they are analyzed in a particular context and moment in time making the resulting analysis a snapshot, which cannot convey the full complexity of the subjects. The research process and strategies are designed in such a way that these characteristics of the research are respected, but also the limitations and concerns are addressed.

3.2 Research framework

The research process by which the research questions were addressed, has been structured in different steps. These steps are identified in the research framework (see Figure 3.1); the boxes show the activities performed, while the arrows show input-output relations between the different steps. For clarity, it also has been indicated in which chapters the main results of the separate steps are presented. Because of the explorative and iterative character of the research, the research process has been adapted at several times and iteration steps were performed. For a structured and clear representation of the research process, and considering the fact that this report is meant to present the results of the whole research,

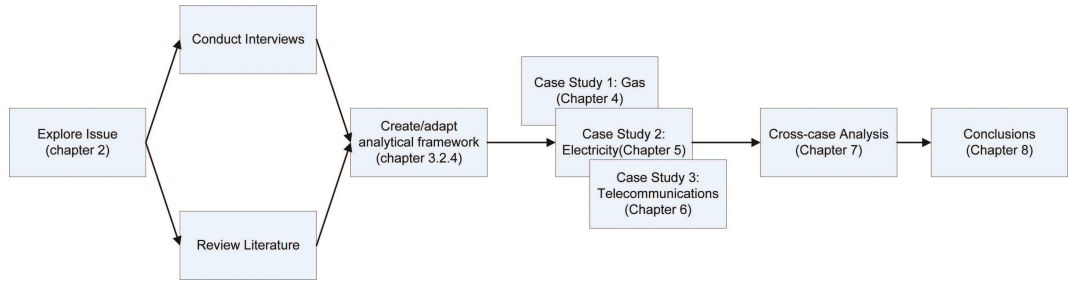


Figure 3.1: Research framework

and not intermediate results and analyses, these iterations and changes are omitted from the research framework. For a further discussion on these changes and iterations, we refer to the reflection in §8.3.

3.2.1 Exploring issue, reviewing literature and conducting interviews

Prior to the analysis, an exploratory literature review was performed to identify the relevant research fields, the infrastructures most suitable for analysis and an initial list of factors that were reasonable generalizable and operationalizable in the different network infrastructures. This initial list was helpful, because it stimulated a structured and uniform description of the different infrastructures, which helped increase the comparability of the case studies to be performed. After this broad scope was determined, data gathering in the form of reviewing literature and conducting interviews was performed, from which an analytical framework was developed to perform the case studies.

Because of the lack of comparable multi-infrastructure analyses a broad field of research has been studied in the literature review. Among these were literature on:

- Individual infrastructures, discussing technical, economic and institutional aspects of the researched infrastructures.
- Literature on vital infrastructures (e.g. Wetenschappelijke Raad voor het Regeringsbeleid (2008)).
- Literature on reliability, security of supply and quality of service (e.g. de Bruijne (2006); Egenhofer et al. (2004); Gozdecki et al. (2003); National Economic Research Associates (2002)).

The literature review was extended to create a rich description of the individual infrastructures. This was done by analyzing a broad range of publicly available reports, created or commissioned by infrastructure companies, regulators and governmental organizations. To describe the context of an infrastructure, a system analysis was made. This systems analysis is based on the general system analysis knowledge acquired in the Systems Engineering, Policy Analysis and Management master and the infrastructure paradigm used in the course "Electricity and Gas Markets" in particular.

The interviews were crucial in determining the relation between theory and practice. The interviews were used both to confirm assumptions made from the literature review and to identify concepts that were overlooked during the review. The interviews were conducted in an open fashion and in exchange with the literature review, mirroring the explorative and iterative character of the research. After the exploratory literature review, the literature has been step-by-step enfolded around sequential interview data, converging the scope of both the literature review and the interviews along the way. The questions and substance of the interviews has thus changed significantly between interviews, based on new information and insights.

Because of the specific knowledge needed from the interviewees, the interviewees were experienced senior employees of network operators and regulators; while politicians and user

Table 3.1: List of interviewees

Name	Function	Organization
GTS1 ¹	Senior Infrastructure Expansion	National Gas TSO
GTS2	Senior Infrastructure Expansion	National Gas TSO
GTS3	Senior Infrastructure Expansion	National Gas TSO
GTS4	Senior Infrastructure Planning	National Gas TSO
TenneT1	Senior Infrastructure Expansion	National Electricity TSO
EK1 ²	Senior Economic Advisor	Regulator Gas and Electricity

opinions are very relevant for the context, their expected input was deemed to be too un-specific for this research. Also obtaining this information would have required other research methods (e.g. surveys). The interviews were based on an open questionnaire, with a small number of general questions. When important or previously unknown issues arose during the interviews, more specific follow-up questions were used. Most interviews took 1 to 1.5 hours and a summary was made, which was confirmed with the interviewee. To preserve the open and explorative character of the interviews no recording equipment was used and no literal transcripts were made. An anonymized list of interviewees and their functions is presented in table 3.1.

3.2.2 Create and adapt analytical framework

In the

introduction, the risk management process has been introduced as a starting point for the analytical framework. The framework was adapted both to focus on the issue of infrastructure reliability and to enable a comparison of different infrastructures. Within the framework (see Figure 3.2) the following aspects are identified:

- the different parts of the risk management process to be analyzed
e.g. establishing the context, risk assessment and risk treatment.
- the relations between the different parts of the risk management process
e.g. the context influences the assessment of reliability and determines the feasibility of treatment options to ensure or increase reliability. At the same time, the assessment of reliability determines the necessity of the treatment options.
- the concepts or factors that constitute the different parts of the risk management process
To enable a structured analysis, a number of concepts have to be identified that are applicable to all cases. This is further discussed in paragraph 3.2.4.
- the relations between these concepts
We are interested in the interactions and dependencies between the concepts we have identified. How exactly does a certain context factor influence the assessment of reliability and/or is this influence dependent on other context factors as well?

Due to the complexity of the research subjects, identifying all possible concepts and relations is an impossible task. To make the research structured and feasible, the analysis thus has to be confined to a certain set of concepts and relations. These concepts and relations should be selected based on parsimony, relevance and completeness. During the research, the set was constantly adapted and concretized based on new information gathered through the iterative process of literature review and interviews. Also, there was a constant evaluation of the individual case studies and the cross-case analysis as is displayed in Figure 3.2. By

² GTS1 had significant previous working experience in fixed line telecommunications infrastructure at KPN and thus also contributed information for the telecommunications case.

² Due to confidentiality restrictions, the discussion with interviewee EK1 did not follow the interview format, but consisted of a discussion and validation of the case study.

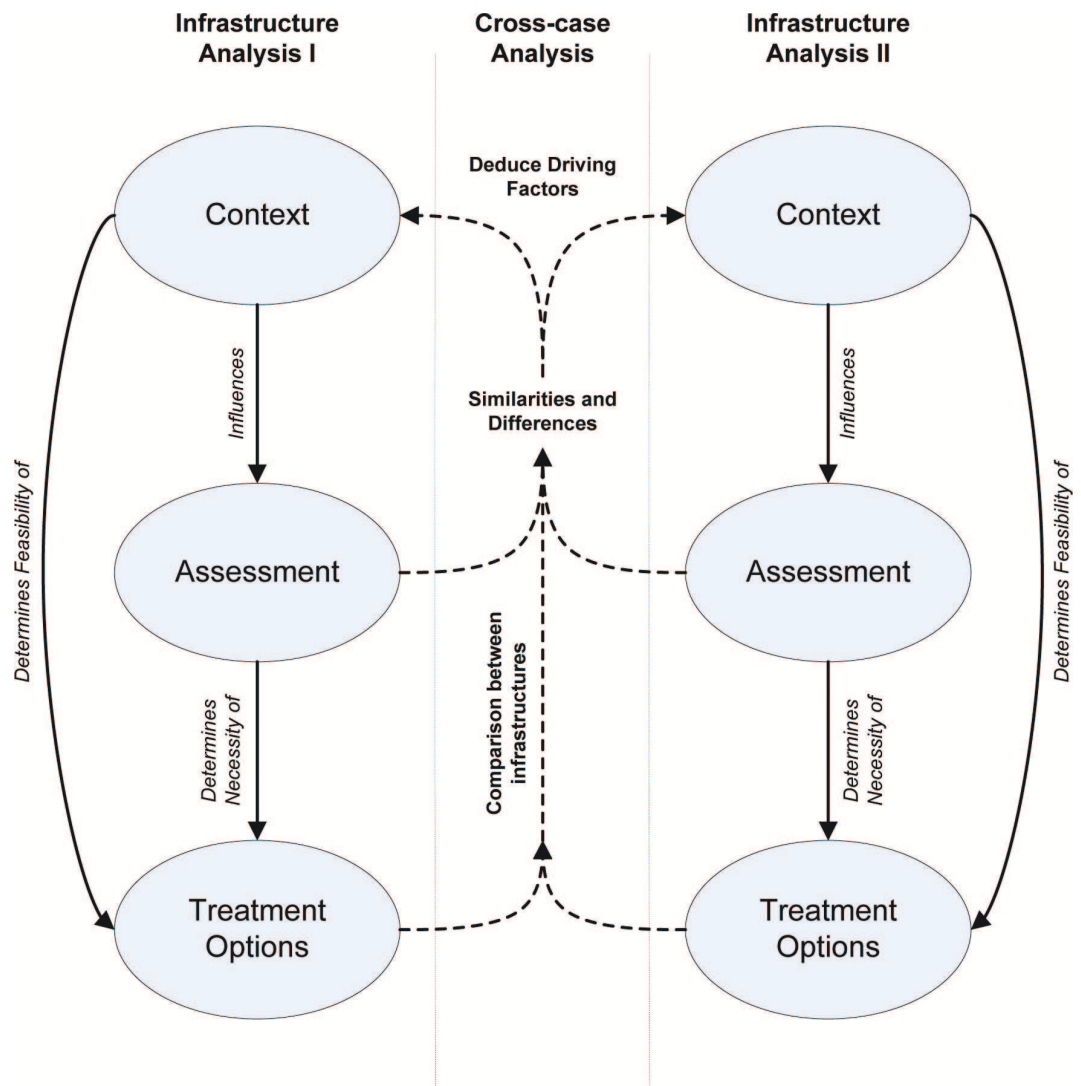


Figure 3.2: Analytical framework

comparing the results of the case studies and identifying differences and similarities it was possible to determine the most important (or "driving") factors and eliminate factors that had limited influence or were too case specific. By then refining the individual case studies by using those driving factors, we were able to make a better cross-case analysis and so forth.

3.2.3 Case studies

The case study research strategy forms the center of the research project, being the dominant strategy used to answer research questions 2 through 5. The reason for employing this research strategy over rival strategies is that the research exhibits four proponents for case study research (Yin, 1994, p. 1):

- Most research questions have an explanatory rather than a descriptive character, dealing with distinguishing operational links between factors and symptoms, rather than mere frequencies or incidences.
- There is no control over the research objects during the research (network infrastructures are large and complex technical and socio-political systems).
- Reliability is a contemporary phenomenon within a real-life context.
- For the structure and comprehensiveness of the study, the research is based on a conceptual theoretical framework and does not include close-up, detailed observation as a source of evidence.³

Case study design

The scope of this research project (as a master's thesis project) and the desire to undertake a more in-depth than broad analysis poses several requirements on the design of the case studies. The selected cases are limited in number and diverse, because multiple infrastructures are compared in a comparative and sequential case study. This limited number of research objects is often seen as a limitation to the explanatory power and validity of case studies. The fact that only one or a couple of cases in a category is examined can give an inappropriate weight to cases, as the presence or absence of certain variables and relations in a certain case is subject to probability (Vaughan, 1992, p. 174). In other research strategies this problem is overcome by examining a large number of samples, making it possible to determine the statistical significance of relations between variables. However, the goal in qualitative research is often not the representative capture of all possible variations (i.e. probabilistic sampling) but gain a deeper understanding of the analyzed cases and development of an analytic framework and concepts (i.e. theoretical sampling) (Corbin and Strauss, 2008).

This theoretical sampling corresponds to the replication logic in multiple-case studies described in (Yin, 1994, p. 46). Across case studies, two forms of replication are distinguished: (a) literal replication, in which the cases predict similar results and (b) theoretical replication, in which the cases produce contrasting results but for predictable reasons. To include both forms of replication in the research, it was chosen to analyze three infrastructures for the case study; the gas infrastructure, a relatively comparable infrastructure and an infrastructure that significantly differs from the first two on some aspects.

Another strong argument for using theoretical sampling with a limited number of cases is the fact that we deal with very complex systems that are in constant dialogue with their environment. The resulting processes and interactions are often contingent, haphazard and fuzzy, so analyzing them with probabilistic sampling, which cannot address action, agency and complex event sequences, but relies on simple one-step rational and deterministic description, would only describe them in crude and ad hoc ways (Abbott, 1992). Furthermore, properly capturing all factors and dependencies using probabilistic sampling would be unmanageable, given the sheer number of possible combinations (Lieberson, 1992). This complexity also necessitates that every case is analyzed separately in its own narrative before making the comparative study. For this reason, each case study is presented in a separate chapter.

³ This fourth proponent is not used directly by Yin to advocate case study research, but is used later to distinguish it from qualitative research (and grounded theory in particular). This distinction is confirmed by Corbin and Strauss (2008).

Selection of cases

For the selection of cases, a trade-off has to be made between the comparability of the case studies and the new information they can produce. Analyzing completely identical case studies does not lead to new insights, while comparing infrastructures with only very little similarities makes it very hard to make realistic comparisons at all. Because the Dutch gas infrastructure performs very well in comparison to neighboring gas infrastructures, being at the same time one of the most reliable and least expensive (Arthur D. Little, 2008) networks in Europe, a comparison between multiple gas infrastructures was considered to provide only limited additional insight. Therefore it was chosen to make a comparison between vital infrastructures in the Netherlands; in this way the geography and political and social environment of the infrastructures are comparable, while at the same time the infrastructures can differ significantly from a technical and financial perspective.

To select the most viable cases for the analysis, we started from a list of vital infrastructures as identified by the Ministry of Interior and Kingdom Relations. In (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2005) 12 vital infrastructures are identified, which assist in delivering 33 vital products and services. Moreover, we focus on physical infrastructures, as these infrastructures have specific investment and planning characteristics. According to Wetenschappelijke Raad voor het Regeringsbeleid (2008, p. 56-57) physical infrastructures are characterized by long-term investments, a high degree of dependence on technical developments and parallel needs for maintenance and system innovation. Investments in physical infrastructures are characterized by their lumpy character, their sunk nature and their long depreciation period.

Because the research project has been inspired by the increasing uncertainties due to regime change and internationalization, the infrastructures selected should preferably have experienced the same or more changes than the gas infrastructure. From the ten physical vital infrastructures identified in (Wetenschappelijke Raad voor het Regeringsbeleid, 2008), this applies best to other energy infrastructures and electronic communications infrastructures (see Figure 3.3). Of all physical infrastructures, these infrastructures are characterized by the most heterogeneous constellation of involved parties and decision-making on multiple levels (e.g. national, European). Furthermore these infrastructures were all considered public utilities before the liberalization process.

Because GTS is the principal company for this research, the gas infrastructure was selected for the first case. By first analyzing this infrastructure, we had access to the information and expertise at GTS, which helped in developing a rich case description and validating assumptions.

The electricity infrastructure was selected for the second case. Being an energy infrastructure as well, the electricity network is subjected to much of the same research and regulation, making it perhaps the infrastructure best comparable to the gas infrastructure. Also the supply chain exhibits strong similarities. On the other hand, there are significant technical differences between the operation of a gas and an electricity network and also the regulation of the electricity infrastructure is considered further advanced than the regulation of gas infrastructure.

For the third case study, a specific part of the telecommunications infrastructure, namely the fixed line telecommunications infrastructure, was selected. This infrastructure was developed from the public switched telephone network (PSTN) which, like the gas and electricity network was considered a public utility and operated by a state-owned firm. However, the telecommunications infrastructure was liberalized much earlier than the gas and electricity infrastructures and the resulting technological development and competition have changed the context of this infrastructure drastically. By analyzing this case, we can thus identify what the possible influences of a fast changing context are and so it forms both a good contrasting case and a learning case. The fixed line telecommunications infrastructure is used to deliver a large number of different products and services. To keep the analysis structured and feasible, we focus on the delivery of one specific service; internet access through digital subscriber line (xDSL) technology. This service was selected because it is both a widely used

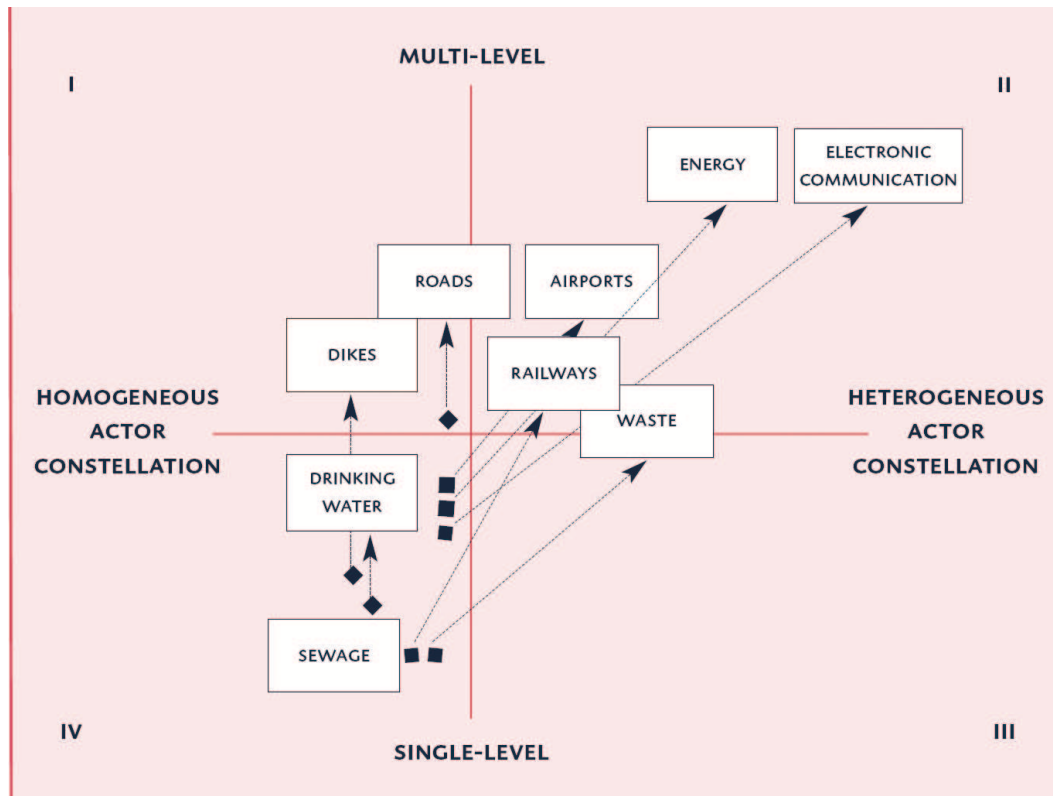


Figure 3.3: Characterization of vital infrastructures

Source: Wetenschappelijke Raad voor het Regeringsbeleid (2008), Figure 1, p. 38

service⁴ and generates significantly more data traffic than other widely used services, such as voice telephony. This second characteristic makes it especially relevant to the planning and investment decisions for (new) transport capacity.

3.2.4 Cross-case analysis

The cross-case analysis has been designed in such a way, that the most important differences and similarities can be easily identified and analyzed. To enable this, the individual case studies are performed using a common case protocol and narrative structure. For every case, the most important aspects for the cross-case analysis are summarized in margin notes in the case description and again in the comparative tables in Chapter 7. The narrative structure contains the following five elements:

1. An introduction of the infrastructure, which gives a short overview of the current organization of the infrastructure and significant historical developments.

The introduction gives the uninitiated reader a quick introduction into the historical background of the infrastructure. It is intended mainly as a descriptive segment and is no integral part of the analysis.

2. An infrastructure specific paradigm, which is an adaptation of the general transport infrastructure paradigm introduced in chapter 2.

In the infrastructure paradigm, the most important technical components and the institutional environment of the infrastructure are identified. The paradigm is intended to form both a simple and accessible starting point for the analysis as well as an effective visualization of the infrastructure. On the other hand, the development of the

⁴ Nearly 61% of the 5,9 million broadband connections in the Netherlands is based on xDSL technology (OECD, 2008b). The accessibility (number of people that can potentially connect to the network) is in the same order of magnitude as gas and electricity infrastructures.

Table 3.2: Context factors

Technical	Economic	Institutional
Localization of supply and demand	Commoditization	Price regulation
Controllability	Market maturity	Quality regulation
Swing of demand	Market structure	Public service regulation
Supply characteristics	Cost structure	International dependence

infrastructure paradigms helped make fundamental differences between infrastructures visible, which were included in the analysis.

3. A description on the technical, economic and institutional context of the infrastructure.

The context description is based around a set of important driving factors. These factors have been categorized as either technical, economic or institutional; a practice both structured and common in the SEPAM curriculum. The final set of factors was selected in a number of iterations based on strong relations between the context factors, reliability, assessment and treatment, which were identified through the mental model of the researcher, literature review and interviews. To keep the set of factors functional and clear, it has intentionally been limited in size and balanced between technical, economic and institutional aspects. This high level of aggregation was approached by eliminating, redefining or combining factors that had unclear or weak relations.

However, the final set of factors (see Table 3.2) remains arbitrary and discussible to some extent, as it is based on iterations and individual considerations made by the researcher during the research. The set of factors can however be judged on the following qualities. The set of factors is *parsimonious*, often combining several related lower-level factors and relating to the infrastructure as a whole instead of individual system components. The factors are *relevant*, they have a relatively direct influence on reliability, assessment and treatment and they can be effectively identified and described in all three analyzed infrastructures. Despite of the parsimony of factors, they are intended to provide an analysis of the infrastructure as *complete* and broad as possible. Thus the factors overlap as little as possible.

4. A discussion of the assessment of reliability in the infrastructure

The discussion of the assessment of reliability is structured around the three levels of reliability identified in Table 2.2: dependability, intrinsic quality and perceived quality. Also, specific attention is paid to the dimensions of reliability identified in Table 2.3. The discussion of the separate levels of reliability helps us to clearly demarcate different aspects of reliability and avoid the ambiguity that often surrounds the assessment of reliability.

5. A discussion of the treatment options in the infrastructure

Initially it was intended that actual treatment options in different infrastructures were compared directly to each other. However, during the research it became evident that the treatment options available the TSO in a given infrastructure are very dependent on the technical, economic and institutional context and the other business goals of the TSO. As a result, the options are often very specific and not easily comparable between infrastructures. However, the options can be categorized according to more generic high-level treatment strategies, which can be compared between infrastructures.

For this research, we identified a limited and functional set of four high-level treatment strategies. The treatment strategies were selected in such a way that they are relatively independent and contrasting, covering a broad spectrum and allowing the categorization of most identified individual treatment options. Furthermore, the set is as complete as possible, incorporating all three main segments of the value chain in different strategies and clearly relating to both operational, strategic and long-term solutions. The four treatment strategies identified in this research are:

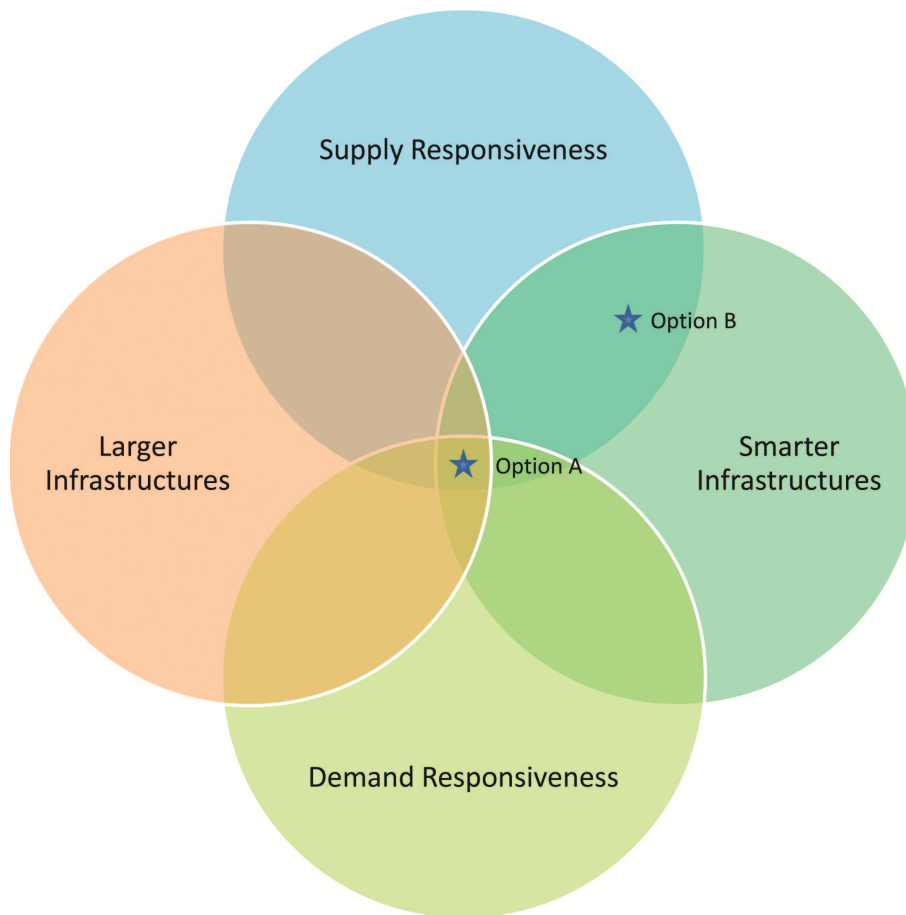


Figure 3.4: Treatment options contributing to multiple strategies

- (a) Larger infrastructures; increasing the capacity of infrastructures according to the current design paradigms.
- (b) Smarter infrastructures; Implementing new technical solutions and operational procedures to operate infrastructures more efficiently.
- (c) Supply responsiveness; create technical and institutional solutions so supply becomes more responsive to demand and network conditions.
- (d) Demand responsiveness; create technical and institutional solutions so demand becomes more responsive to supply and network conditions.

In reality, options often do not fit one single, individual strategy, but rather can contribute to multiple strategies, as visualized in Figure 3.4. Thus it has also been analyzed how actual treatment options contribute to the treatment strategies in each individual infrastructure. This results in a indication of the potential of and the emphasis placed on the different treatment strategies.

In the cross-case analysis the differences and similarities between the infrastructures are discussed and common relations between the context, assessment and treatment are identified. While some of these relations can readily be explained and described as causal tendencies, there is also a large number of very complex and tentative interactions within an infrastructure that cannot be explained in a simple and unambiguous way. A number of these interactions form the basis for a more in-depth analysis, intended to facilitate discussion and input for future research. After that, we discuss the consequences of the cross-case analysis for dealing with reliability in vital infrastructures.

Chapter 4

Case I: The Dutch gas infrastructure

This chapter presents the results of the case study on the Dutch gas infrastructure. First a short overview of the history of the infrastructure is given (§4.1), followed by the paradigm within which the infrastructure is analyzed (§4.2). Then we focus on the technical, economic and institutional context of the gas infrastructure (§4.3). Then we analyze what the impact of the context is on the assessment of reliability (§4.4) and the employment of treatment options (§4.5).

4.1 Introduction

The Dutch gas infrastructure originated from a number of separate municipal gas networks, which operated on gas that was extracted from coal and stored in gasholders. These networks, which provided gas for both industrial and domestic use, were often limited in size and connected only a small share of the Dutch population. Not until the discovery of the Groningen gas field in 1959 and the subsequent founding in 1963 of Gasunie, a joint venture of Shell/Exxon and the Dutch Government (which was represented by publicly owned DSM), did the development of a national gas infrastructure take form. At that time, it was feared that natural gas would lose the competition with rival energy sources, most likely nuclear energy, and thus become obsolete within a short period of time. As a reaction, an extensive (inter)national infrastructure was developed, installing natural gas appliances in nearly every home, to ensure high domestic demand and large export volumes.

However this policy was questioned in the 1970s, after the first oil crisis in 1973 showed the negative consequences of an increasing dependence on fossil fuels from foreign sources and the negative effects associated with nuclear energy limited its promise. As a reaction, the small fields policy was implemented in the Netherlands; by providing incentives to exploit smaller natural gas fields, the Groningen gas field could be conserved, extending the life time of the field and extending its function as a strategic balancing reserve. Additionally, large new reserves were found in surrounding countries like Norway, Russia and Algeria, increasing competition in the upstream market. Both the small domestic fields and the foreign fields were found to have a different calorific value than the original Groningen gas. As a result separate infrastructures and markets were developed for multiple gas qualities (see §4.3.2 for more information).

Until well into the 1990s, the gas infrastructure had strong monopolistic characteristics; Gasunie controlled the majority of supply sources as well as the national and regional transmission networks, while public owned utility companies like Nuon and Essent controlled the regional and municipal distribution networks. Gasunie was responsible to deliver reasonably priced gas at a very strict security of supply condition, which required continuous supply in all but the most severe winters (also known as the 1-in-50 winters requirement). Like other infrastructures however, in the late 1980s and 1990s the gas infrastructure was confronted with the debate on liberalization. As a result, Gasunie and the utility companies had to provide access to their infrastructure to third parties, so that they could also deliver gas to

consumers. According to the first European gas directive in 1998¹ and the resulting Dutch Gas Act of 1999 the market was liberalized in steps, initially for the large consumers in 1999 followed by the middle and small consumers in 2002 and 2004 respectively (Ministerie van Economische Zaken, 2008, p. 141).

With the liberalization of the markets, it was considered that the traditional incumbents, which were active in both the upstream, transport and downstream markets, had a potentially disruptive influence on the market. To ensure a level playing field and avoid cross-subsidies, the second European gas directive² and the Gas Act thus also prescribed that gas transport and trading had to be legally unbundled. Later on, this prescription was intensified in the law on independent network management (Won) in 2007, and transport and trading could no longer be integrated in one company and should be ownership unbundled. Because gas transport was considered a natural monopoly, it was decided that the networks should be publicly owned. This resulted in 2005 in the separation of Gasunie into a wholly public owned transmission company (Gasunie) and a trading company (GasTerra), with the same ownership structure as the original Gasunie. The split of the utility companies was finished in 2008, separating the distribution companies (e.g. Stedin, Enexis, Alliander) from the trading companies (e.g. Eneco, Essent and Nuon).

4.2 Gas infrastructure paradigm

The paradigm used to analyze the gas infrastructure is a concretization of the general infrastructure paradigm presented on page 7. The paradigm distinguishes some of the most important characteristics of the physical infrastructure and the institutional environment.

Physical infrastructure

The physical infrastructure can be separated in four segments: supply, transmission, distribution and consumption. The gas infrastructure has a diverse number of supply sources: producers (the Groningen field, the small fields and other production fields), storages (depleted gas fields, salt caverns and a LNG peaking installation) and imports. These supply sources are connected to the transmission network through 35 feeding points for Dutch gas fields and 17 import connections with neighboring transmission networks.

The transport segment consists of the transmission network and the distribution networks, which are considered to be natural monopolies. The transmission network consists of the high-pressure national transport network (HTL) and the mid-pressure regional transport network (RTL). The gas leaves the transmission network through connections with one of the regional distribution networks (approximately 700 connections), large industrial complexes (approximately 400 connections) or one of the 23 export connections with neighboring transmission networks (GTS, 2008c). Through the mid- and low-pressure distribution networks, the gas is then delivered to approximately 6 million small consumers.

Institutional environment

Many different stakeholders are involved in the functioning in the gas infrastructure. First, there are the *suppliers* who sell the gas from their gas production, storage and/or import to *shippers*. Shippers is the term used for network users that deliver gas through the network to the *consumers*; either directly for large consumers and export or through *retail companies*, which supply small consumers. To deliver the gas through the transmission network, shippers have to contract gas volumes with both producers and consumers and contract transport capacity, balancing and flexibility services from GTS, the national transmission system operator. Furthermore, a shipper needs to obtain a license to operate from GTS.

To allow the transport of gas, the transmission and distribution networks have to be managed, operated and developed by *system operators*; GTS as the TSO of the national transmission network and 13 DSOs for the various regional distribution networks. Because

¹ Directive 98/30/EC, Official Journal L 204 , 21/07/1998 p. 1-12

² Directive 2003/55/EC, Official Journal L 176, 15/07/2003, p. 57-78

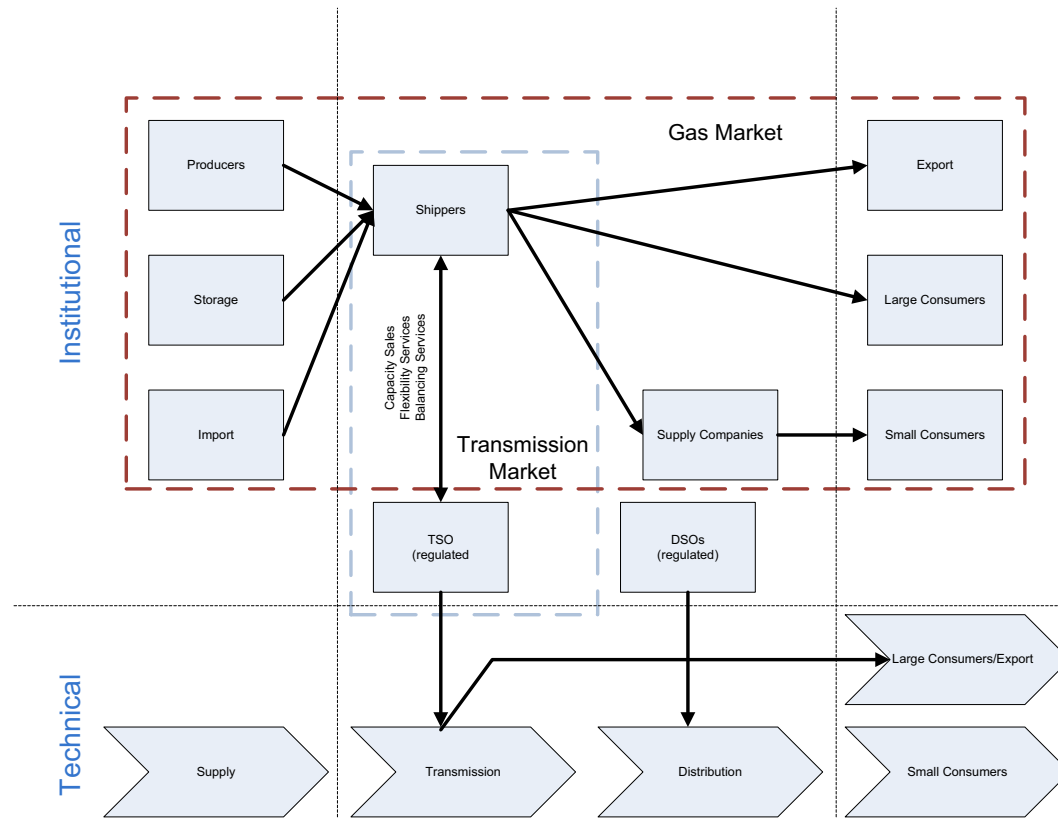


Figure 4.1: The gas infrastructure paradigm

Source: based on de Vries (2007)

of the natural monopoly characteristics of these transmission and distribution networks, the system operators are regulated by the national regulatory authority *Energiekamer*.

4.3 Infrastructure context

4.3.1 Technical context

Localization of supply and demand

The natural gas market is characterized by a strong localization of supply; a large share of Europe's natural gas resources is concentrated in only a few regions. Currently, the most important sources of natural gas for North-west Europe are the Netherlands, Norway, Russia and Algeria. The demand on the other hand is much more dispersed; while large industrial consumers might be concentrated in certain regions, almost all households are connected to a finely grained gas network.

Few sources

Long distance to market

The strong localization of supply has two important negative consequences for the gas infrastructure. First, it means that gas has to be transported over rather large distances before it can be consumed and thus it requires more transport capacity. Second, because of the time needed to transport gas over long distances, the flow profile from distant sources is relatively stable and cannot be controlled or adjusted for balancing purposes.

Because of the large share of indigenous production from the Groningen gas field, the Dutch gas infrastructure is only confronted with these negative consequences to a limited extent. However, with indigenous production declining and domestic demand expected to remain at least stable and transit demand to increase, additional transport capacity and balancing options will have to be developed.

Controllability

Flows controllable to a limited extent

No control over individual connections

Buffer mechanism

In a natural gas network the system operator can direct the gas flows in several ways; by operating compressors he can change the pressures in the network and by operating valves he can adjust or interrupt certain flows. In practice these changes require large amounts of manpower and planning, and are thus mainly used for maintenance procedures and seldom as operational controls. Because gas always flows in the direction of decreasing pressure, the network is basically unidirectional; the gas in a given segment can only move in one direction at a time. Because individual molecules in a gas move at random, it is impossible to transport a specific packet/molecule of natural gas from a certain location to another location. As a result, a gas flow entering the transport network at an entry point becomes part of an aggregated gas flow and the gas flow extracted from the network at an exit point is not physically related to the entry flow. However, the total of aggregated flows should be in balance. This characteristic of the gas network is reflected in the unbundled exit and entry system that GTS uses for its network; a shipper can book separate exit and entry capacities, but the total of entry and exit flows should be balanced.

While the flows of suppliers and large consumers can be controlled by the system operators through remotely operated valves and meters, the flows of small consumers cannot. This limits the control options of the system operator in a significant part of the infrastructure. This lack of control also creates an inherent safety concern in gas networks; when the pressure in the network drops below a critical value, the pilot lights in boilers and furnaces will be extinguished. Old domestic appliances like boilers, geysers and furnaces do not have a fail-safe protection for this, so when the pressure is restored the unburnt natural gas will flow into homes and create a potentially explosive mixture. As a result, after a pressure drop every individual home should be visited before the pressure can be restored (DTI, 2006b, p. 13).

Another important aspect of controllability is the speed and extent with which a sudden change somewhere in the network influences the rest of the network. The gas network contains a large volume of gas, which can act like a buffer when supply and demand are not balanced.³ This buffer can be increased by using linepack; by increasing the pressure more gas can be stored in the network. This is often used to accommodate the increased demand in the morning hours; by using line-pack in the night when demand is low, there is an excess of gas available in the morning, reducing the transport requirements (GTS, 2009a, p. 15). Furthermore, the pressures within the system are allowed to vary within certain bandwidths. These characteristics allow network flows to temporarily be in imbalance, without negative effects to network stability.

This relative stability is clearly reflected in the new balancing regime proposed by GTS, which is schematically represented in Figure 4.2. Within the normal operation zone, the buffer is able to accommodate all imbalances. Within this zone, programme responsible parties (PRPs)⁴ can correct the imbalances in their hourly programmes within a certain period of time. When the collective imbalances become greater than the buffer can handle, a procedure is started in which the TSO collects the balancing flows offered by market parties and sells them to the programme responsible parties in imbalance. If this fails to restore the balance, the TSO deploys emergency measures (e.g. gas supply from storages). The costs of these emergency measures are then accounted to the parties which were responsible for the imbalance. Currently, the total imbalances amount to only 0,1% of the gas transported.⁵

Normally, the measures to correct imbalance become progressively more expensive, so there is a strong incentive for PRPs to reduce their imbalance. The buffering effect in gas networks also has a negative effect on controllability; because the effect of changing flows is delayed it is also difficult for the system operators to precisely determine the status of the network in real-time. As a result imbalance can only be acted upon after a certain period of time. This explains for a large part the choice for programme periods of 1 hour; the technical possibilities and restrictions of the gas transmission network and communication systems, do

³ For example, the available buffer volume in the national transmission network operated by GTS is estimated at 14 million cubic metres of natural gas (GTS, 2006a).

⁴ Any party that supplies or removes gas from the grid has a programme responsibility. However, for small consumers, the supplier submits a programme.

⁵ Information provided by GTS

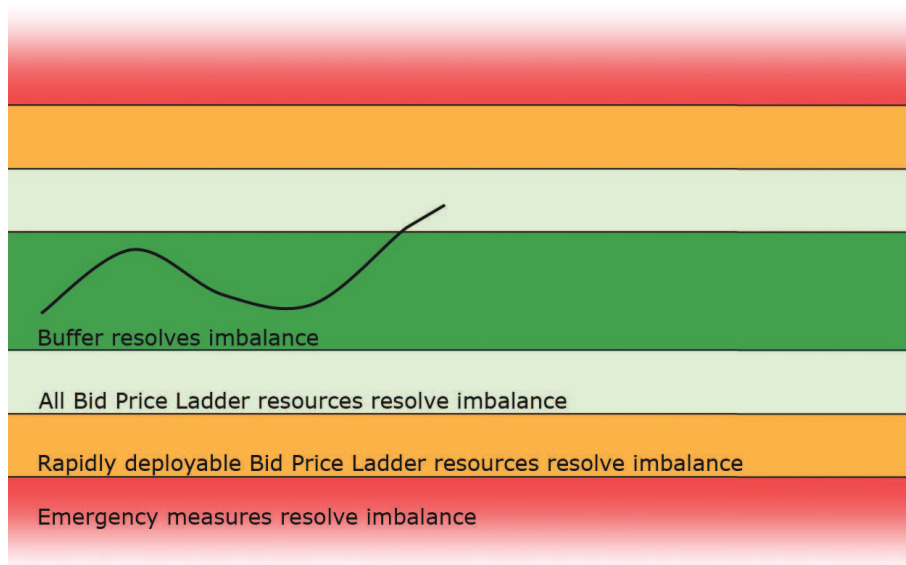


Figure 4.2: Balancing regime
Source: based on GTS (2009a), p. 36

not allow for a shorter programme period yet (GTS, 2009a, p. 14).

Swing of demand

We can analyze the variation in gas demand on three different time-scales; the short-term, daily and seasonal swing. The short-term swing of gas demand is limited for two reasons. First, while small gas appliances can be turned on or off rather quickly, industrial or power demand displays a more gradual profile, where the use is ramped up or down over a longer period of time. Second, the impact of this short-term swing is further limited due to the buffering characteristic of the gas network; a change of an individual flow only has a delayed and muted influence on the total network.

Limited and gradual short-term swing

Strong daily pattern

Very strong seasonal pattern

Because of the widespread use of natural gas for space heating in the Netherlands, the gas demand of residential consumers is strongly temperature dependent as can be seen in Figure 4.3. On the other hand, the demand from industry is almost temperature independent, because it often operates on a 24/7 basis. The demand from gas powered electricity plants depends on the demand for electricity and the relatively competitiveness compared to power generation based on other technologies on any given time. While electricity demand follows roughly the same daily and seasonal patterns as gas demand, the operating costs of a gas powered electricity plant are for a large part determined by fuel costs. Thus, when the total demand for natural gas and electricity is high, the prices are high and the relative competitiveness of gas powered plants is low, resulting in a largely temperature independent demand.

The daily swing of demand is for the largest part determined by space heating demand and power demand from gas powered electricity plants. As a result, the demand peaks in the morning and evening and is low during the night, as can be seen in Figure 4.3. The size of this demand swing is significant, as demand can differ by a factor of 3 during the day. As discussed before, the buffering characteristic of the network can be used to accommodate a part of the increase in demand in the morning. Because of the temperature dependency of gas demand, the seasonal swing in gas demand is very large, with demand in winter months usually 3 to 4 times as high as in summer months. In extreme conditions, demand can be more than 10 times higher than in minimum conditions. The large seasonal swing in demand necessitates dimensioning the transport network capacity on exceptionally high demand. As a result the average utilization rate of the network is inherently low.

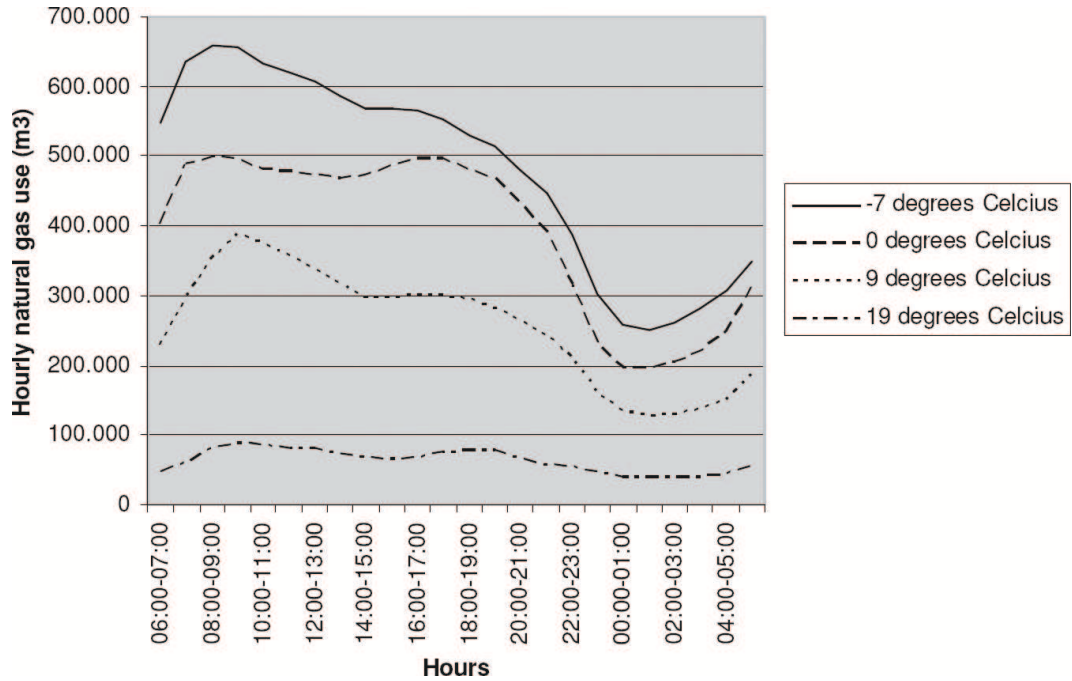


Figure 4.3: Hourly gas use of residential consumers at different temperatures
Source: Huitema (2009), Figure 7, p. 22

Table 4.1: Supply flexibility of different sources

Source	Short-term flexibility	Seasonal flexibility
Groningen	☑	☑
Small Fields		
Foreign Fields		☑
Depleted Fields		☑
Salt Caverns	☑	
LNG Storage	☑	

Supply characteristics

Flexibility mainly provided by Groningen system

Concerns over long-term flexibility

In this section we focus on the characteristics of the different supply sources, identifying constraints and possibilities for supply flexibility. Gas can be supplied from gas production fields and storages. Both these supply sources can be divided in different classes, which have different supply flexibility characteristics (see Table 4.1). We distinguish three classes of production fields for the Dutch gas infrastructure: the Groningen field, domestic small fields and foreign fields. Because of technical and geological constraints, most gas production fields are not able to change their production rate on short notice. Significantly adjusting their production will take up to several hours and is detrimental to the efficiency of gas production. The Groningen field is a notable exception, as it can adjust its production rapidly and without negative consequences and it has been and still is the most important supply source for the Dutch gas infrastructure. As a result, it can function as both a short-term and seasonal swing producer; meeting the changes in demand by adjusting the production level to the pressure in the network.

Apart from technical and geological constraints, both the domestic small fields and the foreign fields have additional restrictions on flexibility. For domestic small fields these restrictions are mainly driven by economic considerations: small fields have relatively high investment costs, making maximal production and short pay-back periods the most attractive option. As a result the flexibility of these fields is intentionally restricted through the

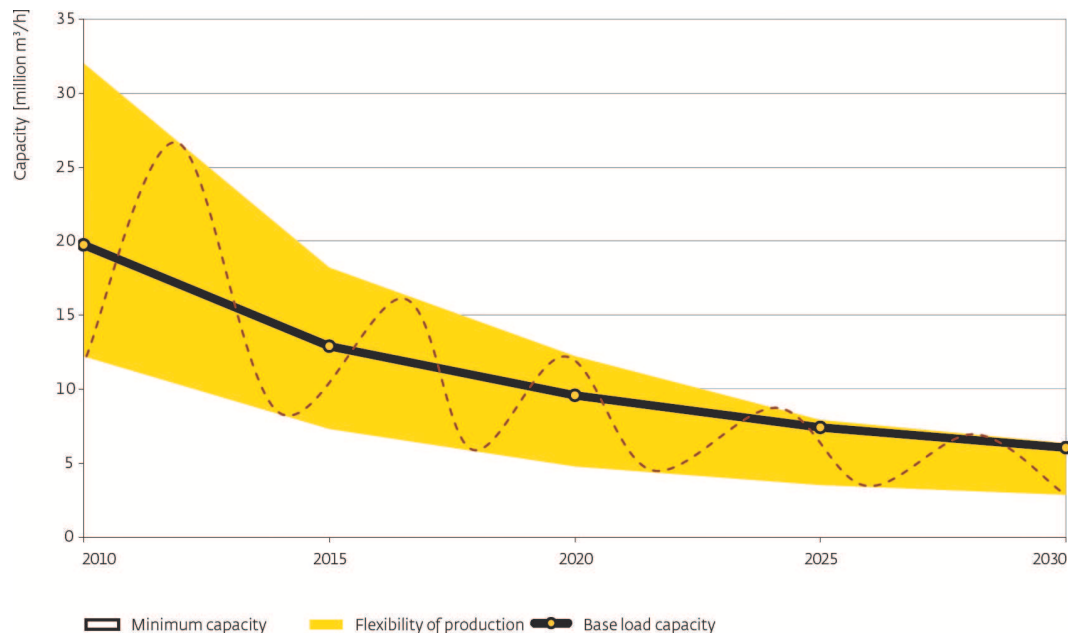


Figure 4.4: Production flexibility in North-West Europe
Source: GTS (2009c), p. 16

small fields policy; by using the balancing function of the Groningen system⁶ to compensate for the inflexibility of the small gas fields, their exploitation becomes more attractive (de Joode and Touber, 2008, p. 31). For foreign production fields, that are often located at a long distance from consumption, the flexibility is limited because it is economically more attractive to have a high utilization rate for long distance transport pipelines (accommodating production swing would require much more transport capacity) and the large time delay when transporting gas over long distances.

Storages are used to create additional flexibility close to consumption. The type of flexibility offered depends on the characteristics of the storage; LNG storage and storage in salt caverns are attractive to provide short-term flexibility because of their limited volume and large discharging capacity, while storage in depleted gas fields is attractive for seasonal storage, because of their large volumes and low discharging capacity (Clingendael International Energy Programme, 2006). Because of the availability of the Groningen system and the flexibility it provides, storage capacity in the Netherlands is lower than in surrounding countries.

However, the flexibility the Groningen system is providing is expected to decrease for two reasons. First, due to the unbundling of production and transport, the opportunities for the system operator to balance supply and demand have reduced. Second, with the depletion of this field also its possibilities to provide swing production are decreasing. With dropping wellhead pressures, the maximum production capacity decreases and so will the maximum production swing capacity (see Figure 4.4). Based on scenarios, the daily peak production of the Groningen system could decline by as much as 50% by 2020, necessitating investment in other sources of flexibility (de Joode and Touber, 2008, p. 31).

4.3.2 Economic context

Commoditization

In the gas infrastructure, two main qualities⁷ of natural gas are distinguished: the high calorific H-gas and the low calorific G-gas. Both qualities of gas are provided through their own transport networks and markets. Industrial consumers and the largest part of the export

Gas is a commodity

⁶ The Groningen system consists of the Groningen gas field and the Norg and Grijpskerk storages.

⁷ Gas quality is usually expressed with a Wobbe label; a value that indicates the burning characteristics and interchangeability of fuel gases.

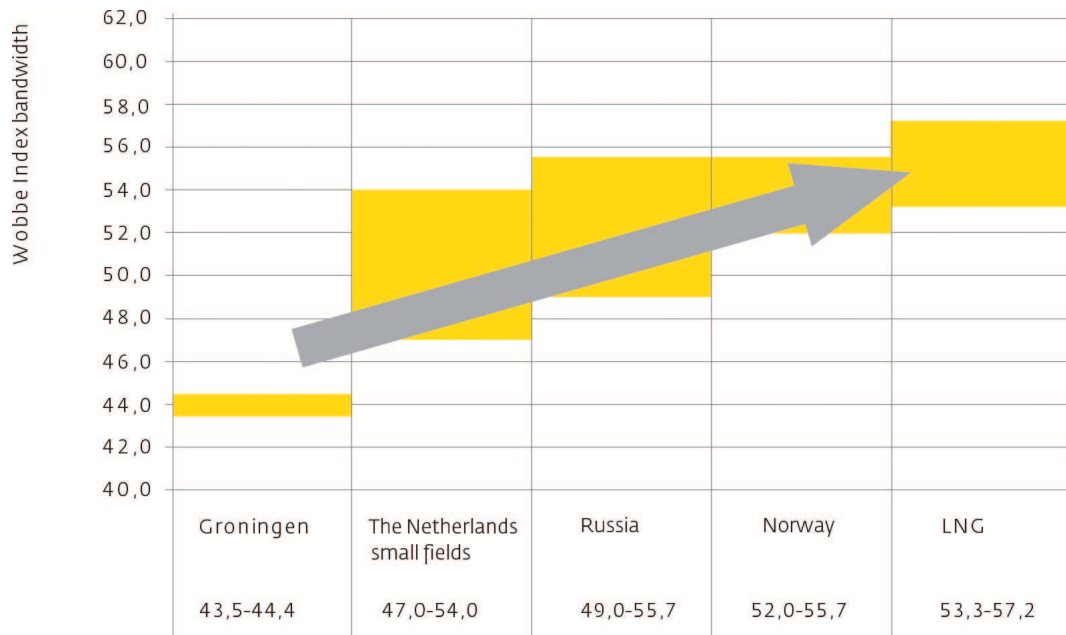


Figure 4.5: Gas quality related to origin of gas supply
Source: GTS (2009c), p. 23

are connected to the H-gas network, while domestic consumers in the Netherlands and parts of Germany, Belgium and France are connected to low calorific gas networks. The development of these separate gas qualities is actually for a large part the result of path-dependency. The Groningen gas field has a deviating quality from most fields (mainly due to the high nitrogen concentration in the gas) and as a result the whole Dutch small consumer market and appliances have been adapted to this gas quality when it was first discovered. With the subsequent discovery of gas supplies with a different quality (see Figure 4.5), new consumer bases had to be developed because the existing appliances could not deal with deviating gas qualities.

In the Dutch transmission network it is possible to convert between different gas qualities. This *quality conversion* process was mainly developed to support the small fields policy. By allowing H-gas from the small fields to be included in the G-gas streams, the small fields do not have to alter their production if there is a temporary lack of demand for H-gas. There are two ways to convert H-gas into G-gas, known as enrichment and blending. Enrichment is to blend a little amount of H-gas in the G-gas stream, ensuring that the mixture stays within the calorific bounds required for G-gas. Blending is to convert H-gas to G-gas by mixing in nitrogen in the H-gas at mixing stations, before adding it to the G-gas flow.

To further increase market transparency and liquidity, GTS aims to integrate the H-gas and G-gas markets into one market. For this reason, the quality conversion process is now treated as a system service, which costs are socialized over all gas contracts (GTS, 2009d). While the H-gas and G-gas networks are still operated separately and each entry and exit point still has clearly specified quality standards, the price of a volume of gas is purely determined by its calorific value.

This commoditization of natural gas is also evident in the fast development of spot markets; a good example is the Title Transfer Facility (TTF), a virtual trading point for natural gas in the Netherlands operated by GTS. Established in 2003, volumes traded on the TTF have increased dramatically over the last year (see Figure 4.6). From a marginal share in the total gas trade, TTF trade has increased to a total trading volume of 65,4 billion cubic meter (bcm) and a physical volume of 20,3 bcm⁸, compared to the total domestic gas consumption of 47 bcm. The presence of such a large spot market increases market liquidity.

⁸ The same volume of gas can be traded multiple times, leading to a larger trading volume than the actual physical volume that is delivered. The ratio of traded versus physical volume is known as the churn ratio. A high churn ratio is an indication for high market liquidity.

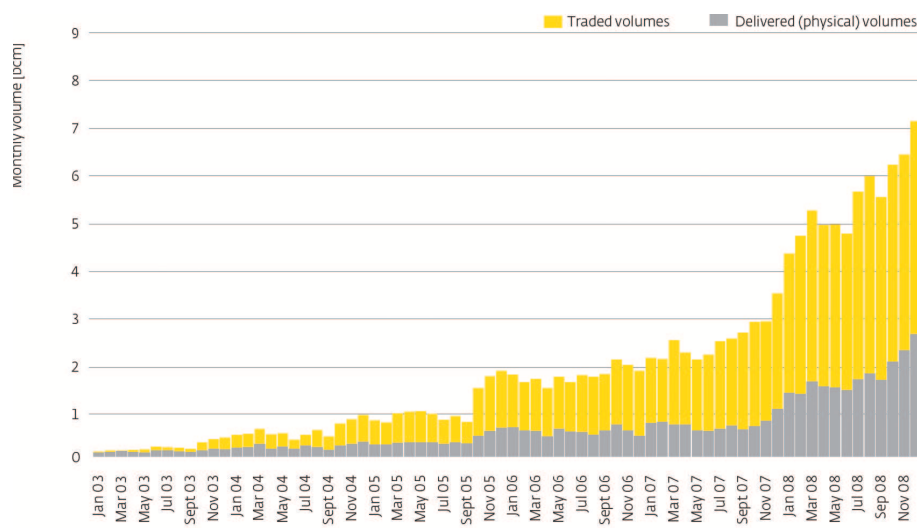


Figure 4.6: Monthly trade volumes on the TTF 2003-2008

Source: GTS (2009c), p. 15

Gas roundabout

The gas roundabout is a strategy of the Ministry of Economic Affairs and supported by Gasunie (Ministerie van Economische Zaken, 2009; GTS, 2009c). The strategy covers the complete Dutch gas infrastructure and connected facilities (Energieraad, 2009) and aims to ensure the continued use of this infrastructure. This strategy should increase the security of supply in North-west Europe, enhance the strategic position of the Netherlands in the European gas market and ensure the continued generation of added value with Dutch infrastructure assets (Wetenschappelijke Raad voor het Regeringsbeleid, 2008). This strategy necessitates investments in transport capacity, flexibility and diversification (e.g. LNG terminals and green gas).

Market maturity

The gas market exhibits all the characteristics of a mature market. The inflation-corrected consumer *price* of gas has displayed a strongly increasing trend over the last years (increasing 8,2% per year for the period 2002-2008 based on CBS data). This rise of gas price is mainly attributed to tight supply and demand conditions on the gas and oil⁹ markets. The domestic *demand* is stable and even decreasing a little over the last years (decreasing 0,5% per year for the period 2002-2008 based on CBS data), while the transit demand is stable. The wish to develop the latter market might increase the transit demand, but the decrease in gas reserves might increase gas prices and limit the market in the long run.

Mature market

Overall, the *technology* of the gas network is very mature. The basics of pipelines, compressors and valves have been relatively unchanged over the last decades. There are some new technological developments like delivery through LNG terminals, but even this is relatively established technology, that only becomes attractive now because of increasing gas prices. Because of the envisioned development of the transit/hub function of the Dutch network (the gas roundabout strategy, see box for a more detailed description), new transport routes are developed and current ones are improved. However, the current configuration of the network, with its principal technical hierarchy of national, regional and local networks, is likely to remain relatively unchanged. It can be concluded that technical change in the gas network is rather limited and improvements are mostly incremental.

⁹ Traditionally, a large share of gas contracts is coupled to the price of oil products (Clingendael International Energy Programme, 2006).

Market structure

<i>Ownership unbundled</i>	Traditionally the Dutch gas infrastructure has been characterized by a highly integrated and centrally coordinated structure, where Gasunie and the DSOs had a monopoly position to supply and trade natural gas. The Gasunie bought up most of the gas production from the Dutch Oil Company (NAM) and supplied directly connected large consumers, the public utilities and exports through their national transmission network. The public utilities supplied small consumers through their regional distribution network. Gas was supplied through integrated contracts; the consumer paid a "bundled" tariff, including both transportation and fuel costs (Wetenschappelijke Raad voor het Regeringsbeleid, 2008, p. 144). This market structure has changed markedly in the last decade, most notably through the introduction of competition and ownership unbundling as described in §4.1.
<i>Supply: Oligopoly</i>	
<i>Transmission: Monopoly</i>	
<i>Distribution: Monopoly</i>	
<i>Downstream: Increasing Competition</i>	

The upstream production segment can be characterized as an oligopoly; the majority of gas production fields is operated by a small number of domestic and foreign producers. This is unlikely to change because of the large financial risks associated with exploration and exploitation of gas fields, which can only be borne by large companies, the strong localization of sources and the strategic ownership of natural gas resources. The transmission and distribution networks are considered natural monopolies, while shippers can compete on the infrastructure thanks to regulated third party access. As a result, the shippers are also able to compete on the downstream retail and wholesale markets, where relatively little assets are needed to operate. Currently the competition among shippers is still somewhat limited, with 60 traders active on the TTF and certain parties, most notably GasTerra, having a significant market share. However, the number of shippers has increased with 20% in 2008 alone, indicating a increasingly competitive market (GTS, 2009c, p. 15).

The unbundling of transport activities from upstream production activities and downstream retail and wholesale activities has changed the conditions for system operators dramatically. For example, in the integrated Gasunie transport was considered a necessary cost to deliver the commodity gas. Because the value of gas typically exceeded the cost of transport by a large amount, it was imperative to invest heavily in a highly reliable network to ensure a certain gas delivery, and thus command a higher price based on reliability. As a negative example, in April 1986 the Norwegian gas producer Statoil was confronted with some severe supply interruptions as a result of a strike among offshore workers (National Economic Research Associates, 2002). As a result, the supply of Statoil gas was considered less reliable and this drove down the prices they could secure on gas contracts. Because gas contracts typically have a very long duration, this had very negative financial consequences.

For Gasunie, transport capacity changed from a cost to their main product after unbundling. To maximize profits, now it is imperative to ensure the efficient use of capacity and increase the amount of capacity that can be offered to the market. With a stable domestic demand, that requires securing transit streams and developing the hub function of the Dutch gas network in the internationalizing market. Therefore the gas roundabout strategy is very attractive for GTS.

Cost Structure

<i>Volatile product price</i>	The composition of the final costs of gas delivery for a small consumer are shown in Figure 4.7. Although the costs may vary for different types of consumers (especially if they are connected directly to the transmission network), the costs for small consumers gives a good overview of the overall cost composition, especially because of the large number of connections (approximately 6 million). The results here are based on an analysis of retail (Eneco, 2009b) and transport tariffs (Stedin, 2009b; Arthur D. Little, 2008). ¹⁰ The contribution of transport costs (including both transmission and distribution costs) is relatively low in gas infrastructures, as the transportation losses, due to the friction in the pipeline and the resultant pressure drop, are fairly limited compared to the physical gas flow; the distribution and transmission costs form approximately 7% and 1% of the total costs respectively. This
<i>Transmission costs $\approx 1\%$ total costs</i>	
<i>Entry and exit capacity tariffs</i>	

¹⁰ The difference in cost calculation between sources necessitated some estimations, so these results should only be used as an indication of the share of transport costs in the total costs. The represented values are validated by several other analyses carried out by GTS, where the share of transmission costs is estimated to be around 1-3% of total costs.

■ Taxes ■ Energy cost ■ Distribution cost ■ Transmission cost

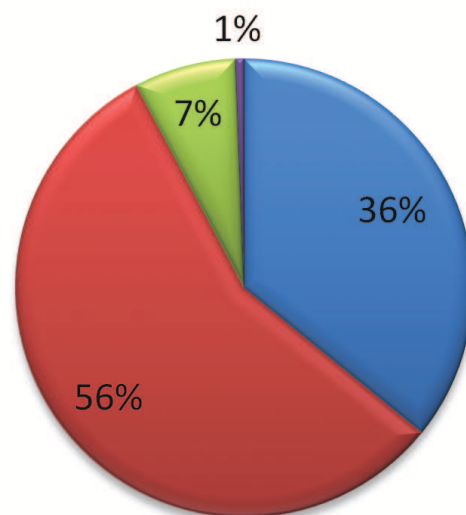


Figure 4.7: Composition of the retail gas price

includes the costs for system services offered by the network operators. This low share in total costs means that consumers notice relatively little from transportation cost changes, especially given the relatively strong volatility of energy prices. As a result they are probably insensitive to these costs changes, especially given that consumers typically pay only all-in energy tariffs.

The transmission is mainly paid for by shippers through entry and exit capacity tariffs. This entry and exit system is mandated by European regulation¹¹ and facilitates trade, as entry paid gas may be moved freely in the transmission network. However, the entry and exit system limits the relation between the actual costs of transmission and the tariffs. Furthermore, it causes cross-subsidies from short to long distance transport, which is a concern because local consumers effectively subsidize investments made for long-distance transit flows. Also in an entry and exit system the TSO is confronted with complicated and uncertain planning because it does not have information about flow directions (Correljé et al., 2009).

4.3.3 Institutional context

Price regulation

Price regulation has a large impact on the expected income from transport services and the viability of investments. In the case of the gas transmission network currently tariff regulation is employed, in the form of RPI-X price-cap regulation. For GTS, the average x-factor for the current period (2009-2012) is 5.4%, meaning that the average tariffs should decrease with an inflation-corrected 5.4% per year during the regulation period (Energiekamer, 2009b). This x-factor is relatively high, meaning that earnings will be under considerable stress during this regulation period. However, an important remark to make is that price regulation of GTS has been put off in the past and this is the first official price regulation period for GTS. Up until this regulation period earnings were thus unregulated and the impact of the price regulation in this period might be overemphasized. This has to be considered when price regulation is used as a context factor to describe actual behavior up to this moment.

The choice for tariff regulation puts the volume risk with the TSO instead of the users. This means that GTS can reap both the rewards of higher than expected utilization and run the risk of lower than expected utilization. Furthermore, the Gas Act does not contain a

*Tariff regulation
(volume risk for TSO)*

¹¹ Article 13.1 Regulation EC/715/2009, Official Journal 14/8/2009

Open Season procedure

In an open season procedure, a TSO inventories the need for transport services and the willingness to make long-term capacity reservations from interested market parties. This is done by identifying the demands, refining the design and increasing the commitment in several predetermined stages. By making this an open and non-discriminatory process, the TSO is able to attract and combine many requests from market parties. This helps create an optimal scale for new investments, which is necessary given the large economies of scale of pipeline investments (Correljé et al., 2009). The Open Seasons of GTS are successful and show a market-based need for transmission capacity (Correljé et al., 2009; GTS, 2009c). To ensure the effectiveness of Open Seasons, GTS takes into account the Open Seasons in neighbouring transmission networks (GTS, 2009d).

provision for "substantial" investments.¹² This means that large investments made by GTS are only included in the tariffs in the first new regulation period after the investments are put into use (Algemene Rekenkamer, 2009). This poses a large investment risk for GTS, which has resulted in a conflict of interest between the regulator Energiekamer and GTS, especially considering the need of expansion investments in the network.

For example, in 2006, based on the investment need identified in the 'Open Season' procedure (See box for more information), GTS requested the Energiekamer recognise the need for the investments *ex ante*. The Energiekamer however, in the aim of reducing tariffs for consumers on the short-term, heavily scrutinized both maintenance and expansion investment plans presented by GTS and limited the investments GTS could include in the calculation of its tariffs.¹³ This conflicted with the goal of GTS and the Ministry of Economic Affairs to develop the gas roundabout, as needed investments could not be recovered through the tariffs. One of the main disputes arose around the societal benefits of the investments; as a lot of the expansion investments were aimed at increasing transit streams¹⁴, the Dutch consumers would have no direct benefit from those streams, although they would pay for the investments through higher transport tariffs (Wetenschappelijke Raad voor het Regeringsbeleid, 2008; Correljé et al., 2009, p. 156).

Quality regulation

Quality regulation in the gas transport infrastructure is enforced through various methods: e.g. performance publications, quality standards and compensation payments. The performance publication to be fulfilled by system operators consists of two documents:

- A two-yearly quality and capacity document, conform article 10 of the Ministerial Decree on the Quality Aspects of Transport System Operation Electricity and Gas (MQR).¹⁵
- A yearly report on quality indicators, conform Article 35a of the Gas Act and article 2 of the MQR.

Performance publications are a form of indirect quality control; they do not directly influence the quality, however they expose the TSO to public scrutiny and provide quality information to the public (Ajodhia, 2005).

In the connection conditions¹⁶, several quality standards for the delivery of gas are defined, the most important being the pressure, gas quality and capacity. When these quality standards are not met, this can lead to off-spec delivery or interruptions. The compensation

¹² In contrast with the Electricity Act discussed in the next chapter.

¹³ The investment plans presented by GTS called for € 1.27 billion worth of investments, the EK eventually approved € 740 million worth of investments.

¹⁴ Transit streams are streams that imported and directly exported again, without being used in the Netherlands.

¹⁵ Regeling van de Minister van Economische Zaken van 20 december 2004, nr. WJZ 4082582, houdende nadere regels ten aanzien van de kwaliteitsaspecten van het netbeheer op het terrein van elektriciteit en gas (Regeling kwaliteitsaspecten netbeheer elektriciteit en gas)

¹⁶ Aansluitvoorwaarden Gas - LNB per 12-9-2008, Staatscourant 175, 11/09/2008, part of the conditions as specified in article 12b of the Gas Act

*Performance
publications*

Quality standards

Compensation payments

for interruptions is arranged in the connection conditions. Consumers are only compensated when an interruption lasts for more than 4 hours, the connection conditions distinguish between small consumers (eligible for a compensation of 35 euros) and large consumers (eligible for a compensation of 910 euros)(Energiekamer, 2008). The height of payments bears no relation to the actual costs suffered by consumers due to supply interruptions, but is rather meant as an incentive for network operators to improve quality. The height of the compensation payments has been directly adopted from electricity regulation. Given the limited costs associated with these compensation payments for GTS, they have a negligible steering influence on investment and planning decisions.¹⁷

Public service regulation

Because of the public interest in a well-functioning gas supply, certain public tasks have to be performed. According to the Gas Act, GTS has been assigned a number of these public service obligations. We distinguish three important public service obligations in the gas infrastructure: the supplier of last resort obligation, the connection policy and the obligation to support the small field policy.

Supplier of last resort

Connection policy

Small fields policy

GTS fulfills the role of supplier of last resort (SOLR) in the Dutch gas infrastructure(GTS, 2009b). As the SOLR, GTS is obliged to make supply and transport arrangements when a supplier fails to deliver or defaults and to ensure peak delivery at very low temperature. The SOLR arrangement only concerns the delivery to small consumers. The peak delivery corresponds to the gas delivery to small consumers when the effective daily temperature is between -9 °C and -17 °C.¹⁸ The SOLR obligation forces GTS to contract supply and transport capacity, by tendering for peak capacity. This capacity mechanism offers increased reliability at increased costs, which are socialized in the transport tariffs. It also requires GTS and third parties who participate in the tenders to create more transport and storage capacity than when such an obligation did not exist, possibly resulting in inefficiently high levels of reliability. Other concerns with the SOLR arrangement are that the protection it provides to consumers, reduces their incentives for demand-side response (DTI, 2006a, p. 34) and the fact that GTS provides gas to the market, which is in conflict with the unbundling principle (Knops and Wenting, 2004).

The European gas directive¹⁹ and the Gas Act do not prescribe universal access. However, the connection policy includes the duty for GTS to non-discriminatory offer connections to applicants. The applicant pays only the shallow connection charges²⁰, while the deep connection charges²¹ are socialized through the transport tariffs. This ensures the accessibility of the gas infrastructure.

The small fields policy has already been addressed in this chapter. As the transport system operator, GTS has to offer favorable connection conditions for these fields and ensure that the gas from small fields can be taken up in the gas transport system for these fields (GTS, 2009b). The extra transport costs incurred by providing these conditions are socialized in the transport tariffs.

¹⁷ Interview with GTS2, held June 25, 2009

¹⁸ The effective temperature is a function of the average daily temperature in de Bilt and the wind speed. The transmission network is designed in such a way that the network capacity is able to meet demand till an effective temperature of -17 °C. This will be discussed in more detail in §4.4.

¹⁹ Directive 2003/55/EC, Official Journal L 176, 15/07/2003, p. 57–78

²⁰ Charges directly related to the establishing of the new connection

²¹ Charges related to the needed expansion of the existing network to accommodate the new connection

Table 4.2: Quality indicators gas infrastructure

	Period	SAIDI (minutes)	CAIDI (minutes)	SAIFI (per year)
Transmission	2005-2008	0.60	1693	0.0004
Distribution	2005-2008	0.63	122	0.005
Total	2005-2008	1.23	N/A	0.005

Source: based on GTS (2005, 2006b, 2007b, 2008b); KIWA (2009)

International dependence

*Increasing dependence
on import*

*Increasing international
flows*

Due to the localization of sources, the gas market is characterized by a large international dependence. Over 60% of the gas in the Dutch network is part of international trade (i.e. either produced or consumed or both in foreign countries) and as a result GTS has relatively little insight and control over the development of supply and demand outside its own network. With decreasing domestic and regional sources and an expected increase in transit flows, the international dependence of the Dutch gas market is expected to increase even further in the future.

By 2020 the import needs for the Netherlands alone will have increased by approximately 25 bcm compared to the level of 2005; this increase constitutes nearly half the expected domestic demand. In the same period, the domestic production will probably be halved, as will the production flexibility it provides (GTS, 2009c). This growing international dependence increases the uncertainty about supply and demand development and requires both additional transport capacity (as transit streams and the distance from source to market increase) and additional flexibility options to ensure the control GTS has over the network.

4.4 Assessment of reliability

The analysis of the assessment of reliability in gas infrastructures is structured around the three levels of reliability that were identified in Chapter 2: dependability, intrinsic quality and perceived quality.

Dependability

*Average interruption
duration 1 minute per
year*

*Large interruptions are
very rare, affect 1,000+
consumers*

We evaluate the dependability of the gas infrastructure in two ways: by looking at the quality indicators and by evaluating large interruptions. The quality indicators for the gas infrastructure are reported yearly and separately for the transmission and distribution networks. GTS reports the quality indicators of the transmission network, while Netbeheer Nederland reports for the distribution networks. Because the majority of consumers is not connected directly to the transmission network, but to the distribution networks operated by the DSOs, GTS has to rely on the information provided by the DSOs for the reporting on quality indicators (GTS, 2007a, p. 30). For dependability, the most important quality indicators are those related to supply interruptions experienced by consumers: the average duration of interruption averaged over all consumers (commonly known as SAIDI), the average duration of interruption per incidence (CAIDI) and the interruption frequency (SAIFI).²² The achieved quality levels in the period 2005-2008 are depicted in Table 4.2.

It is clear that the dependability of the gas infrastructure is extremely high, over the last 4 years consumers experienced an average interruption of their gas supply of only 1.23 minutes per year and yearly approximately 1 in 200 consumers was actually confronted with a supply interruption. This corresponds to an astonishing availability of 99,9998%. It is also evident that these interruptions are far more likely to be caused in the distribution networks than in the transmission network. When analyzing the quality indicators provided by GTS, it even becomes clear that the values for the transmission network are actually distorted by the large disruption in Hulst in November 2006. This interruption corresponds to more than 99% of the accumulated SAIDI and SAIFI values in the period 2005-2008.

²² These are well-known and broadly used customer-based indicators. The main advantage of these indicators is that they consider reliability from the customer perspective (Ajodhia, 2005, p. 187).

Because of the high reliability of the gas infrastructure, large interruptions are rare. In 2008, the 5 largest interruptions affected just 31 to 933 consumers and caused between 36,983 and 335,880 accumulated minutes of supply interruptions (KIWA, 2009). However, two large interruptions can be identified in the last couple of years. In November 2006, 9,408 consumers in Hulst were affected and in March 2009, 3,190 consumers in Reeuwijk were affected. Important to mention is that neither of the interruptions were the result of a lack of transport capacity, but rather were caused by maintenance activities. When the direct financial impacts of the Reeuwijk interruption are analyzed, even the consequences of such a large interruption seem very limited, when compared to the costs of network investments.²³

Intrinsic quality

As was discussed before, the quality parameters for the delivery of natural gas are set within strict bounds. As a result, users typically do not experience significant changes in intrinsic quality and so it does not play a major role in the assessment. A significant deviation of the intrinsic quality from the set quality parameters is regarded as an "off-spec" delivery and has roughly the same consequences as an actual supply interruption. GTS regards an off-spec delivery as an interruption. However, GTS makes a distinction between interruptions in the GTS network and interruptions at the consumer. An interruption in the GTS network does not necessarily cause an interruption at the consumer. In the "Rapportage Kwaliteitsindicatoren" off-spec deliveries are not explicitly specified.

Strictly specified quality

Perceived quality

Unlike dependability and intrinsic quality, the perceived quality is much more subjective and dependent on the historic developments in the gas infrastructure. Thus, it is important to discuss those developments and their influence on the public interests associated with the gas infrastructure. After the discovery of the Groningen gas field, the gas infrastructure was rolled out at an incredible pace. Within mere years, the majority of domestic consumers was connected to the national infrastructure and large volumes were exported throughout Europe. As a result, gas quickly had become a commodity for all and the public interest associated with a reliable supply was eminent.

Strong public good characteristics

Very strong public value characteristics

Very soft public value

Very strong risk aversion

This public interest was strengthened by the strong public good characteristics of gas infrastructure reliability. Because of the network lay-out and the absence of real-time meters and switches for small consumers, it is generally impossible to disconnect a single small consumer, while keeping the other consumers in the area connected. Large consumers often do have connections that can be closed of individually, and consequently they can choose a lower level of reliability by signing interruptible contracts at a lower price. However, this only covers expected interruptions, as with unexpected interruptions the large consumers will most likely be exposed to the same risk of interruption as the other consumers in the area, because an interruption in the gas supply typically afflicts a larger area. Reliability is thus largely non-excludable in gas infrastructures. In normal operation, the consumption of gas by one consumer will not hamper other consumers in their consumption. This makes transport reliability largely non-rivalrous in gas networks. However, when the collective use leads to physical congestion, this increases the risk of interruptions in the system, and thus by increasing ones demand, one increases the risk of their own connection becoming interrupted (National Economic Research Associates, 2002).

The interest in high reliability was further strengthened for three reasons. First, the paramount importance of natural gas for the Dutch economy and the Dutch State; a significant part of Dutch welfare can directly be derived from the exploitation of the domestic gas reserves and the resultant income for the Dutch state (the "Gasbaten"). This has resulted in a very complex construction between private and public parties (the "Gasgebouw"), to ensure an efficient exploitation of the gas infrastructure, while ensuring acceptable incomes for all involved stakeholders. As a result, the public interests are stronger and more complex than in other vital infrastructures. Second, the pioneering role of the Netherlands in gas infrastructures, and the resultant pride and ambition to fulfill a leading function, fuels the

²³ Based on calculation with confidential information.

demand for high reliability. Third, high reliability was also an important selling point when compared to competing suppliers; thus there was a great incentive to invest heavily in the reliability of the comparatively cheap gas transport network.

This strong interest in high reliability was coupled with the typical design principles in traditional public utilities. The networks had a highly hierarchical structure and were engineered according to a very risk averse design. As a guideline, the capacity of the network should be able to meet demand except for in the most severe winters. This is mirrored in the once every 50 winters (1-in-50) design requirement, where the network is designed to meet the demand conditions which occur on average once every 50 years. Combined with the redundant design of active network components (the N-1 design principle) and the relative stability of the gas network, this has resulted in a very limited number of interruptions.

While this very high reliability makes the gas infrastructure a very reliable vital infrastructure, it also makes it very hard to determine or decide on the optimal level of reliability. Reliability in gas networks can be considered a very soft public value for a number of reasons. First, while users almost never experience interruptions, the fact that the gas supply is so reliable makes people unaware of the risk of supply interruptions and possible mitigation strategies, making them very vulnerable to actual interruptions (according to the double vulnerability paradox). This lack of *visibility* can also be witnessed by the media exposure of major gas interruptions; the two interruptions described above had relatively limited media exposure.

Because of the limited number of interruptions, there is also limited empirical evidence to analyze and *operationalize* the impact of supply interruptions and the resultant value of reliability.²⁴ Accordingly, the research into the valuation of reliability in gas infrastructures is limited compared to infrastructures which experience more interruptions, like electricity and telecommunications infrastructures. In designing the network, GTS does not assign monetary values to interruptions, but rather adheres to a strict rules considering pressures at the edges of the network, to ensure the 1-in-50 design requirement is met. A confounding issue is that gas interruptions are assumed most likely in very harsh conditions, because the infrastructure capacity is only fully used in very cold weather.²⁵ In such conditions a gas interruption leading to loss of heating might lead to severe health and safety risks, which cannot be unambiguously valued.

Because of the current state of the gas infrastructure, a decrease in reliability would only be noticeable in the very *long term*. Combined with the fact that current quality regulation aimed at ensuring reliability is both ex-post regulation and has limited disciplinary effect (due to the fact that the interruptions payments are in no way related to the actual costs and are so limited that they do not warrant improvement), it is hard to *enforce* reliability in relation to other values.

4.5 Treatment

In this section we describe how GTS employs treatment options to deal with reliability. First, we present an overview of the existing practice and then we discuss future trends.

4.5.1 Current practice

Network design

As was discussed before, the level of network investment in gas infrastructures is high, resulting in a very reliable infrastructures. This high level of investment has several reasons. The large seasonal fluctuations, long transport distances and relatively low transport costs make investing in additional transport capacity an easy and effective way to increase reliability. This is strengthened by decisions made in the planning process. By dimensioning on worst case scenarios like the 1-in-50 winters, the reluctance to include backhaul in the determination of needed capacity (and thus negating the netting of opposite streams) and the

²⁴ Reliability is a so-called "negative" public value, it is determined as the ability to prevent supply interruptions.

²⁵ Ironically, the two large interruptions described above did not occur for this reason.

consideration that an event of physical congestion (where the physical capacity usage larger is than 100% nominated capacity) is inherently undesirable, the planning automatically results in large transport capacities.

Like in most vital infrastructures, the gas transmission network is designed in such a way that it will be able to meet capacity requirements even if critical equipment fails. In the transmission network, most critical components (compressor stations, mixing stations) are designed using the N-1 design philosophy, ensuring that redundant and independent backup components are available. These components are also designed so that they do not experience common mode or common cause failures. However not all components are designed according to N-1 design philosophy. The pipelines themselves are not constructed according to a full N-1 design, because their reliability and availability is extremely high. Also very expensive equipment, like the nitrogen separation plants needed for quality conversion, is not constructed according to a full N-1 design.

The majority of flexibility for the Dutch gas infrastructure is provided by the Groningen system, which is able to adjust its production at a quick pace. This has resulted in relatively limited investment in backup and storage facilities in the Netherlands (de Joode and Touber, 2008). Backup and storage can be used for different goals: most notably to support reliability, for trading purposes and as a strategic reserve. In the Netherlands, the Groningen system already fulfills the role of strategic reserve and by the flexibility it provides it limits the trading possibilities for additional gas storage. The Dutch infrastructure gives access to approximately 5 bcm of seasonal storage and 0.5 bcm for peak situations and short-term use. Most seasonal storage is provided by the depleted gas fields at Norg and Grijpskerk, both owned by the shipper Gasterra. The depleted gas field at Alkmaar (owned by Gasterra) and the LNG peaking installation on the Maasvlakte (owned by GTS) provide storage for peak situations (GTS, 2009c). Most storage capacity in these storages is in the hands of the owner, with very small amount free for contracting to third parties, which constrains the market for flexibility. This also hampers GTS, because as a network operator and supplier of last resort, it has to contract peak delivery capacity from the storage owners.

Supply and demand responsiveness

Investments in gas production and transportation are capital intensive and risky. As a result the gas market is traditionally characterized by long-term supply and transport contracts, which guarantee income for the investor and thus reduce the investment risks. However, these long-term contracts reduce the liquidity²⁶ of the gas market, which is necessary for market reflective prices and efficient market functioning. Therefore, there is a strong focus to develop spot and futures markets (for example the TTF) alongside these long-term contracts and develop adequate secondary markets for capacity (GTS, 2009d). Currently however, the share of long-term contracts remains high.

Increasing market liquidity

The current low liquidity of the gas market reduces the possibilities and incentives for market parties to react to scarcity of gas or transport capacity. This necessitates additional investments in infrastructure capacity to guarantee reliability even in extreme supply and demand situations. At the supply side, most production fields produce according to a base-load profile, independent of the current market conditions; the flexibility to meet swings in demand is provided by the Groningen system. At the demand side, small consumers lack information on energy prices and technology (real-time meters) to participate in demand adjustments in case of scarcity. Most small consumers pay a price that is fixed over a longer period of time and their usage is measured only in large time intervals. For instance, the metering data of small consumers are collected by the distribution companies only once a year.²⁷ Large consumers have access to real-time metering and can thus potentially adjust their demand in response to demand and price signals; because of the large volumes they

²⁶ Market liquidity is defined as the opportunity to quickly buy or sell a product without significantly influencing its price and without significant transactions costs. An important aspect of a liquid market is the presence of a large number of buyers and sellers that are continuously willing to trade (CREG, 2009).

²⁷ Actually, data are collected by the users themselves and sent to the distribution companies. The distribution companies perform a calibrated measurement of the individual meters only once every couple of years

consume, their impact on the total adjustment is larger and the transaction costs involved in demand adjustments is also less significant than for small consumers (National Economic Research Associates, 2002, p. 33).

Balancing regime

There are several instruments in the gas infrastructure that can increase the incentives for supply and demand responsiveness, for example balancing regimes and interruptible gas and capacity contracts. The main function of the balancing regime operated by GTS is to guarantee the balance between supply and demand needed for system stability, by forcing users of the network to minimize their imbalances between supply and demand to avoid incurring imbalance costs. Recently a new balancing regime was proposed, making the imbalance costs more market-based and increasing the incentives for responsiveness from users, such that "every market party will be able to make its own contribution towards keeping the gas transport network in balance." (GTS, 2009a, p. 2).

Interruptible contracting

Interruptible contracts can fulfill an important role in responsiveness, by transferring the risk of interruption to the user in exchange for a discount. By offering interruptible contracts based on overbooking²⁸, more supply and transport capacity can be offered, without investing in more resources. Because the chance that all parties use their contracted supplies and/or capacities to their full extent at the same time is negligible, even if all capacity is contracted there will always be some physical capacity left. This "extra" capacity could then be offered to the market as interruptible capacity. As an integrated company, Gasunie was able to offer combined interruptible contracts for gas and transport capacity. For large consumers like electricity producing plants, this was attractive because of the discounts provided and the relative ease of reducing output. However, the use of interruptible contracts has changed significantly since the unbundling of supply and transportation activities. Where interruptible supply contracts are still attractive for some large consumers, interruptible transport capacity contracts have become much less attractive. Because of the low price of transport capacity, the financial gain for forfeiting reliability and the flexibility to arbitrate between supply sources is very limited.

4.5.2 Future trends

Network design

Most planning and investment decisions are based on an expected increase in demand and decrease in domestic production. As a result the need for transport capacity increases, especially to accommodate transit flows. This is combined with the uncertainty about network flows created by unbundling; as an integrated company it was possible to estimate and optimize both gas production and transport, using sophisticated planning models. These models used predictions of future supply and demand to determine the adequacy of the existing network and the need for investments in additional capacity. As a separate system operator, GTS has no direct insight into the development of gas supply and demand anymore and the operation of the network is dependent on the choices made by shippers. Therefore both the planning methods and the investment decision process had to be adapted.

The new planning process had to take into account the fact that the network operator no longer decides on the use of sources, but is dependent on the decisions of shippers. This requires the use of scenarios to determine the effect of different decisions of shippers; the resulting solution should be robust in many different scenarios. Because of this new approach in the planning method and the high requirements posed on the availability of the transmission network (such as the 1-in-50 requirement), the analyzed scenarios result in high capacity requirements when compared to normal operating conditions.²⁹

Increasing transport capacity

To counter the limited insight in supply and demand developments, the Open Season instrument was developed to enable economically sound network investments. By consulting shippers about their interest in capacity, GTS is able to ensure long-term certainty and commitment for capacity investments. The Open Season instrument is based on long-term (10 year) contracts, to ensure the viability of the investments. While the Open Season instrument gives a certain insight in the market developments, it does not create insight in the deliberations of shippers; they could be requesting extra capacity to create the possibility

²⁸ Overbooking means selling more capacity than is physically available

²⁹ Interview with GTS2 and GTS3, held June 25/29, 2009

to arbitrate between supply sources or because the costs of additional capacity are so low compared to the reliability it provides. The current capacity market has limited liquidity because most contracts are long-term, fixed capacity contracts and shippers want to ensure available capacity at all times, even if this means an inefficient use of capacity.

The Open Season instrument is thus likely to result in significant capacity investments, which might exceed the actual need for capacity. This is reason for concern, as these investments are mostly sunk costs; if the capacity demand does not materialize they cannot be recovered. GTS acknowledges this concern and it forms one of the main reasons for this research project.

Another concern for reliability is the decrease of flexibility provided by production fields; this reduces the capability of the gas infrastructure to respond to swings in demand. While this decrease of flexibility is seen as a large and imminent problem (GTS, 2009c), GTS cannot develop flexibility itself. Because of unbundling, GTS is not allowed to engage in trading activities and it is thus severely hampered to develop gas storages, because it cannot fully exploit the possibilities of such a storage, while having to bear the full costs. It can only encourage the development of storages by commercial third parties, for instance by providing information about the growing need and by contracting larger amounts of flexibility. There is however a significant chance that the development of storages will lag the increasing demand of flexibility, considering the development time needed for storages and the fact that commercial parties will only invest in flexibility when the prices make it financially attractive. At this moment there are several plans to significantly increase the storage capacity in the Dutch gas infrastructure: by expanding the storages at Norg and Grijpskerk, creating a new large seasonal storage facility at Bergermeer and connecting German storage facilities to the Dutch network (GTS, 2009c).

Increasing storage capacity

There are two system innovations that potentially can increase reliability: the connection of LNG terminals to the transport network and the production and injection of green gas. By importing LNG through LNG terminals, there is less need for import through pipeline capacity and the terminals can function as an additional backup supply. However, the potential of an LNG terminal as a backup facility is doubtful; the availability of LNG for seasonal flexibility is heavily dependent on the global LNG market (GTS, 2009c), while for peak and emergency situations the functionality depends on the LNG that is available at the terminal at that specific moment (de Jooode and Touber, 2008, p. 41). Green gas can contribute to the domestic production of gas and thus decrease both international dependence and the need for transport capacity. However, the infrastructure needs to be significantly adapted to allow the injection of large amounts of green gas.

*Decentral feeding:
LNG and green gas*

Supply and demand responsiveness

The technical and economical constraints on production fields and imports will continue to limit their scope for supply responsiveness. The development of more storage capacity will give more possibilities for supply responsiveness, however there exists a risk that the storage capacity is only developed after flexibility becomes scarce and thus reliability may be threatened in the mean time. Given the low average utilization rate of capacity by the shippers and the large demand for additional capacity, there may be possibilities for offering more interruptible capacity. This can result in more efficient use of the capacity and a reduction of the capacity needed in peak conditions. However, the current first come first serve form of capacity contracts and the low price of capacity, severely limit the incentives for shippers to contract interruptible capacity instead of firm capacity.

The implementation of smart meters can significantly contribute to the demand responsiveness of small consumers. Smart meters collect gas usage data more frequently and make the measurements visible to both users and network operators. This metering provides "additional information that enables customers to better understand their usage pattern and the cost implications, while also enabling suppliers to offer more efficient tariff options to reflect the variable marginal cost of the product" (Oxera, 2007, p. 68). By doing this, smart metering can increase both the incentives for fuel-efficiency and the range of consumers participating in demand responsiveness (DTI, 2006a, p. 46).

Smart metering

For fuel-efficiency, there is scope for improvements in space heating because investments in energy efficiency measures, such as insulation and switching to more efficient heating equip-

ment, become more attractive, creating a one-off gain in absolute demand. Consumers could also respond to temporarily high prices by reducing their heating demands, for instance by decreasing their thermostat temperature. However, the potential of this demand responsiveness is limited because the main drivers behind daily and seasonal demand patterns cannot be altered by smart metering (Oxera, 2007, p. 68); the winters stay cold and consumers are not going to heat their house during the night, just because the gas price is low.

Chapter 5

Case II: The Dutch electricity infrastructure

This chapter presents the results of the case study on the Dutch electricity infrastructure. First a short overview of the history of the infrastructure is given (§5.1), followed by the paradigm within which the infrastructure is analyzed (§5.2). Then we focus on the technical, economic and institutional context of the electricity infrastructure (§5.3). After that, we analyze what the impact of the context is on the assessment of reliability (§5.4) and the deployment of treatment options (§5.5).

5.1 Introduction

The electricity infrastructure that developed at the end of the 19th century, was characterized by numerous small-scale generation plants and transport networks that developed around municipalities. The generation plants were realized in close vicinity to the consumers and the low-voltage transport networks were only capable of transporting electricity over small distances. With the technological development of power generation and transmission, it became possible to build larger-scale generation plants, which were much more efficient than small-scale generation, and transport electricity over longer distances using high-voltage alternating current (HVAC) transport networks. This resulted in the construction of generation plants along rivers and canals in the Netherlands, enabling the easy supply of fuel (in particular coal) and access to cooling water.

To connect these centralized generation plants to the load, the regional transport networks had to be expanded. It also became evident that by coupling the individual transport networks production reserves could be shared, which would make the electricity supply much more robust against the failure of individual generation plants. To realize this coupling and to efficiently utilize the production capacity, the municipal and regional electricity utilities established the cooperation of electricity producing companies (Samenwerkende Electriciteits Producenten (SEP)) in 1949. The SEP developed and operated the national coupling grid and determined the economically optimal dispatch of generation plants. The regional and municipal transport networks and the generation plants were still operated and owned by the individual utilities.

Up until the 1980s the network was largely characterized by large-scale centralized electricity production. Technological developments and environmental concerns however led to the development of decentral electricity production. The development of combined-cycle gas plants allowed for efficient production on a smaller scale and the integration of heat and electricity production (CHP). Electricity production from wind turbines allowed for the production of renewable energy, which is decentrally fed into the electricity networks. Also other decentral production technologies were implemented like electricity production from biomass, waste or photovoltaic solar cells. The increasing share of decentral production and the intermittent character of some of these production technologies (wind and solar) has profound impacts on the operation of the electricity infrastructure.

Because of economies of scale and scope, the number of public utilities reduced significantly as a result of mergers. The market structure of the electricity infrastructure has changed significantly as a result of liberalization. The existing utilities had to provide access to their infrastructure to third parties, so that they could also deliver electricity to consumers. According to the first European electricity directive¹ and the resulting Dutch Electricity Act of 1998 the market was liberalized in steps, first for the large consumers in 1998, followed by the market for green energy in 2001 and the market for middle and small consumers in 2002 and 2004 respectively (Ministerie van Economische Zaken, 2008, p. 141).

With the liberalization of the markets, it was considered that the traditional incumbents, which were active in both the upstream, transport and downstream markets, had a potentially disruptive influence on the market. To ensure a level playing field and avoid cross-subsidies, the second European electricity directive² and the Electricity Act also prescribed that electricity transport and trading activities had to be legally unbundled. Later on, this prescription was intensified in the law on independent network management (Won) in 2007, and transport and trading could no longer be integrated in one company and should be ownership unbundled. Because electricity transport was considered a natural monopoly, it was decided that the networks should be publicly owned. The control of the national coupling grid was transferred from the SEP to the newly created and publicly owned TSO TenneT in 1998, which unlike the SEP had no ownership ties with generation facilities. The split of the utility companies was finished in 2008, separating distribution companies (e.g. Stedin, Enexis, Continuon) from the trading companies (e.g. Eneco, Essent and Nuon).

5.2 Electricity infrastructure paradigm

The paradigm used to analyze the electricity infrastructure is a concretization of the general infrastructure paradigm presented on page 7. The paradigm distinguishes some of the most important characteristics of the physical infrastructure and the institutional environment.

Physical infrastructure

The physical infrastructure can be separated in four segments: supply, transmission, distribution and consumption. We can distinguish three main forms of supply:

- Centralized production; large-scale production facilities (>100 Megawatt) connected directly to the transmission network (e.g. coal, gas and nuclear production plants)³
- Decentralized production; small-scale production facilities (<100 Megawatt) typically connected to the distribution networks (e.g. combined heat and power plants and renewables)
- Import from neighboring countries

The transmission network consists of the national extra high voltage grid (EHV) operating at 380/220 kV and the regional high voltage grids (HV) operating at 150/110 kV. The transmission network connects to large industrial complexes, transmission networks in neighboring countries or one of the 27 distribution networks. Currently there are 3 international connections with Germany, 2 with Belgium and 1 with Norway (TenneT, 2004). The distribution networks consist of the regional HV grids between 35 and 50 kV, the midlevel voltage (MV) grids between 1 and 35 kV and the low voltage (LV) grids below 1 kV.⁴ These finely dispersed networks distribute the electricity to small consumers.

¹ Directive 96/92/EC, Official Journal L 27, 30/01/1997, p. 20–29

² Directive 2003/54/EC, Official Journal L 176, 15/07/2003, p. 37–56

³ Actually many different arguments and classifications are used throughout literature to distinguish between centralized and decentralized production. For this analysis, we follow the definition used in the European electricity directive 2003/54/EC, which specifies decentralized production as electricity production connected to a distribution grid.

⁴ Internationally and throughout literature many different divisions are used, especially between transmission and distribution networks and/or high voltage and midlevel voltage levels. We use the current ownership division in the Dutch infrastructure to distinguish the networks and follow the classification of voltage levels used in (KEMA, 2009).

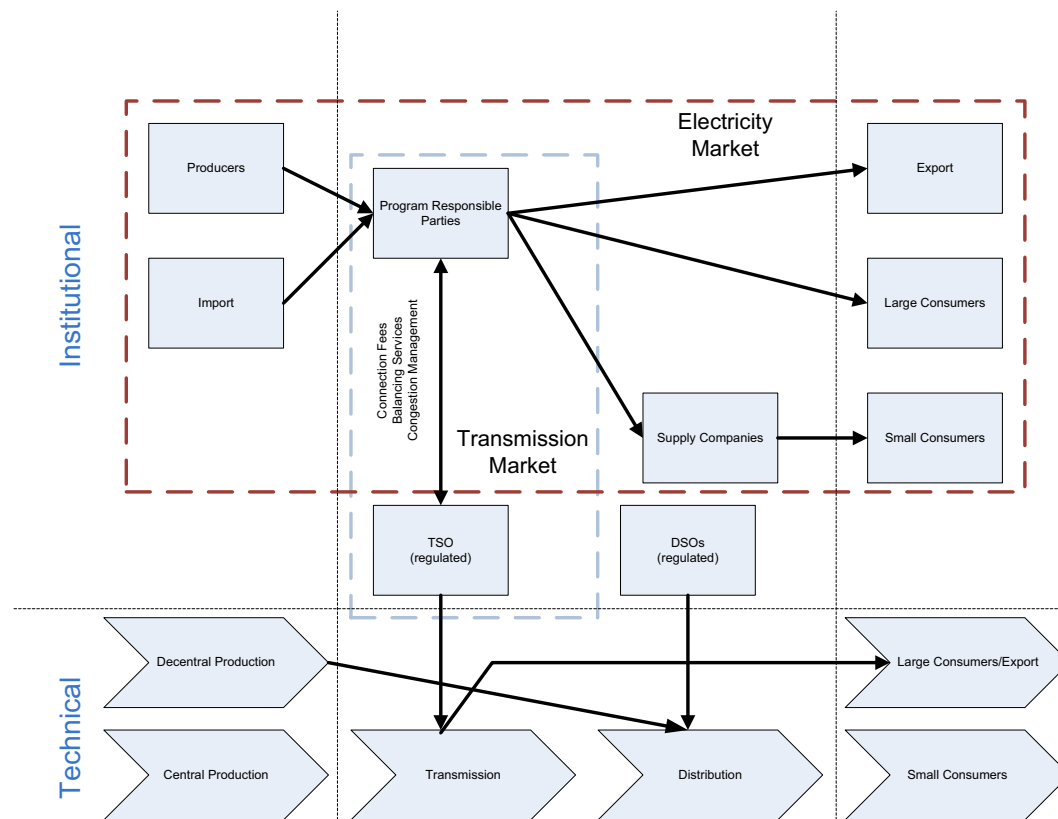


Figure 5.1: The electricity infrastructure paradigm
Source: based on de Vries (2007)

Institutional environment

Many different actors are involved in the functioning in the electricity infrastructure. First, there are the *suppliers* who supply the electricity from production facilities or import. To transport electricity over the transmission network, connected parties need to have programme responsibility. These program responsible parties (PRPs) are the network users that deliver the electricity through the network to the *consumers*; either directly for large consumers and export or through *retail companies*, which supply small consumers. To deliver the electricity through the network, PRPs have to contract electricity volumes with both suppliers and consumers and contract access to the transmission network from TenneT, the national transmission system operator. Furthermore, a PRP needs to obtain a license to operate from TenneT. To allow the transport of electricity, the transmission and distribution networks have to be managed, operated and developed by *system operators*: TenneT as the TSO for the national transmission network and 9 DSOs for the various regional distribution networks. Because of the natural monopoly characteristics of these transmission and distribution networks, the system operators are regulated by the *Energiekamer*.

5.3 Infrastructure context

5.3.1 Technical context

Localization of supply and demand

The almost universal access to electricity in the Netherlands has resulted in finely meshed distribution networks with a high number of connections. The demand is concentrated around urbanized areas and industrial complexes (further referred to as load centres). The scalability of electricity production facilities (ranging from solar cells with a power of mere milliwatts to generation plants with a power of several gigawatts), allows for a far-going adjustment of

Centralized and decentralized production

Optimal distance to market

generation to demand. From an efficiency standpoint it is optimal to minimize the transport distance of electricity, thus generation plants are normally realized relatively close to load centres. Decentralized production (e.g. windpower and CHP) allows for production close to the demand and thus reduces the need for transport capacity. On the other hand, a large share of total electricity production is provided by large-scale production plants at some distance from the load centres. These large plants offer economies of scale for efficiency, while being located at locations where the emissions have a less negative impact and with easy access to fuel supply and cooling water. The international coupling of electricity networks also allows for the import of electricity from foreign production sources, most notably nuclear energy from France and hydropower from Norway.

While it is expected that load centres will not shift significantly, the development and location of new generation capacity is dependent on a large number of factors and considered much more uncertain. To give a few examples of these developments:

- The coastal areas in the north and west of the Netherlands are very attractive for new large-scale production plants, because of the large availability of cooling water and the easy supply of fuel. These production plants are further removed from the largest load centres in the west and middle of the country than current production facilities and will also increase the export flows.
- The increasing use of small-scale CHP and solar panels connected directly to the load or the distribution network.
- The creation of large off-shore wind farms, which have to be connected to the transmission network.

The eventual realization of these developments has a large impact on the functioning of transport networks and the need for transport capacity.

Controllability

Flows unpredictable and uncontrollable

No control over individual connections

No buffer

The flow of electricity is determined by the Kirchhoff laws; the largest currents flow through the path of least resistance. This has profound impacts on the electricity flows through meshed networks, which are essentially uncontrolled. A change in the network, for instance as a result of a change in supply and demand or components failures, will influence all the flows in the network. Another important phenomenon in meshed networks is that of loop flow. Because electricity flows to its destination through all available paths, it crosses networks which are not involved in the financial transaction of electricity. The effect of these loop flows can be immense; the export of 1000 MW from the north of France to Italy can cause flows through the Dutch (150 MW), German (370 MW) and Czech networks (40 MW), while only 380 MW flows through the direct connection between France and Italy (Leveque, 2003, p. 30).

Another characteristic of electricity networks that has a negative impact on controllability is instantaneity. A change in the network will almost instantaneously have an impact on the whole network, because of the fact that an electric current somewhere in a conductive circuit almost instantaneously has an impact anywhere in the circuit.⁵ If a generation plant goes offline in France, it has direct impact on the Dutch electricity infrastructure. This combination of both uncontrolled and instantaneous flows greatly increases the risk of cascading failures in the network. When one network component fails as a result of overload, the electricity flow is immediately redistributed over other network components, which are then at risk of being overloaded as well. This increases the risk of large-scale blackouts (Dobson et al., 2007).

One way to increase controllability in networks is by using power electronics to restrict and redirect electricity flows. Currently these power electronics are applied to some extent in the transmission networks, while the application in distribution networks is limited. However the application of power electronics in transmission networks is mainly to avoid overload conditions and safety hazards, they are not used to guide flows. In network planning, the Kirchhoff laws and their unpredictable flows are still the leading design principle.⁶

⁵ The electrons themselves do not travel that fast, but a domino effect between all charge carriers in the circuit causes a near instantaneous effect (Bertrand, 2008).

⁶ Interview with TenneT1, held October 16, 2009.

In electricity networks, supply and demand need to be in balance at every moment and congestion of individual power lines has to be avoided. To achieve this, the TSO needs to ensure an acceptable dispatch programme for generation capacity. Before liberalization, the SEP directly instructed power producers to increase and decrease production based on demand and network conditions. Confronted with the loss of this hierarchical control, a new system of program responsibility was installed. To inject or withdraw electricity into the transmission network, a party needs to be recognized by TenneT as a program responsible party. These PRPs need to submit programmes for their production, transport and consumption needs and behave according to these programmes. TenneT is able to balance supply and demand in advance with these programmes and determine the expected load in different parts of the network (TenneT, 2008c).

Because of unexpected changes in supply, transport and demand there are always small deviations from the submitted programmes and resulting system imbalances. These imbalances are corrected by dispatching regulating and reserve power (RRP). RRP is available from generation facilities that can quickly adjust their output. RRP is contracted from market parties by TenneT through a single-buyer market. TenneT buys the needed RRP from the cheapest provider and charges the costs to the PRPs that are in imbalance. The actual determination of these costs includes incentives for market parties to have a surplus rather than a deficit, further stimulating system balance. Currently, this system works well to limit system imbalances; less than 3% of total load has to be balanced using RRP. When the imbalance cannot be resolved using RRP, TenneT has to dispatch contracted emergency power (van der Veen and de Vries, 2009), which preferably consists of interruptible power and thus often results in supply interruptions.

Swing of demand

We can analyze the variation in gas demand on three different time-scales; the short-term, daily and seasonal swing. Because most electrical appliances can be switched on and off relatively fast and the instantaneous effect this has on the connected circuit, short-term demand swing can clearly be significant. However given the wide dispersion of electrical appliances connected to the infrastructure, the net effects on an aggregated level (e.g. in regional or national networks) are limited.

Limited but transient short-term swing

Strong daily pattern

Strong seasonal pattern

The demand for electricity has a clear daily profile; the demand is high during the day, with peaks in the morning and the early evening, and low during the night. This profile is often counteracted by differentiated peak/off-peak electricity tariffs, making it attractive to use energy intensive appliances like washing machines in the weekends or nights.

The electricity demand also has a clear seasonal pattern. In winter the electricity usage is significantly higher, mainly due to the limited periods of daylight and the extra demand for lighting and space heating. However, the seasonal pattern is much weaker than in gas demand. The electricity demand in winter is approximately 15% higher than in summer, while the gas demand in winter is 3 to 4 times higher than in summer (see Figure 5.2).⁷

Supply characteristics

The ability of electricity generation facilities to provide flexibility depends highly on the technology used and the relation between the fixed and variable costs of the generation facility. To function as RRP, generation facilities must be able to quickly and significantly increase or decrease their generation levels.⁸ This potential is often indicated by the ramp rate or regulating speed; the percentage by which the capacity can be adjusted per minute. While gas-based generation plants are typically able to quickly adjust their generation levels (2-20%/min.), coal-based generation plants have a lower regulating speed (around 2%/min.) and relatively high fixed costs, making functioning as RRP less feasible. Nuclear plants have an even slower regulating speed and their variable costs are almost negligible compared to

Flexibility mainly provided by gas-based generation

Concerns over flexibility requirements caused by renewable generation

⁷ Based on analysis of CBS data on Dutch electricity consumption in the period 1995-2008 (CBS, 2009).

⁸ Especially the requirements for regulating power are strict, as a generation facility must have a response time of 30 seconds or less and a regulating speed of 7% per minute to be eligible (TenneT, 2009a). These requirements are typically only met by specialized peak generation gas turbines.

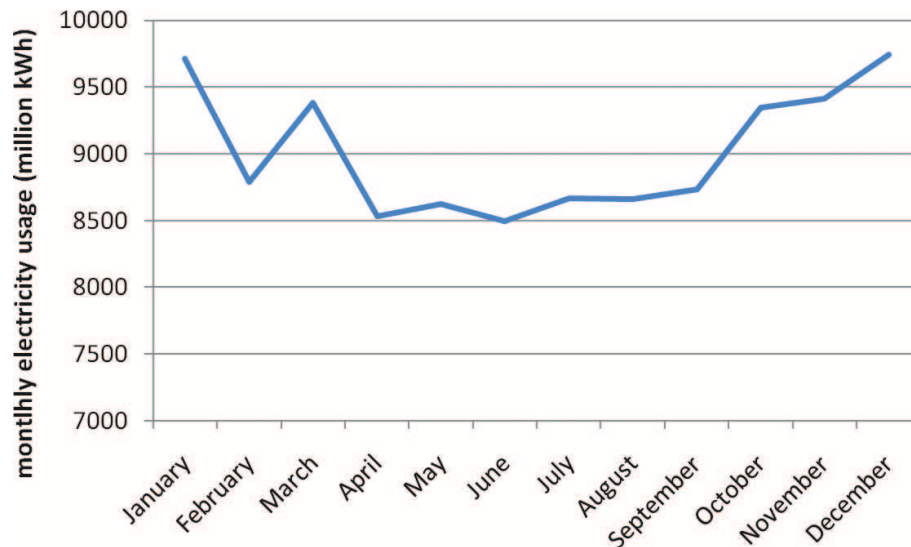


Figure 5.2: Average monthly electricity usage in the Netherlands 1995-2008

the fixed costs, virtually excluding them as RRP (Dijkema et al., 2009; Boot et al., 2010). Another issue is intermittent electricity production; solar and especially wind electricity production can decrease very quickly depending on weather conditions. This negative production swing has to be compensated by balancing generation capacity. The expected increase of these decentralized, sustainable production technologies will thus necessitate an increase in RRP capacity.

5.3.2 Economic context

Commoditization

Electricity is a commodity

Electricity provided through the transmission and distribution networks is a very homogeneous product. The synchronous grid coordinated by the ENTSO-E⁹ that spans a large part of Europe, is a single-phase 50 Hz frequency electricity grid, which has very strong quality guidelines for parameters like frequency, voltage and phase angle. For example, the frequency should be in a bandwidth of ± 180 mHz around 50 Hz; till a frequency of 49.2 Hz the electricity grid should be able to compensate deviations by engaging regulating or reserve power and below 49 Hz forced black-outs are mandatory. To give an impression of the strictness of this requirement, the failure of the largest power plant in the ENTSO-E grid would account for a shift in frequency of approximately 50 mHz by itself (TenneT, 2008a, p. 23), or more than 25% of the total allowed deviation. Depending on the power requirements and location of the consumer, the electricity can be delivered at different voltages levels; large industrial users can be directly connected to the high voltage transmission grid, while small consumers are commonly connected at low voltage levels.

Electricity is also widely traded on well-developed spot and futures markets, e.g. APX and ENDEX. Electricity can thus be considered a very commoditized product.

Market maturity

Mature market, however:

Possibility of paradigm changing developments

The electricity market exhibits strong features of a mature market. The inflation-corrected consumer *price* of electricity has displayed a slightly increasing trend over the last years (increasing 3,5% per year for the period 2002-2008 based on CBS data). Also, the domestic *demand* is increasing modestly (1,6% per year for the period 2002-2008 based on CBS data).

The design and operation principles in the electricity infrastructure have remained fairly unchanged and innovations are mostly incremental. However, there are developments (most

⁹ The European Network of Transmission System Operators for Electricity, representing the TSOs in 34 European countries.

notably sustainable and decentralized electricity production) that can influence the hierarchy of flows within the networks. Therefore multiple scenarios are envisioned for the development of the grid, possibly leading to a very different paradigm for electricity transport in the mid-term future. Another development that could cause large changes in the electricity network is the large-scale deployment of electric vehicles, which would pose a large number of new requirements on the grid.

Market structure

Like the gas infrastructure, the Dutch electricity infrastructure was characterized by a highly integrated and centrally coordinated structure. The public utilities had a regional monopoly to supply their bound consumers and the SEP (which was owned by the public utilities) coordinated the operation and power flows in the national coupling grid. The public utilities constructed new production capacity based predominantly on electricity demand in their region and in consultation with the other public utilities and the SEP, and decided on the investments in their regional grids and the national coupling grid. Electricity was supplied through integrated contracts; the consumer paid a "bundled" tariff, including both transportation and fuel costs (Wetenschappelijke Raad voor het Regeringsbeleid, 2008, p. 144). Due to the introduction of competition and unbundling, this market structure has changed significantly over the last decade.

Ownership unbundled
Supply: Imperfect Competition
Transmission: Monopoly
Distribution: Monopoly
Downstream: Increasing Competition

The upstream generation segment of the electricity market can be characterized as an imperfectly competitive market (Perrot, 2003). The market is dominated by the former public utilities and large foreign utilities (e.g. EdF, Electrabel and EON). These parties own and operate almost all centralized generation plants and a significant share of decentralized generation. Currently the arrangements for small-scale generators (e.g. CHP) to participate as suppliers are limited. The transmission and distribution networks are public owned natural monopolies, while PRPs can compete on the infrastructure thanks to regulated third party access. As a result, PRPs are able to compete on the downstream retail and wholesale markets, where relatively little assets are needed to operate. The downstream market is increasingly competitive; while the traditional utilities still hold a large market share, there are many new organizations offering retail and wholesale contracts to consumers.

Cost Structure

The transportation costs in electricity are relatively high compared to the other infrastructures. These costs are caused because of the resistive, capacitive and inductive losses in the grid lines; these physical losses are much larger than for instance in gas transport. Because electricity basically is a force, storage is only possible through conversion (for example in chemical or potential energy) and transport over large distances is accompanied by rather large energy losses (TenneT, 2008a, p. 22). Based on an analysis of retail (Eneco, 2009a) and transport tariffs (Stedin, 2009a; NMa, 2009) for small consumers (see figure 5.3), it is estimated that the distribution and transmission costs form approximately 18% and 1% of the total costs respectively. This includes the costs for system services offered by the network operators. Given the high volatility of electricity prices and the small share of transmission costs, consumers notice relatively little from transmission cost changes.

Very volatile product price
Transmission costs $\approx$ 1% total costs
Non-cost reflective consumer tariffs

The transmission costs are mainly paid through tariffs for transport services and system services. These tariffs are based on the allowed revenue of TenneT and as a result bear almost no resemblance with the transmission costs caused by actual electricity flows. The tariffs are also exclusively paid by the consumers as producers are exempted from payment. This exemption stimulates investment in new generation capacity, but further confuses the relation between transmission costs and tariffs.

■ Taxes ■ Energy cost ■ Distribution cost ■ Transmission cost

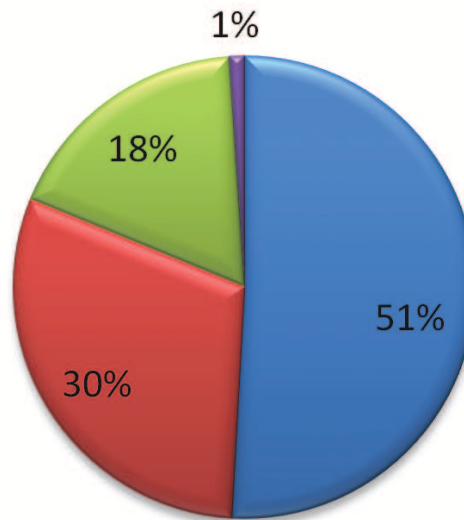


Figure 5.3: Composition of the retail electricity price

5.3.3 Institutional context

Price regulation

*Revenue regulation
(no volume risk for
TSO)*

*Substantial investment
policy*

As a publicly owned natural monopoly, the transmission network is subject to price regulation, in the form of revenue regulation. Unlike with tariff regulation, with revenue regulation the regulated party does not face a volume risk. While the exclusion of this risk gives the TSO less incentives to optimize the efficient use of the network during the regulation period, the nature of electricity flows necessitate revenue regulation. In the transmission grid, the direction and quantity of flows is largely unpredictable and beyond the control of the TSO, and the costs of network operation are insensitive to short-term variations in flow quantities. As a result, tariff regulation would lead to wildly varying income for the TSO (Algemene Rekenkamer, 2009).¹⁰

The price regulation also contains a provision for "substantial" investments. The TSO is allowed to include investments which are useful and necessary for domestic users into the tariffs. However, these investments are normally only included in the regulation period after the investments are put into use and their necessity and efficiency have been approved by the regulator afterwards. This creates a significant risk for the TSO, given that the investment has to be made up front and the potential revenue is uncertain. The provision for "substantial" investments provides an ex ante assessment of necessity and usefulness by the regulator and the possibility to include the costs of investments in the tariffs during regulation periods. This reduces the risk for the TSO and thus stimulates investments (Algemene Rekenkamer, 2009). However, the final assessment of necessity and usefulness is still made ex post by the regulator. Especially with a constantly changing and evolving regulatory framework, this creates a risk of regulatory opportunism, because the regulator can deviate significantly from their initial assessment. This increased risk makes it harder to finance investments, especially in the current economic downturn.¹¹

Currently the Dutch transmission network is in its fourth regulation period, for which an x-factor of 2.1% has been determined. The x-factor has changed significantly over time, as evidenced in Table 5.1. This is largely the result of ongoing debate between the regulator and the system operators on the valuation of the investments in the current "sunk" infrastructures and the reasonable return on investment. Given this wide variation in regulation and the long time before the effects of changes in maintenance and expansion investments

¹⁰ Interview with TenneT1, held October 16, 2009.

¹¹ Interview with TenneT1, held October 16, 2009.

Table 5.1: X-factors TenneT per regulation period.

Regulation period	Duration	X-factor
1st	2001-2003	3.0%
2nd	2004-2006	7.2%
3rd ¹³	2007-2010	1.4%
4th	2008-2010	2.1%

become clear, it is hard to establish the effects of price regulation so far. However, according to the Energiekamer, price regulation has contributed significantly to the affordability of network operation (Energiekamer, 2009a). According to TenneT, revenue regulation has mainly resulted in changes in the maintenance strategy. To achieve the cost savings necessitated by the x-factor, a shift has been made from preventive maintenance to more corrective maintenance. As a result the maintenance process is more efficient, but the risk of component failure has increased.¹²

Quality regulation

Quality regulation in the electricity transmission network is enforced through sanctioned performance publications, quality standards and compensation payments. The performance publication to be fulfilled by system operators consists of two documents:

- A two-yearly quality and capacity document, conform article 10 of the Ministerial Decree on the Quality Aspects of Transport System Operation Electricity and Gas (MQR)¹⁴
- A yearly report on quality indicators, conform Article 19a of the Electricity Act and article 2 of the MQR.

Performance publications

Quality standards

Compensation payments

TenneT fulfills this duties by respectively publishing the "Kwaliteits- en Capaciteitsplan" and "Transportbalans". While the performance publications are only indirect quality controls, they have a disciplinary effect on TenneT and encourage them to continuously evaluate and improve their business processes.¹⁵

In the Netcode¹⁶, several quality standards for the delivery of electricity are specified, the most important being voltage and frequency. When these quality standards are not met, this can lead to unstable electricity quality or interruptions. The potential negative impact of unstable electricity quality is increasing, due to the increasing use of IT equipment, that is sensitive to spikes in voltage and frequency.

Like in the gas infrastructure, there is a compensation arrangement for users experiencing an interruption as a result of transport failure. The compensation arrangement is described in article 6.3 of the Netcode and distinguishes between different compensations based on the network in which the interruption is caused, the voltage level of the connection and the duration of the interruption. According to the regulator, the height of compensation payments is not directly related to the costs experienced as a result of interruptions, but is rather meant as an incentive for network operators to maintain transport quality (Energiekamer, 2001). This incentive is flawed for a couple of reasons. First, because the arrangement does not reflect the real social costs of interruptions and it does not include the much more frequent short interruptions, it does not lead the network operator to a socially optimal solution

¹² Interview with TenneT1, held October 16, 2009.

¹³ The passing of the Wet Onafhankelijk Netbeheer (law on independent netmanagement) on 21 november 2006 necessitated the renewal of the regulation period, because TenneT would assume control over the regional high voltage grids (Rekenkamer, 2009)

¹⁴ Regeling van de Minister van Economische Zaken van 20 december 2004, nr. WJZ 4082582, houdende nadere regels ten aanzien van de kwaliteitsaspecten van het netbeheer op het terrein van elektriciteit en gas (Regeling kwaliteitsaspecten netbeheer elektriciteit en gas)

¹⁵ Interview with TenneT1, held October 16, 2009.

¹⁶ Netcode Elektriciteit per 27-10-2009, Staatscourant 27-02-2009, nr. 39, p. 20, part of the conditions as specified in article 31, paragraph 1, sub a of the Electricity Act

(Baarsma et al., 2004, p. 5). Second, because the compensation costs associated with the arrangement are much lower than the investments needed to avoid these costs.¹⁷

Public service regulation

Connection obligation

TenneT has a coordinating role in emergency supply

Because of the public interest in a well-functioning electricity supply, TenneT has to fulfill certain public services. These public services are included in regulation as public service obligations, for example the connection obligation and the supervision of the emergency power arrangements.

The connection obligation entails the duty for network operators to non-discriminatory offer a connection to every applicant. Furthermore, the applicant only has to pay the shallow connection charges¹⁸, while the deep connection charges¹⁹ are socialized through the transport tariffs. The connection obligation ensures universal access, even for connections that are not economically viable on themselves. Universal access for all domestic consumers is mandated in directive 2003/54/EC, given the vital and irreplaceable function of electricity. The connection obligation however is not limited to consumers but also extends to producers; considering the fact that producers also do not pay transmission tariffs, this might cause an unjust and inefficient subsidization from consumers to producers (Energieraad, 2009).

In the electricity infrastructure, a supplier of last resort is arranged for almost all consumers. Unlike GTS in the gas infrastructure however, TenneT itself does not fulfill the role of supplier of last resort for the electricity infrastructure. This is because of unbundling, which does not allow a network operator to operate as an emergency supplier. Because of its role as system operator, TenneT however does fulfill a coordinating role in the tendering for emergency supply (Knops and Wenting, 2004).

International dependence

Decreasing dependence on import

Increasing dependence on international flows

Traditionally, the Netherlands has been a net importing country of electricity. In the last years, the amount of import is decreasing and there is even a trend towards the Netherlands becoming a net exporting country of electricity, mainly due to the newly constructed or planned electricity plants in the Rotterdam and Eems port areas. As a result, the international dependence on foreign generation sources is decreasing.

On the other hand, due to the increasing coupling between national transmission networks, the international dependence is increasing. Due to the low controllability of electricity flows, disruptions within the ENTSO-E region can very quickly lead to disruptions in the Dutch grid if there is no adequate response. This requires more internationally oriented planning and control.

5.4 Assessment of reliability

The analysis of the assessment of reliability in electricity infrastructures is structured around the three levels of reliability that were identified in Chapter 2: dependability, intrinsic quality and perceived quality.

Dependability

Average interruption duration 30 minutes per year

Large interruptions occur 3-4 times per year, affect 20,000+ consumers

We evaluate the dependability of the electricity infrastructure in two ways: by looking at the quality indicators and by evaluating (the occurrence of) large interruptions. KEMA (2009) presents the aggregated quality indicators for both the transmission and the distribution networks in the period 2004-2008, which are represented in Table 5.2. Overall the quality of the electricity infrastructure is very high, with consumers experiencing only 28,4 minutes of supply interruptions per year on average and an availability of 99,995%. On the other hand, almost all consumers have experienced a supply interruption sooner or later, because approximately 1 in 3 consumers per year experiences a supply interruption.

¹⁷ Interview with TenneT1, held October 16, 2009.

¹⁸ Charges directly related to the establishing of the new connection

¹⁹ Charges related to the needed expansion of the existing network to accommodate the new connection

Table 5.2: Quality indicators electricity infrastructure

	Period	SAIDI (minutes)	CAIDI (minutes)	SAIFI (per year)
Transmission	2004-2008	6,2	26	0,102
Distribution	2004-2008	22,2	125	0,235
Total		28,4	N/A	0,338

Source: based on KEMA (2009), Table 0.1, p. 7

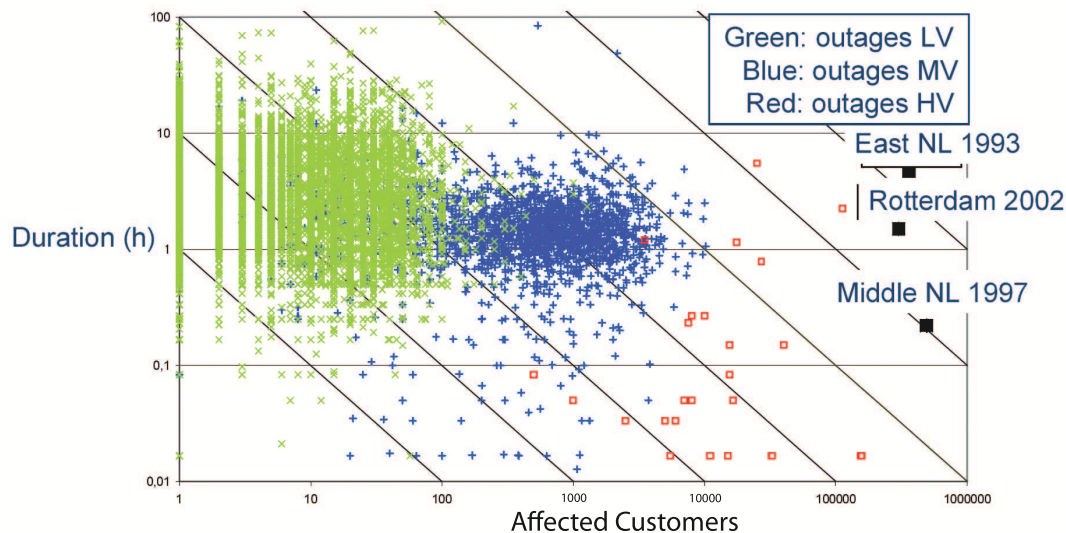
Figure 5.4: Interruptions in the Dutch grid in 2002
Source: Keller and Franken (2006), Figure 2.1, p. 8

Figure 5.4 shows the size and duration of all interruptions in the Dutch electricity grid in 2002, with each marker representing one interruption. It clearly shows that interruptions caused in the transmission network are much less likely than interruptions caused in the distribution networks, however they usually affect far more people. Based on the SAIDI and SAIFI values in Table 5.2, we can conclude that the interruptions caused by the transmission network have a significant influence on overall reliability.

In 2008, the ten largest interruptions affected between 4,737 and 27,892 consumers and caused between 895,293 and 3,024,200 accumulated consumer minutes of supply interruptions. Only one interruption was classified as a very large interruption (more than 2,500,000 consumer minutes), while in the period 2004-2008 there were on average 3.6 very large interruptions per year (KEMA, 2009). Of the ten largest interruptions in 2008 only two were caused in the transmission network, which further reflects its high reliability.

The interruption in Haaksbergen and Eibergen in 2005 is a good illustrative example of a very large interruption caused in the transmission network, which is thoroughly analyzed in (DTe, 2006). The interruption was caused by extreme weather, which led to a line break and a subsequent short circuit in both high voltage circuits connecting Haaksbergen and Eibergen. The resulting interruption affected nearly 20,000 consumers and lasted between 30 and 61 hours. Such a large interruption could occur because Haaksbergen was connected to an offshoot²⁰ in the transmission network and was thus vulnerable to a common cause failure in both high voltage circuits. Unlike the rest of the transmission network, an offshoot is not part of the ring structure of the network and thus there is only one path to the load.

The size and severity²¹ of the interruption in Haaksbergen prompted questions by the Ministry of Economic Affairs if and how additional investments in the transmission network could prevent comparable interruptions. DTe (2006) analyzed the costs and benefits of eliminating all offshoots in the transmission network. Because of the high reliability of the

²⁰ Dutch: uitloper²¹ Because of the extreme weather conditions.

Dutch electricity network these network additions would only reduce the average interruption per consumer from 30 to 25 minutes per year. This was estimated to amount to 3.6 million euros in savings per year, while the costs of the network additions would amount to 90 million euros per year. Thus it was concluded that investments in eliminating all the offshoots were not feasible and that investments to improve network reliability had to be analyzed on a case by case basis.

Intrinsic quality

Strictly specified quality

As was discussed before, the quality standards for electricity delivered are set within strict bounds. As a result, users typically do not experience significant changes in intrinsic quality and so it does not play a major role in the assessment. A significant deviation of the intrinsic quality from the set quality standards will result in the shedding of load and thus leads to supply interruptions.

However, the quality standards are typically minimum standards, some of which are not specified strictly enough or too weak (Keller and Franken, 2006). As a result the intrinsic quality might not be adequate, while meeting the minimum standards. For instance, sensitive equipment can experience malfunctions and additional wear and tear as a result of transient higher voltages, which are not addressed in the quality standards (VEMW, 2009).

Perceived quality

Strong public good characteristics

Strong public value characteristics

Soft public value

Strong risk aversion

Unlike the dependability and the intrinsic quality, the perceived quality is much more subjective and dependent on the historic developments in the electricity infrastructure. In the original municipal electricity infrastructures, the consumers were dependent on one or a few generation facilities. As a result, when these facilities went offline, it almost immediately caused interruptions and the electricity infrastructure was thus relatively unreliable. By creating regional, national and later even international coupling networks the reliability was improved drastically. For a long time, the function of the coupling networks was first and foremost to contribute to the reliability of the public electricity utilities (TenneT, 2008a, p. 23).

With an ever increasing number of appliances relying on electricity and no real available alternative, the access to electricity has become more and more important. As a result universal access has become a central public value and almost everyone is connected to the electricity infrastructure. With the growth of IT technology the continuous access to reliable electricity supply with very high quality standards is expected to become even more important in the future.

The public interest is further strengthened by the strong public good characteristics of electricity infrastructure reliability. Because of the network lay-out and the absence of real-time meters and switches for small consumers, it is generally impossible to disconnect a single small consumer, while keeping the other consumers in the area connected. Large consumers often do have connections that can be disconnected individually, and they can thus choose a lower level of reliability by signing interruptible contracts at a lower price. However, this only covers expected interruptions, as with unexpected interruptions the large consumers will most likely have the same risk of interruption as the other consumers in the area, because an interruption in the electricity supply typically afflicts a larger area. Reliability is thus largely non-excludable in electricity infrastructures.

In normal operation, the consumption of electricity by one consumer will not hamper other consumers in their consumption. This makes reliability largely non-rivalrous in electricity networks. However when the collective use leads to physical congestion, this increases the risk of interruptions in the system, especially in electricity networks which have no buffer capacity. Thus by increasing ones demand, one increases the risk of their own connection becoming interrupted (National Economic Research Associates, 2002).

The design principles in the electricity infrastructure were typical for a public utility, concerning an integrated system that should function at all times. The generation plants delivered exactly the demanded energy, the transport networks were always able to transport this energy and the voltage was at the required level in every part of the network. To achieve this, the planning of generation and transport capacity was risk averse. There

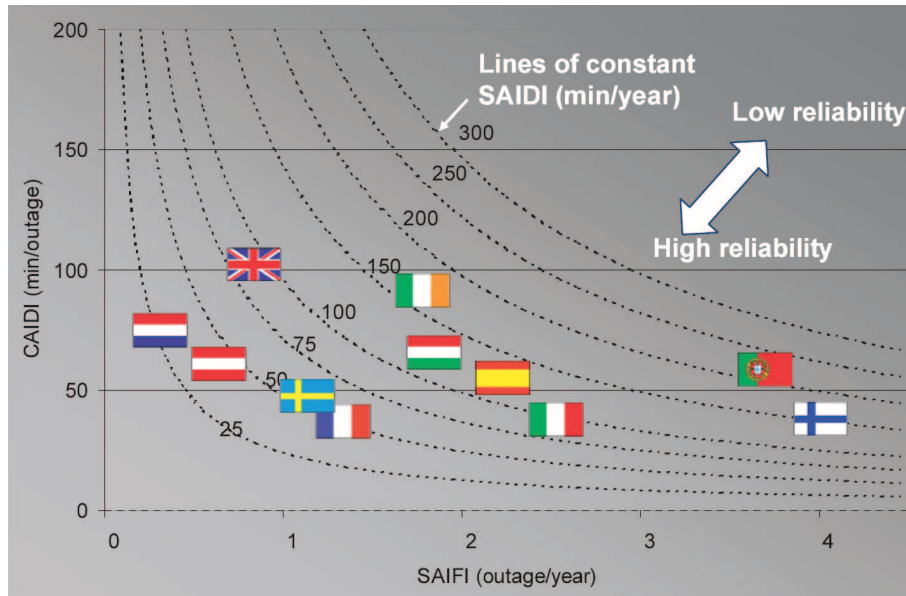


Figure 5.5: Comparison of electricity reliability in Europe

Source: Keller and Franken (2006), Figure 2.2, p. 12

was always enough regulating and reserve power available to compensate for failing generation plants (TenneT, 2008a). The reliability constraints in network planning were often more demanding than the operational constraints which the system operators imposed on the network. In turn, these operational constraints were designed to meet a desired level of reliability, which required a higher level of investment than was justified in strict economic terms (Perez-Arriaga and Smeers, 2003). Combined with the favorable geographical conditions in the Netherlands, which allowed for a ring structure in the transmission network and an underground distribution network to increase reliability, these design principles led to a very reliable electricity infrastructure. In comparison to other European countries, Dutch consumers experience two to eight times less interruption time (see Figure 5.5).

Like in the gas infrastructure, the high reliability in the electricity infrastructure makes it hard to determine or decide on the optimal level of reliability. However, due to the inherent uncontrollability of the electricity infrastructure everyone has been confronted with supply interruptions and thus people are aware of the risks to a certain extent. This is also evident in the media exposure of large interruptions. Often, they get national media coverage and very large interruptions cause significant public debate. While excessive black-outs like those in California and Italy have not occurred in the Dutch electricity infrastructure, their consequences have had a significant influence on the perception of reliability.

The research into the impact of supply interruptions and the resultant valuation of reliability is long-standing and extensive, dating back at least to the cornerstone publication of Munasinghe and Gellerson (1979). Many different reliability valuation methods have been developed and used, for instance to determine the possible savings of avoided interruptions in the Haaksbergen case described above. However, the results of these methods are not unambiguous, mainly due to a lacking market for reliability given the public good characteristics and the differing risk averseness between consumers. Furthermore, the complexity of the electricity infrastructure prohibits the determination of strict cost and benefit causal relations between infrastructure investments and reliability (Perez-Arriaga and Smeers, 2003). Because of these ambiguities in valuing reliability and the critical importance of the transmission network, the risk-averse technical design principles still determine the level of reliability.²²

While reliability is relatively more visible and operationalized in the electricity infrastructure than in the gas infrastructure, it is still a rather soft value. Because of the current state of the electricity infrastructure, a decrease in reliability would only be noticeable in

²² Interview with TenneT1, held October 16, 2009.

the *long term*. Combined with the fact that current quality regulation aimed at ensuring reliability is both ex-post regulation and has limited disciplinary effect (due to the fact that the interruptions payments are so limited that they do not warrant improvement), it is hard to *enforce* reliability in relation to other values.

5.5 Treatment

In this section we describe how TenneT employs different treatment options to improve reliability. First, we present an overview of the existing practice and then we discuss future trends.

5.5.1 Current practice

Network design

Increasing transport capacity

In principle, the connection obligation entails that every application to connect new generation capacity should be honored by the network operators. As a result the network operators have relatively limited discretionary power in developing the network, which has to follow supply and demand developments. This makes the investments in networks very susceptible to sudden surges and shortfalls in planned generation capacity. Where there were virtually no plans for new capacity a few years ago, the market is now flooded by new capacity plans (TenneT, 2009b).²³ This results in a mismatch between generation and transport capacity, which can lead to contractual and/or physical bottlenecks in the network. This creates concerns for reliability and the functioning of the electricity market.

Congestion management

Currently, large bottlenecks exist in the Westland area, the North of the Netherlands and Zuid-Holland. To address these bottlenecks, TenneT has sophisticated their connection policy and starts the administrative procedures for network expansions in a very early stage, so the delay in connecting new generation capacity is minimized.²⁴ The connection policy now allows the TSO to offer conditional access to electricity generators based on the situation of the transmission network. This system of conditional access is known as congestion management (discussed in more detail below). This system allows the connection of more generation capacity than would be possible based on the traditional guaranteed access. However, the congestion management process conflicts with the current connection obligation of the TSO and thus is a patchwork solution until regulation and contractual arrangements are changed (TenneT, 2008b). Typically, the planning and investment procedures for generation and transport capacity take a long time. By proactively responding to plans for new generation capacity instead of passively waiting for the generation capacity to be realized, TenneT tries to ensure a timely realization of transport capacity.

The current transmission infrastructure design and control principles have developed over time. As a result, most models and functions have not been designed with overall network performance in mind, but rather developed as ingenious engineering inventions to solve specific problems. This has resulted in a complex infrastructure, with many different components and control mechanisms that all have to be taken into account when assessing the system. To deal with this complexity, the current performance and expansions of the network infrastructure are often tested using extensive network studies, which rely on scenarios and statistic models of critical component failure. Based on the results of the network studies preventive measures are taken to increase reliability, and thus this approach results in network designs that are very reliable under known system conditions. However, this preventive approach often requires over dimensioning generation reserves and network equipment and, due to the contingencies which might cause unknown system conditions in such a complex infrastructure, may not ensure guaranteed performance (Ilic et al., 2005).

²³ Interview with TenneT1, held October 16, 2009.

²⁴ Interview with TenneT1, held October 16, 2009.

Supply and demand responsiveness

The balancing system with program responsibility is the most important measure to ensure supply and demand responsiveness. Because of the constant need for balancing in the electricity infrastructure, the balancing system has been used and developed constantly, creating sophisticated mechanisms. The cooperative nature of the SEP, in contrast with the hierarchical structure of Gasunie in the gas infrastructure, may have contributed to this. Even before liberalization, the balancing in electricity infrastructures was a partially negotiated process between the regional utilities, in contrast with the optimization processes typical in vertically integrated infrastructures. The high volatility of electricity prices also increases the incentives for market parties to reduce imbalances or provide regulating and reserve power, because the gains or losses can be significant.

Balancing system

As discussed before, the ability of electricity generation facilities to provide flexibility depends highly on the technology used. At the demand side, small consumers lack information on energy prices and technology (real-time meters) to participate in demand adjustments in case of scarcity. Most small consumers pay a price that is fixed over a longer term and their usage is measured only in long time intervals. For instance, the metering data of small consumers are collected by the distribution companies only once a year.²⁵ Large consumers have access to real-time metering and can thus potentially adjust their demand in response to demand and price signals. Because of the large volumes they consume, their impact on the total adjustment is larger and the transaction costs involved in demand adjustments is also less significant than for small consumers (National Economic Research Associates, 2002, p. 33).

Interruptible contracting

The congestion management system provides an additional measure to ensure supply responsiveness. Congestion management is a market mechanism which distributes transmission capacity to suppliers in areas where there is a shortage of transmission capacity. In congested areas, suppliers can offer to reduce their electricity generation for a certain price. TenneT will then contact a supplier in a non-congested region to compensate the reduction in electricity generation. In this way the congestion is alleviated, while both involved suppliers can increase their earnings (TenneT, 2008d).

Congestion management

5.5.2 Future trends

Network design

The ongoing technological development and increasing international coupling between grids, increase both the complexity of the infrastructure and provide new options to increase reliability. TenneT aims to develop a smarter network design that can limit disruptions to limited parts of the networks (so-called load pockets), for instance through Flexible Alternating Current Transmissions Systems (FACTS) and/or High Voltage Direct Current (HVDC) connections. They also try to develop control and prevention systems that provide fast and adequate resilience in case of a beginning interruption (TenneT, 2008a). However, these technological developments will have limited influence on planning methods, which continue to be based on worst-case, uncontrollable electricity flows. The international coupling also requires increasing consultation and cooperation with neighbouring TSOs on operational and strategic decisions (TenneT, 2008a), because the bottom-up analyses on which the individual practices of TSOs are based no longer hold in an increasingly complex and interconnected electricity infrastructure (Ilic et al., 2005).

Smarter grid controls

The increasing availability of storage options might also have a profound impact on network design. Currently, the options for electricity storage in the Dutch electricity infrastructure are very limited; the only applied form of large-scale electricity storage is pump storage at hydropower plants, which are not available in the Dutch electricity infrastructure. Electricity can also be stored using batteries; however at the current technological level large-scale storage in batteries is prohibitively expensive. New storage technologies, for example in the batteries of electrical cars or energy storage in reservoirs can potentially provide finan-

Increasing storage capacity

²⁵ Actually, data are collected by the users themselves and sent to the distribution companies. The distribution companies perform a calibrated measurement of the individual meters only once every couple of years

cially attractive means to store energy in the electricity infrastructure. By charging electrical cars when overall electricity consumption is low, the demand fluctuations for transport and generation capacity can be reduced. At the same time, temporary surpluses in electricity generation can be reduced and put to effective use. Because of the limited size and technical limitations of these storage methods, their contribution towards the reliability of the electricity infrastructure is however expected to remain limited.²⁶

Supply and demand responsiveness

Smart metering

The implementation of smart meters can significantly contribute to the demand responsiveness of small consumers. Smart meters collect electricity usage data more frequently and make the measurements visible to both users and network operators. This metering provides "additional information that enables customers to better understand their usage pattern and the cost implications, while also enabling suppliers to offer more efficient tariff options to reflect the variable marginal cost of the product" (Oxera, 2007, p. 68). By doing this, smart metering can increase both the incentives for fuel-efficiency and the range of consumers participating in demand responsiveness (DTI, 2006a, p. 46).

The scope for demand responsiveness through smart metering is often considered greater for electricity than it is for gas for several reasons. First, electricity prices have a higher volatility than gas prices, creating a greater incentive to reduce demand in peak periods. Second, there is a greater scope for short-term energy-saving measures like energy-saving lighting, consumers products and climate control (electric heating and air conditioning). Finally, there is considerable potential to change the within-day demand profile, for instance by using energy intensive but relatively time independent systems (e.g (dish)washers and dryers) in the cheaper night-periods.

Additionally, the combination of real-time metering with increasing switching technologies and decentral production can increase the controllability of the infrastructure. Distribution companies could gain access to additional balancing power provided by decentral production units and consumers can provide flexibility, by contracting an interruptible or capped service (for example through the implementation of active fuses) at a discount. However, an increase of demand responsiveness will have relatively little impact on the reliability of the transmission network. Fluctuations in generation and international flows have much more influence on the functioning of the transmission network than fluctuations in demand and the transmission network operator only has to deal with the strongly aggregated exchange flows with the distribution networks.²⁷

Stimulate complementary generation

The increasing share of sustainable, intermittent electricity generation has limited potential for supply responsiveness. Especially now that the Ministry of Economics of Affairs has proposed that sustainable generation gets connection priority²⁸ it is important for the TSO to develop favorable conditions for generation capacity that is complementary to the intermittent nature of this sustainable generation.

²⁶ Interview with TenneT1, held October 16, 2009.

²⁷ Interview with TenneT1, held October 16, 2009.

²⁸ TK 2008-2009, 29023, nr. 63.

Chapter 6

Case III: The Dutch telecommunications infrastructure

This chapter presents the results of the case study on the Dutch telecommunications infrastructure. First a short overview of the history of the infrastructure is given (§6.1), followed by the paradigm within which the infrastructure is analyzed (§6.2). Then we focus on the technical, economic and institutional context of the telecommunications infrastructure (§6.3). Then we analyze what the impact of the context is on the assessment of reliability (§6.4) and the employment of treatment options (§6.5).

6.1 Introduction

Like in most Western European countries, the telecommunications industry in the Netherlands was treated like a public utility until the late 1980s. The public switched telephone network (PSTN), through which services such as voice telephony and fax were provided, was controlled by the Netherlands Postal and Telecommunications Services (PTT), which formed part of a corporate unit of the Ministry of Transport and Public Works. At the end of the 1970s, as a reaction to the perceived lack of efficiency and innovation in government-owned, monopolistic public utilities, the discussion on privatization and liberalization started. As a result, the PTT was privatized on January 1, 1989 creating the new holding company Royal KPN Netherlands N.V. (KPN) and two separate post and telecommunications subsidiaries.

At the same time the design and use of the PSTN was changing. The network moved from analogue to digital switching, and data communication became more and more important for a network that was originally designed for voice communication. At the start, data communication was restricted to large companies and universities in dedicated networks, but in the beginning of the 1990s data communication over the internet became more accessible and interesting for small consumers as well. This resulted in the creation of Internet Services Providers (ISPs), companies that provided access to the internet through the PSTN with the use of dial-up modems. On May 1, 1993 XS4ALL became the first ISP active in the Netherlands. Originally, the data streams were transmitted over the same frequencies as those used for voice communication. Because of this limited frequency bandwidth, the achievable throughput (and hence the connection speed) of these dial-up connections was limited. While the technological possibilities and the user base of internet access were still limited at this time, the enormous growth potential of this market led KPN to the expansion of its activities to internet access provision. They did this by setting up their own ISPs and by acquiring several other ISPs, including the aforementioned XS4ALL.

At the start of the 2000s, as a result of the explosive growth of traffic flows and demand for higher connection speeds, the bandwidth limitations of internet access through dial-up modems became clear. Together with the emergence of the RTV cable networks as a rival infrastructure for providing internet access, this necessitated development of the PSTN to remain a viable and competitive option for internet access. By using a range of frequencies originally intended to carry RF (radio frequency) television channels, cable network operators were able to offer much higher bandwidths and connection speeds than achievable

through dial-up modems. As a reaction, KPN began to roll out ADSL (Asynchronous Digital Subscriber Line) technology on its PSTN network to offer broadband internet access. This technology, while comparable to dial-up access in that it still used complex waveforms to carry digital data over the network, was able to offer vastly increased bandwidth by using higher frequencies and advanced multiplexing techniques.

In 2000, ISPs were able to offer ADSL connections to consumers, instantly increasing the connection speeds almost tenfold.¹ Since then, the DSL technology has developed significantly as has the PSTN network. As a result the offered download speeds for DSL have increased from 512 kilobytes to 20 megabytes per second and even higher speeds are expected in the future. Currently DSL is the dominant technology for broadband internet access in the Netherlands, representing nearly 61% of the 5,9 million broadband connections in the Netherlands, compared to 37% for cable internet access (OECD, 2008b).² The PSTN is used to deliver a large number of different products and services. To keep the case study structured and feasible, we focus on the delivery of one specific service; internet access through DSL technology. This service was selected because it is both a widely used service and generates significantly more data traffic than other widely used services, such as voice telephony. This second characteristic makes it especially relevant to the planning and investment decisions for (new) transport capacity.

6.2 Telecommunications infrastructure paradigm

In this section, the paradigm used to analyze the telecommunications infrastructure will be presented. However, the introduction of the internet and the associated internet protocol (IP) has dramatically changed the nature of the telecommunications industry. Therefore, the impact of the internet on the telecommunications infrastructure has to be discussed before the paradigm can be introduced.

6.2.1 A changing infrastructure

Traditionally, the main function of the PSTN was to transport a single product, namely voice communication. With the introduction of data communication over the internet, a whole new product that could be transported over the same network was introduced. This product also posed very different requirements on the infrastructure than voice communication, which will be discussed later on. At the same time, the internet allowed another form of product differentiation. Besides offering interconnectivity between users, the network could now also be used to deliver content (e.g. websites, music, video) to the users. This again has had huge implications on the functioning of the infrastructure.

The internet protocol also provides an universal method for transferring data, which is technology and infrastructure independent. As a result, infrastructures that first were dedicated to a specific function, like the PSTN, the cable television network and the mobile telephony networks, are merged into one interconnected telecommunications infrastructure. This convergence has had an immense impact on how telecommunications networks are managed, operated and designed. This can best be illustrated by discussing the layer model, which is often used to describe the telecommunications infrastructure.³

First, we look at the traditional layer model (see Table 6.1), as it existed when voice communication was the main product offered through the PSTN. In this model, three layers are distinguished. First is the equipment layer, containing the physical components that make up the network, like switches, copper transmission lines and communication devices. Second is the network layer, which consists of the network that connects the senders and

¹ For example, the first ADSL subscription offered by XS4All had a 512 kilobyte per second download speed, while the fastest dial-up connection available had a 56 kilobyte per second download speed.

² The rest of the connections is offered through technologies like direct glass fiber connections, LANs and wireless connections.

³ Actually, "the" layer model does not exist. Throughout literature many different layer models have been presented, but the concept of describing the telecommunications infrastructure in the form of layers is widely accepted. In this research the layer model presented by Fransman (2003) is used. This model provides a nice high-level overview, while omitting technical details that are too specific.

Table 6.1: Old layer model of telecommunications infrastructure

Layer	Description
3: Services Layer	Voice, fax, 0800 services
2: Network Layer	Circuit-switched network
1: Equipment Layer	Switches, transmission systems, customer premises equipment

Source: based on Fransman (2003), Exhibit 1, p. 7

Table 6.2: New layer model of telecommunications infrastructure

Layer	Description
5: Applications Layer	Information services, web-design, broadcasting services
4: Navigation & Middleware Layer	Browsers, portals, search engines
3: Connectivity Layer	Internet access, web hosting, voice
	IP Interface
2: Network Layer	e.g. optical fiber network, xDSL local network, cable network, radio access network
1: Equipment & Software Layer	e.g. Switches, transmission equipment, servers, billing software

Source: based on Fransman (2003), Exhibit 7, p. 37

recipients of information. Originally this network was circuit-switched, creating a dedicated circuit between the sender and the receiver through physical switches. Following technological developments, these circuit-switched networks were replaced by package-switched digital networks, which were both cheaper and more efficient.⁴ Third is the services layer, which consists of the actual services provided by the network, like voice telephony and fax. This traditional layer model has a strong resemblance with the current organization of the gas and electricity networks, where a single, dedicated network is used to deliver a small variety of products.

The technological and functional change of the infrastructure is clearly reflected in the new layer model (see Table 6.2). In the equipment layer, a lot of hardware equipment has been replaced by software solutions. In the network layer, instead of dedicated networks, we now see competing networks. This is a result of the IP interface, which has created *"a bridge, facilitating easy and cheap interoperability across radically different networks using radically different technologies."* (Fransman, 2003, p. 38) The services layer has been replaced by three layers of services: the connectivity layer, which offers access to the networks and the internet; the navigation & middleware layer, which allows easy access of information on the internet; and the applications layer, which offers information services and applications. This clearly reflects the diversity of services offered in the new infrastructure, as well as the reliance on other service layers to access high level services. To access a website (a service in the applications layer), an user not only needs an internet browser (in the navigation layer) but also internet access (in the connectivity layer).

6.2.2 The "new" paradigm

The paradigm (see Figure 6.1) used to analyze the telecommunications infrastructure is a concretization of the general infrastructure paradigm presented on page 7. The paradigm distinguishes some of the most important characteristics of the physical infrastructure and the institutional environment.

⁴ Packet switching divides the information flows in separate packets, which are routed to their destination independently based on available transmission resources.

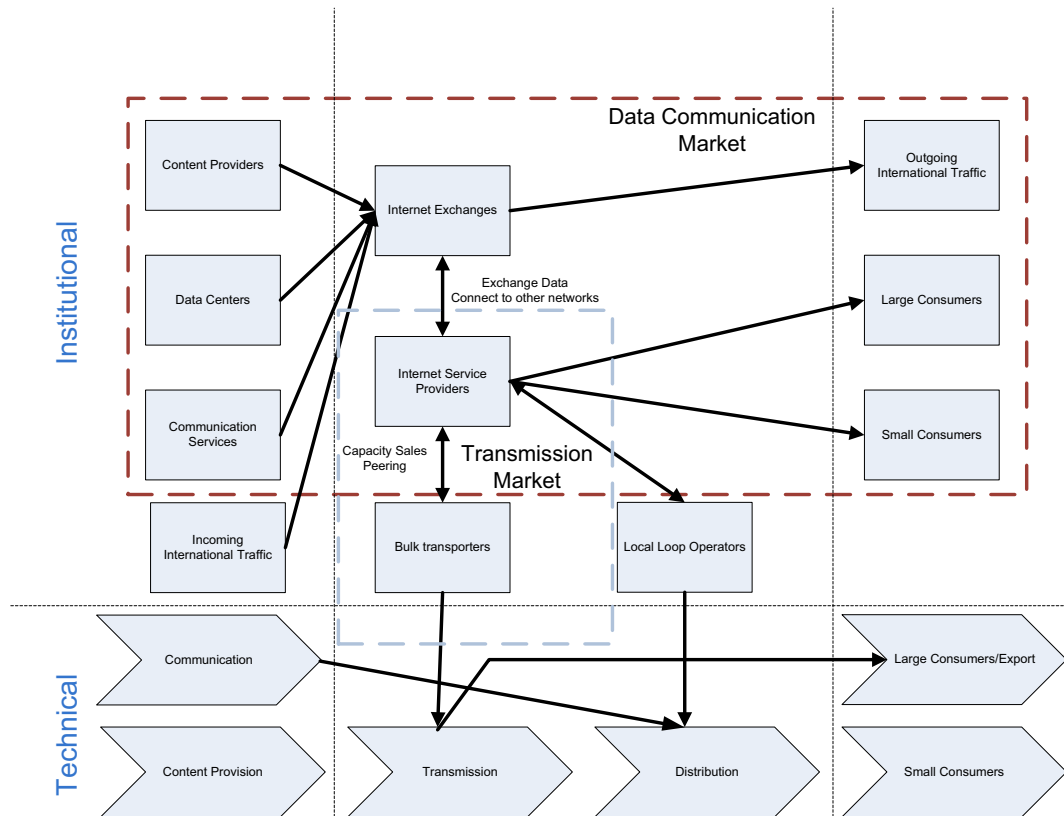


Figure 6.1: The telecommunications infrastructure paradigm

Source: based on de Vries (2007)

Physical infrastructure

Unlike in the gas and electricity infrastructure, in the telecommunications infrastructure we can often not make a clear distinction between supply and consumption of information. Communication is typically a two-way process; an user is often both a supplier and consumer of information. On the other hand, the provision of content represents a more classical supply-demand chain. A large supplier of information broadcasts this information through a television channel or provides it through an extensive website. However, the representation of the physical infrastructure in supply, transmission, distribution and consumption segments still provides a good basis for the analysis, as long as we acknowledge that this is a simplification. We can then distinguish two prominent information flows:

Content provision typically a one-way information flow, where the supplier is a large content or service provider connected directly to the transmission grid and supplies a large number of consumers.

Communication typically a two-way information flow, where both the "supplier" and "consumer" are often connected directly to distribution networks and the number of users is limited.

In the telecommunications infrastructure we distinguish four types of suppliers: content providers, data centers, communication services and international traffic. Data centers provide a way to store large amounts of information on locations close to the users. This reduces the traffic load when the information is requested by the users, as the information does not have to be sent directly from the provider (which can be far removed given the global character of the internet). Also data centers provide the opportunity to store information on multiple locations and ensure their availability even when parts of the infrastructure are congested. As such, data centers can fulfill a comparable role to storages in the gas infrastructure.

Internet Exchanges

Internet exchanges perform a special function in the telecommunications infrastructure. Intuitively, they perform the same function as interconnectors in the gas and electricity infrastructures, allowing flows from one network to another. However, in the telecommunications infrastructure many different networks exist next to each other. For example, while you could be using the PSTN for internet access, your neighbour could be using the television cable network. To adequately deliver services to all of its customers, ISPs and content providers need access to many networks. Because of the high costs associated with contracting capacity on all networks separately, especially for foreign networks, ISPs often engage in peering. Peering is an agreement between parties to carry each others traffic over the networks where they contracted transport capacity. This reduces the need for transport capacity as the booked capacity can often be utilized more efficiently, especially if more parties are involved in the peering and multiple paths are created to transport the information. To peer, parties need a location to exchange information. An internet exchange is a prime example of a location where many parties can peer. The largest exchange in the Netherlands, the Amsterdam Internet Exchange (AMS-IX) connects over 300 parties. Some parties have peering agreements with over 200 other parties on the AMS-IX and the individual networks are on average connected to 5 separate internet exchanges (AMS-IX, 2009). An internet exchange is thus much more than a simple interconnector.

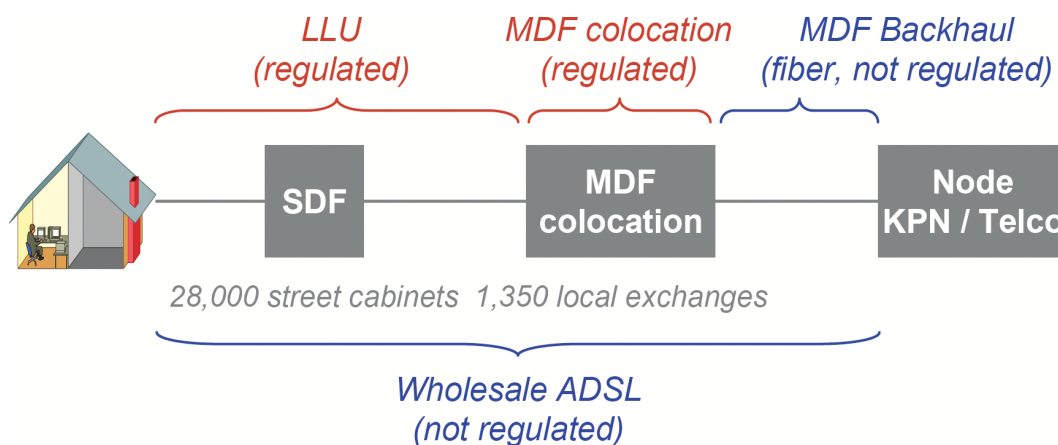


Figure 6.2: Current PSTN structure
Source: KPN (2007), slide 10

The transmission infrastructure exists of a number high-capacity glass fiber networks. These networks are referred to as the core or trunk networks. The distribution infrastructure is formed by the copper PSTN network and the coaxial cable television network, with 98% of all households connected to both infrastructures (Broadband Wales Observatory, 2005). These networks are often referred to as the access networks or the local loops. In the Dutch KPN network, the transmission and distribution networks are connected at one of the 1,350 main distribution frames (MDF, see figure 6.2). The distribution networks are further divided at one of the 28,000 street distribution frames (SDF). The various transmission networks are interconnected at internet exchanges (see box Internet Exchanges for more details). Based mainly on their traffic demands, consumers are connected to either directly to the transmission networks or through the distribution networks.

Institutional environment

Most users are connected to the telecommunications infrastructure through a service provider. For simplicity reasons, we assume in the rest of this analysis that every user, both suppliers and consumers, are connected to the telecommunications infrastructure through an ISP.⁵ An ISP is assumed to provide access to users and handle all the traffic these users generate. To achieve this, the ISP contracts capacity from network operators and peers with other ISPs at internet exchanges. The transmission networks are operated by several bulk transporters, while the distribution networks are operated by local loop operators. Because of the monopolistic characteristics of the distribution networks, the access to the local loops is regulated by the independent telecommunications regulator OPTA. Because transport activities do not have to be unbundled from other activities in the telecommunications infrastructure, parties can be active in multiple roles (e.g. KPN is active as a content provider, bulk transporter, local loop operator and ISP). In this way, they can offer both end-to-end services and services in a specific segment of the infrastructure.

6.3 Infrastructure context

6.3.1 Technical context

Localization of supply and demand

*Traditionally local
transmission*

*Increasing long-distance,
international
transmission*

The distribution networks of the PSTN are finely meshed networks, which connect the majority of homes in the Netherlands.⁶ The demand for internet access is thus finely dispersed and centered around urbanized areas and industrial complexes. Traditionally, most communication traffic was intended for local transmission, for example within the same city. This was mainly due to the high costs of long-distance transmission over analogue circuits, especially international calls were often prohibitively expensive for most users. However, due to the introduction of efficient optical transmission techniques over glass fiber networks along with the improvement of network hardware and software, the costs of long-distance transmission has decreased dramatically. Furthermore, the internet made content available on a global scale, which further increased international traffic flows. As a result the pattern of traffic flows is changing and more traffic is being transported over transmission networks (Nilsson, 2003; Odlyzko, 1998).

Another important change in traffic flows is the aggregation of flows and the concentration of traffic around hubs, like internet exchanges and data centers. Where traditionally communication flows were transported along a switched path in a dedicated network, information flows now concentrate where different networks meet. While the internet made content globally accessible, at the same time it also increased the need for transport capacity and increased the risk of congestion on certain paths (leading to undesirable characteristics like low throughput and high delay), especially when specific content suddenly becomes highly sought after (e.g. a newly released update for Windows). To avoid this, the process of mirroring is widely employed on the internet. By supplying the content from servers at a datacenter close to the consumer, instead of from the location of the content provider, the traffic load is dispersed and the need for transport capacity is reduced, increasing the reliability of information flows.

⁵ In reality, the variety of stakeholders and contract structures in the telecommunications industry is immense. However, for every interaction over the network the user needs both service provision and network access which, especially for small consumers, are often offered as an integrated package by ISPs. By making this simplification, the role of ISPs in the telecommunications infrastructure can clearly be compared with the role of shippers in the gas infrastructure and PRPs in the electricity infrastructure.

⁶ Currently 3,6 million homes have a broadband DSL connection provided through the PSTN (OECD, 2008b).

Controllability

In the traditional PSTN, the flow of information was very controlled. For every phone call a circuit switched, dedicated path was created between the two users, carrying only the information exchanged in that phone call. In telephone calls it is necessary that the transmission delay (latency) is minimal, as people do not tolerate a significant delay (Odlyzko, 2008, p. 8). As a result, a failure in the dedicated path would cause an almost immediate interruption of the phone call, however the impact of the failure on the rest of the network was limited.

Flows largely controllable

Control over individual connections

Buffer and recovery mechanisms

In the current network, where a lot of the information flows are aggregated and packet switched rather than circuit switched, the network operators have less control over the traffic flows. This is especially true in the transmission networks where many different information flows are aggregated. On the other hand, the total volume of the traffic flows is more stable and predictable in the large transmission networks than in the more dispersed distribution networks (Nilsson, 2003, p. 1).

The controllability of package-switched networks is increased by intelligent control mechanisms. Where a very short failure would lead to interruptions in e.g. traditional voice communication or the electricity infrastructure, it is possible to identify and resend packages that were lost in the transmission, correcting the failure before the whole information flow is interrupted. Furthermore, communication protocols can help routing information flows in an intelligent way. For instance, one of the central protocols for internet traffic is the Transmission Control Protocol (TCP), a cooperative protocol which includes flow and congestion control (Odlyzko, 2008, p. 6). By using this protocol individual packets can be routed in such a way, that the information flow is reliable, and the risk of congestion and network collapse are reduced.

Swing of demand

We can distinguish three important timescales for the variation in information demand; short-term, daily and seasonal. Individual information flows have always been bursty (telephone calls are interrupted very suddenly from a network perspective) and this has only increased with the introduction of data communication. Most customers also value these bursty transmission characteristics (Odlyzko, 1998, p. 10), wanting to send or receive information as fast as possible and thus using as much bandwidth as possible. This bursty behaviour can lead to sudden and unexpected congestions in the network, that have to be dealt with on an ad hoc basis.

Strong and bursty short-term swing

Strong daily pattern

No seasonal pattern

The daily and seasonal demand patterns of the telecommunications infrastructure can be well described by the traffic patterns on the AMS-IX, as the traffic that flows through this internet exchange gives a good indication of the total traffic flows in the Netherlands (CBS, 2006). In Figure 6.3, we can see a strong daily profile with a very high demand in the evening and a low demand during the night. Up until recently, no significant seasonal demand pattern was observed because of the excessive growth rates of traffic (often above 100% per year). However, in recent years a slight recurring dip is observed in the summer (AMS-IX, 2009). Given the continued fast growth of overall demand and the consequent need to periodically update capacity, these daily and seasonal patterns have limited influence on capacity planning.

Supply characteristics

As was discussed before, we cannot discern supply in telecommunications infrastructures as easily as in gas or electricity infrastructures. Everyone can be a supplier of communication or content and at very different scales. There just has to be an interest in the information they provide. Given the flexibility and modularity of computer equipment and transport capacity, suppliers can emerge everywhere and anytime and increase or decrease their traffic flows on relative short notice, by increasing server or transport capacity.

Flexible equipment

Modular equipment

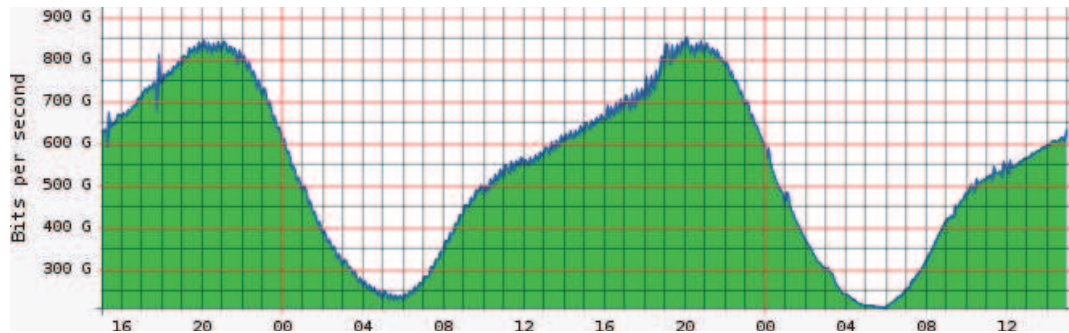


Figure 6.3: Daily traffic pattern AMS-IX
Source: AMS-IX (2009), Daily graph

Table 6.3: Value of bits: approximate price per megabyte of various services

Service	Revenue per MB
Wireless Texting	\$1,000
Wireless Voice	1.00
Wireline Voice	0.10
Residential Internet	0.01
Backbone Internet	0.0001

Source: Odlyzko (2009), Table 1, p. 43

6.3.2 Economic context

Commoditization

*Continuous development
of new and different
products*

The telecommunications infrastructure is used to provide a very broad range of products and services. Especially the transmission networks transport very diverse information flows, not only for the fixed line telecommunications infrastructure, but also to carry traffic for mobile telephony and cable television. As a result, there is an enormous amount of product differentiation, with very diverse characteristics, requirements and revenues. Take for example the values presented in Table 6.3: a megabyte transferred over a transmission network can represent a final revenue anywhere between 0.0001 dollar and 1,000 dollar, dependent on the service for which it is used.⁷ New products and services are also developed all the time and become outdated at the same pace, so there is clearly no sign of commoditization.

Market maturity

*Developing market:
increasing demand,
decreasing prices, high
innovation*

The telecommunications infrastructure is clearly a fast developing and immature market. With the constant introduction of new products and services and the development of ever more efficient hardware, software and transmission networks, the innovation is very strong and the infrastructure is under constant threat of becoming outdated. Concurrently, the traffic flows have grown at an incredible pace⁸ while the prices have also dropped immensely.⁹

⁷ Of course the numbers should not be taken as too precise. However, the differences in order of magnitude are approximately correct and should give a clear indication of the differences.

⁸ In the period 2003-2008, the traffic on the AMS-IX grew by an astonishing factor of 24 (AMS-IX, 2009).

Market structure

Originally the PSTN was characterized by an extremely integrated and centrally coordinated structure. KPN operated a complete nationwide monopolistic infrastructure for fixed telephony, containing the backbones, the local loop and all network equipment. Most contracts contained a monthly connection charge and a metered usage charge per minute. This contract structure remained in place when smallband dial-up internet was introduced. Because the internet user paid for every minute of connection, the connection was often terminated as soon as possible.

The introduction of broadband access and the opening up of the PSTN to third parties have changed the market structure immensely. The growth of data traffic and the demand to stay connected led to always-on broadband access. Instead of disconnecting after every session, the internet connection remained active at all times. This was accompanied with another contract structure; the usage charges per minute disappeared and instead a connection charge dependent on the bandwidth/capacity of the connection was introduced.¹⁰ By differentiating services with different prices and bandwidths, it was possible to appeal to low, mid and high capacity users which greatly stimulated demand.

To create an internal market for telecommunications services and to allow new entrants to compete on the networks of the incumbents, the framework of open network provision (ONP) was introduced. This was included in European legislation through Directive 90/387/EC and subsequently in Dutch legislation in the Telecommunications Act of 1998.¹¹ Among others, the Telecommunications Act introduced a general interconnection obligation for telecommunication networks and services, the obligation to open up the distribution networks to third parties through local loop unbundling (LLU) and the OPTA as the independent telecommunications regulator (Ministerie van Economische Zaken, 2008). LLU was introduced almost directly after the roll-out of DSL in 2000 and has created significant infrastructure based competition, with many competitors competing against the incumbent KPN (Broadband Wales Observatory, 2005).

The transmission segment can be characterized as an oligopoly, with a limited number of parties owning core networks. However, the market for core transport seems competitive enough and core transport is a low-cost commodity, mainly due to overcapacity as a result of the investment boom in telecommunications in the early 2000s and the technological development of fiber optics (Odlyzko, 2004).

The distribution segment can be characterized as a duopoly between KPN and the regional cable network operators. To allow access to the distribution networks to third parties and prevent the abuse of market power, LLU is enforced and the tariffs are regulated. The downstream wholesale and retail segments are regarded as highly competitive due to the fast increasing demand for broadband services. This has resulted in a relatively low share of the incumbent KPN in DSL services.¹²

Unlike in gas and electricity infrastructures, transport activities do not have to be separated from retail and wholesale activities in different companies. Because being active in multiple segments in the supply chain increases control and the possibilities for product differentiation, KPN has employed a strong vertical integration strategy. By setting up and purchasing several content providers and ISPs, KPN has created many different subsidiaries and brands to differentiate their products (Broadband Wales Observatory, 2005). Integrating ISPs is also attractive for network operators for another reason. By aggregating traffic and offering statistical instead of firm bandwidth, ISPs are able to make far more efficient use of their transport capacity than other network users (Odlyzko, 1998). Network operators who also own an ISP can integrate these efficiency gains (more on this in §6.4).

Vertical integration

Supply: Full Competition

Transmission: Oligopoly

Distribution: Duopoly

Downstream: Full Competition

⁹ For instance an analysis based on OECD broadband statistics (OECD, 2008a) shows that the price per Mbit of connection capacity for a representative domestic DSL subscription in the Netherlands has decreased from € 9,37 in 2005 to € 2,50 in 2008. This represents an average annual decrease of 28%!

¹⁰ The connection charge for internet access was originally separate from the connection charge for fixed telephony. With the integration of services, this has more and more been replaced by a single charge.

¹¹ Later replaced by the Telecommunications Act of 2004

¹² 43,3% of all wholesale lines and 31,9% of the retail market in June 2005 (Broadband Wales Observatory, 2005).

Cost Structure

Highly differentiated product costs

Transmission costs <1% total costs

Route specific capacity tariffs

Because of the large price differentiation in services and content, it is very difficult to define the composition of costs in telecommunications infrastructures as clear as in gas and electricity infrastructures. From table 6.3, we can see that the costs for transmission (backbone internet) are approximately 2 orders of magnitude lower than the costs of residential internet (which at least includes transmission, distribution and access services). Like in the other infrastructures, the share of transmission in the total costs is thus very limited in the telecommunications infrastructure.

According to Pollitt (2009, p. 14-15), the share of distribution in the total costs of retail broadband and voice services is higher than the share of distribution in total electricity costs, making the share of distribution costs in telecommunications the highest in the three infrastructures. However, these costs still form only 21% percent of the total retail broadband and voice services.¹³

Transport over core networks is mainly paid through tariffs for firm capacity on a specific transmission route. As a result, the price paid for transmission is much more resembling of actual network costs than in gas and electricity transmission networks. However, the buyers of core network capacity (e.g. ISPs) typically engage in peering to increase interconnectivity and reduce transmission costs. Because peering is non-transitive and often asymmetric (Norton, 2001), relating the costs of transmission and peering to actual traffic flows is often intransparent.

6.3.3 Institutional context

Price regulation

No price regulation

Competition is deemed adequate

Because there is enough competition in core networks, transmission services are not regulated on price. However, core network operators have to grant access to their networks on clear and publicly available terms. The distribution networks on the other hand are regulated on price, given their monopolistic characteristics. Because of the vertical integration within KPN, this does have a significant effect on the investment and planning decisions for the total network operated by KPN. For instance, the All-IP strategy of KPN (discussed in more detail in §6.5.2) is confronted with regulatory uncertainty to which parts of the new and old infrastructure will be price regulated and how (OPTA, 2006).

Quality regulation

No quality regulation

Quality standards safeguarded in service agreements

There is no explicit quality regulation for telecommunications networks. However, quality standards are safeguarded through individual product and service agreements. Given the fast development of the telecommunications infrastructure and the vast number of different products and technologies, this approach is probably preferable to quality regulation, as regulation tends to lag behind technological developments.¹⁴

Public service regulation

Interconnection obligation

According to the Telecommunications Act, the fixed line telecommunications infrastructure has to fulfill at least two obligations: the universal access obligation and the interconnection obligation. The Act determines that every consumer should be able to get access to fixed line telephony at an acceptable price. This obligation has been assigned to KPN, however it only considers voice telephony and not broadband internet access. For a good functioning communications infrastructure it is important that a user can connect to every other user in the market independent of the network to which the user is connected. The interconnection obligation forces all network operators to arrange connections to other networks, i.e. by exchanging traffic or offering transport capacity on its network.

¹³ These are results from an analysis of UK infrastructures. Based on the costs for electricity used in that analysis, it is assumed that the composition of costs is comparable in the Netherlands.

¹⁴ Interview GTS1, held June 24, 2009.

International dependence

As discussed before, international traffic in telecommunications networks is increasing steadily. This increases the dependency on foreign network operators, content and service providers to guarantee good end-to-end delivery of content and services. However, the increase of peering strategies and the deployment of data centers and mirrors close to demand, reduce the potential negative impact of international disturbances.

Increasing international traffic

However, peering reduces impact on data transport

6.4 Assessment of reliability

Dependability

The dependability of the telecommunications infrastructure is hard to determine given the large variety in parties and the services they offer. Because of competitive considerations, network operators and service providers provide no insight into the reliability of their operations. Therefore there are no aggregated analyses of infrastructure reliability. The dependability of the networks themselves is considered to be very high. The performance of the PSTN is almost on par with electricity networks (de Bruijne, 2006, p. 15). For some critical services, like emergency services, the dependability is even guaranteed all the time, a level of dependability not even the gas infrastructure can provide.¹⁵

Average interruption duration hours-days per year

Size and frequency of large interruptions differ per service

When we look at the dependability of the most reliable providers of broadband access, we see that approximately 80-85% of the consumers does not experience an interruption during a given month.¹⁶ This corresponds with roughly 2 interruptions per customer per year, which is much higher than in the other infrastructures. When we look at the guarantees that a reliable ISP provides for dependability, we see a more unsettling picture. The standard guarantee is 95% availability, which corresponds to 438 hours or roughly 18 days of interruption per year! The next level of availability that is offered is 99,60% (equivalent to 35 hours of interruption) at a 10% premium (IS Interned Services, 2009). Even considering that this latter value is probably more realistic for the actual dependability of the standard service, these values are incomparable to the interruptions experienced per consumer in electricity (30 minutes per year) and gas infrastructures (1 minute per year). On the other hand, most interruptions are not caused in the transport networks but rather at the edges; failing equipment like servers and routers or software problems are far more likely to cause interruptions (Odlyzko, 1998, p. 4). Because the cause of the failure can be in any of the layers identified in Table 6.2, the network operator has much less influence on the overall dependability of the infrastructure, than the network operators in gas or electricity infrastructures.

Intrinsic quality

Traditionally the PSTN was a classic public utility; with voice telephony, the network delivered one universally accessible and standardized service. This service was bound to strict quality standards, because a decrease of signal quality or an increase in latency had a very negative impact on the usability of the service. When the transmission was interrupted for a short time, this often resulted in a service interruption in the form of a dropped call. Thus it was necessary to provide a stable and reliable quality of network transport with little variations.

Product differentiation based on quality

Statistical vs. guaranteed quality

Overbooking

With the introduction of packet-switched data communication this all changed. It was no longer important that every packet arrived the first time that it was sent, or that every packet took exactly as long to travel as the previous one or the next, as long as all packets arrived and the total information was usable by the recipient in the end. For most users, it does not matter if a website takes a few seconds to load or if an e-mail takes a couple of minutes to be delivered. While the actual information flow may be interrupted several times and resent completely, the user does not experience these interruptions. This allows for *best-effort* performance in data communication, unlike the guaranteed stability required for voice telephony, gas and electricity.

¹⁵ Interview GTS1, held June 24, 2009.

¹⁶ Based on test results of the number 1 provider in the Dutch Consumers' Union provider test (XS4all, 2010).

Table 6.4: Relevance of quality parameters

	Throughput		Delay		
Service	Down	Up	RTT	Jitter	Packet loss
Browse (text)	++	-	++	-	-
Browse (media)	+++	-	+	+	+
Download file	+++	-	-	-	-
Transactions	-	-	++	+	-
Streaming media	+	-	+	++	++
VoIP	+	+	+++	+++	+++
Games	+	+	+++	++	++

+++ highly relevant ++ very relevant + relevant - not relevant

RTT = Round-trip delay

Source: Wattegama (2008), Slide 17

At the same time data communication allowed for product differentiation based on quality. Higher bandwidth could be purchased to faster send and receive larger information flows. The quality could be guaranteed by purchasing redundant or dedicated lines. But most importantly, consumers could save money by accepting capacity overbooking. Because most consumers do not use their full bandwidth at the same time, it is possible to aggregate their traffic flows, and statistically determine the overall bandwidth needed to fulfill their demands. This overall bandwidth can be much lower than when the full bandwidth of all consumers is added up. In residential broadband connections 1:20 capacity overbooking is not uncommon, meaning that 20 consumers with a 1 Mbit connection share one line with 1 Mbit capacity. Because of the *best-effort* characteristic consumers often only experience a reduction in speed and an increase in latency when more users try to access the bandwidth, instead of the interruptions this would cause in other networks. By accepting a slight reduction in quality, consumers can thus achieve significant cost reductions.

The practice of overbooking has played a very important role in the roll-out of broadband internet over the existing PSTN network. The transport capacity of the original switched and copper based infrastructure was technically limited. As a result of technical developments, the core networks could be replaced by glass fiber networks which increased the transport capacity immensely. On the other hand, the access networks that extended into the houses of the consumers, were often very dispersed in highly populated areas and replacing them has proved to be prohibitively expensive. The only way to offer broadband connections to consumers on a large scale has thus been to implement overbooking, simply because there is not enough transport capacity to go around.

Not only different consumers require different levels and aspects of quality, also different types of information traffic require different quality parameters. For example, where file transfers mainly require fast throughput, streaming media requires little delay in transmission (see Table 6.4). Traffic can be distinguished in two broad categories based on their quality requirements, namely elastic and inelastic traffic. Elastic traffic is best-effort traffic that employs whatever resources it is assigned. Examples include traditional internet services, such as websites and e-mail which are insensitive to a little delay. Inelastic traffic on the other hand, is very sensitive to assigned bandwidth and transmission delay. Examples include streaming media and internet telephony (VoIP). Because the traffic flows in core networks are aggregated, the networks have to be designed and operated in such a way that they can handle both these different types of traffic appropriately. This means reserving a fixed minimal bandwidth for inelastic traffic, while efficiently allocating remaining and additional bandwidth to elastic traffic (Nilsson, 2003, 2006).

Perceived quality

The perceived quality is much more dependent on subjectivity and the historical development of the telecommunications infrastructure. Only 10-15 years ago internet access could be regarded as a niche product, a curiosity with limited practical value for most people. The user base and the available services and content were incomparable with the situation of today. Internet was something that was accessed only for an hour every day or so, where nowadays most users are connected to the internet almost continuously. Consequently the public value attached to internet access was low. The switched nature of the PSTN (and later the packet switching algorithms) allowed for the controlling and monitoring of every single connection. This excludability, combined with the rapidly increasing rivalry for bandwidth, gives internet access strong private good characteristics, in contrast with gas and electricity supply.

Strong private good characteristics

Limited public value characteristics

Risk aversion determined by the market

These private good characteristics allow for product and price differentiation. Bandwidth and reliability are optional in internet access, almost entirely dependent on the amount of money one wants to spend on them. A short personal anecdote might illustrate the perception of quality for small domestic users approximately 10 years ago. Downloading single songs from a website often took about one hour. When the connection was interrupted (be it because the sending server or web browser crashed or another person in the house inadvertently used the telephone) the whole file was lost. The only solution was to download the whole file again or consider it a lost cause, a decision that had to be made rather frequently. While only 50% of the downloads might succeed, this level of quality was deemed acceptable, as there were no viable alternatives. That is until the introduction of download managers, software that allowed resuming a download after the connection was interrupted. Instantly the achievable level of quality was increased tremendously and not coincidentally the minimum acceptable level did as well.

Since then, the internet and the telecommunications infrastructure have developed tremendously, not only technically but also in the scope of use and implementation. Some of these developments also have had massive implications for the perceived quality. First, with the increasing capabilities and dependability of internet access, the use of internet began to change. As an experimental and unproven network, the internet was mainly used for experimenting and entertaining purposes. Its limited reach and limited dependability, made it unsuitable for most corporate and critical processes. However with the continuous development the internet now has achieved a level of reliability that makes it suitable for these processes. In turn, the fact that these processes now rely on the internet increases the minimum acceptable level of reliability and can clash with the best-effort nature of the internet.

Second, new applications and services have changed the composition of internet traffic. Traditionally, the majority of traffic has been elastic, allowing for a constant variation in network reliability. However, with the introduction of VoIP and real-time streaming media (e.g. online television and radio) the share of inelastic traffic is steadily increasing. Because this traffic is very sensitive to assigned bandwidth and transmission delay, it increased the minimum acceptable level of quality. If the infrastructure is not able to transport inelastic traffic correctly most of the time, it will have a severe impact on the user experience and the viability of new services.

Third, with more and more communication and services being offered over the internet, reliable access to the internet has become vital to more and more people. Limited access is considered to create significant social and economic development barriers. As a result, the public value of accessible, reliable and affordable access has increased.

6.5 Treatment

In this section we describe how TSOs employ different treatment options to deal with reliability. First, we present an overview of the existing practice and then we discuss future trends.

6.5.1 Existing practice

Network design

Today's core networks are characterized by high levels of redundancy and low utilization rates. These low utilization rates have two important causes: the fast development of fiber glass transmission technology and the investment boom in telecommunications in the early 2000s. Because glass fiber is able to transmit a large spectrum of wavelengths, it is possible to transmit many data streams simultaneously over different wavelengths in a single fiber. Where originally only one data stream was sent per fiber, the transmission capacity has increased by orders of magnitude in the last decades. As a result, core networks can carry much more traffic than before with essentially the same physical glass fiber connections (a technological scope that is clearly absent in the other infrastructures). As Odlyzko (2004, p. 338) argues core network technology has outrun demand *"as the entire ... internet backbone traffic could in principle be carried on a single fiber strand."*

Increasing transport capacity

The investment boom in telecommunications led to heavy investment in national and international glass fiber networks. Because the demand for network capacity did not develop as quickly as expected, a significant part of these glass fiber connections has remained unused (the so-called "dark" fiber glut) and other connections have relatively low utilization. Given the low costs of core networks compared to the rest of the infrastructure, core networks are more and more run as commodity providers of a uniformly high quality service. While potentially profitable on its own, the market for core networks is unlikely to become very large (Odlyzko, 2004). However, for a vertical integrated company like KPN it is attractive to invest in overcapacity of the relatively inexpensive core networks, to anticipate the growth in demand and ensure the quality of their other services and content provision.

Network coupling

The coupling of networks through peering increases reliability by creating multiple redundant paths to transport information, while also reducing transport costs and helping to fulfill the interconnection obligation. As such, it plays a vital role in network design, as increasing the number of peering partners can be a viable and effective alternative to increasing one's own network capacity.

Supply and demand responsiveness

For content and service providers, the flexibility of their services is for a large part determined by the level of reliability they want to achieve and the costs they want to make. Given the best effort nature of internet and the modularity of server and transport capacity, investment in new capacity is often postponed until the limits are approached and the quality is decreasing notably (of course, this is not the case for critical and/or high-quality processes). Expanding capacity only when the limits are approached is attractive because it can often be done at relative short notice and the costs are constantly decreasing due to technological developments.¹⁷

Overbooking

The traffic patterns of demand are already restricted by statistical aggregation and overbooking in the access networks. In the core networks, this traffic is further aggregated and as a result the traffic flows are relatively stable (Nilsson, 2003), so there is typically no need and no measure to influence demand responsiveness for core network operators.

¹⁷ Investing in an additional server that will only be used regularly after 2 years is inefficient, because at that time a new server will most probably be more powerful and less expensive.

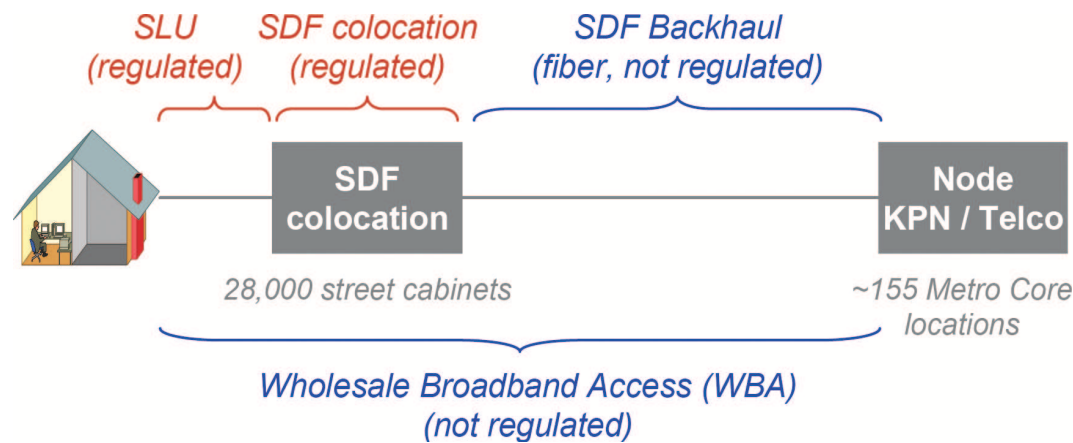


Figure 6.4: All-IP network structure
Source: KPN (2007), slide 10

6.5.2 Future trends

Network design

While the current core network design is likely able to meet the growth of traffic as a result of the steady increase of fiber glass transmission capacity, the network topology and technology will probably still be enhanced for efficiency and reliability reasons. For example, the double-star topology of the AMS-IX which has replaced the ring topology, offers much more redundancy and thus reliability (AMS-IX, 2009). This or an even more advanced topology is likely to be integrated in critical parts of the core networks. Furthermore, the implementation of new technologies (like the IPv6 protocol) also requires adaptations of the network design.

Network technology

Network design

Currently KPN is in the process of implementing the All-IP strategy. The All-IP model is a new infrastructure model (compare Figure 6.4 with Figure 6.2), where the glass fiber penetrates even deeper into the network and where all data transport is based on the IP protocol. This represents a large opportunity to increase transport capacity and to rationalize and simplify the core network by reducing the number of nodes and interconnections. Also the intelligence of the network is distributed to a core of soft switches and routers instead of the hard switches currently in the network.

Supply and demand responsiveness

The telecommunications infrastructure is used more and more to deliver real-time content (e.g. radio and television streams) to consumers. However the telecommunications infrastructure also has to transport other information traffic flows reliably and efficiently. This requires that real-time content is delivered in an efficient way. Traditionally, radio and television streams are *broadcasted* over the RF cable infrastructure to all consumers indiscriminately. The channels are transmitted in dedicated frequency domains, making it possible to watch and listen to radio and TV with simple receivers. However, broadcasting makes very inefficient use of network capacity as a consumer also receives all the channels he is not watching at the moment.

If broadcasting were used to deliver real-time content through the PSTN local loop, consumers would only have access to a very limited number of channels, given that the capacity of the PSTN local loop is much lower than that of the RF cable local loop. Thus, it is attractive for network operators and content providers to use *multicasting* instead.¹⁸ In this way, the network capacity can be used much more efficiently and more channels can be delivered. The drawback is that the consumers needs more sophisticated receiving equipment,

¹⁸ Multicasting is a network technology for the delivery of information to a group of destinations simultaneously using the most efficient strategy to deliver the messages over each link of the network only once, creating copies only when the links to the multiple destinations split.

Prioritizing traffic

which can tell the network which channels it is listening to (Schmidt, 2006). However, this receiving equipment is already widely available as a result of technological developments.

Another method to increase the quality of information flows, without increasing network capacity, is to implement QoS labeling. This method, which is available in IPv6, gives every packet a QoS label making it possible for instance to distinguish between elastic and inelastic traffic (Schmidt, 2006; Nilsson, 2006). Because elastic traffic is less sensitive to delay and assigned bandwidth, giving inelastic traffic priority over elastic traffic can potentially increase the overall quality, without negatively affecting the customer who sends and receives elastic traffic. However, this QoS labeling inevitably makes the infrastructure more complex.

Next to these options to positively influence supply and demand responsiveness, there is also growing concern over the increasing requirements real-time streams pose on the infrastructure. Because these real-time streams require a firm bandwidth and low latency, they require more network capacity than elastic forms of traffic. With more and more parties introducing IP-TV and VoIP services, the demand for higher bandwidth connections with less overbooking is increasing, and KPN is adapting their networks to these changes, for instance through the All-IP strategy.

While the dominant perception is indeed that networks will have to adapt more and more to these increasing real-time streams, Odlyzko (2003, 2009) argues that faster-than-real-time streaming combined with local storage is a much more attractive solution, at one time reducing network requirements and increasing quality of service. In this light, real-time streaming can be seen as an anachronism based on the dominant broadcasting paradigm of firm bandwidth channels and limited local storage. While in fact, the current infrastructure is characterized by the best-effort nature of the internet, overbooking of capacity and vast local storage capacity.

Chapter 7

Cross-case analysis

In this chapter, the findings from the case studies in the previous three chapters are analyzed and integrated. The chapter is divided in three main sections. First, a structured comparison between the three infrastructures is made based on their differences and similarities. This leads to some clear-cut and explainable relations between the context, assessment and treatment of reliability in network infrastructures.

However, there is also a large number of very complex and tentative interactions within the infrastructures that cannot be explained in a simple and unambiguous way. Therefore in the second section, we discuss some of the most important and interesting interactions in more detail. The choice of which interactions to discuss is a personal one and is no attempt to give a complete or conclusive picture, but is rather intended to facilitate discussion and input for future research. In the last section, we discuss the consequences of this analysis for dealing with reliability in vital infrastructures and the gas infrastructure in particular.

7.1 Comparison of cases

The following section provides comparisons between the three infrastructures based on the differences in their context, assessment and treatment of reliability. The comparisons are supported by tables containing the most important aspects of the factors discussed in the case studies. This tabular form enables a quick and clear indication of the similarities and differences between the infrastructures. The tables can however contain only a simplified and crude description of the case material. If the reader is interested in a more in-depth discussion, he/she is referred to the individual case studies in Chapters 4 through 6.

7.1.1 Context

Tables 7.1 through 7.3 give an overview of the technical, economic and institutional context of the analyzed infrastructures. It becomes clear that the infrastructures have a very different technical context. For example when comparing the uncontrollability of electricity flows to the ability to control information flows in the telecommunications infrastructure on an individual packet level. Or the large size and fixed location of gas sources, compared to the flexibility and modularity of equipment in the telecommunications infrastructure.

On the other hand, the economic and institutional contexts of the gas and electricity infrastructure are largely comparable. While the telecommunications infrastructure is very different in this respect, some of the developments it faces are very similar, for instance the increasing importance of international flows and the increasing number and diversity of parties involved in the value chain. The fact that the three infrastructures are very different as a whole, but often have striking similarities on individual context factors, enables us to analyze the particular influence of these factors on the assessment and treatment of reliability. This final set of factors thus forms a strong basis for the rest of the analysis.

Table 7.1: Technical context

	Gas	Electricity	Telecom
Localization supply & demand	Few sources; Long distance to market.	Centralized and decentralized production; Optimal distance to market.	Traditionally local transmission; Increasing long-distance, international transmission.
Controllability	Flows controllable to a limited extent; No control over individual connections; Buffer to compensate for deviations in supply and demand.	Flows unpredictable and uncontrollable; No control over individual connections; No buffer.	Flows largely controllable; Control over individual connections; Buffer and recovery mechanisms.
Swing of demand	Limited and gradual short-term swing; Strong daily pattern; Very strong seasonal pattern.	Limited but transient short-term swing; Strong daily pattern; Strong seasonal pattern.	Strong and bursty short-term swing; Strong daily pattern; No seasonal pattern.
Supply characteristics	Flexibility mainly provided by Groningen field; Concerns over long-term flexibility.	Flexibility mainly provided by gas-based generation; Concerns over flexibility requirements caused by renewable generation.	Flexible equipment; Modular equipment.

Table 7.2: Economic context

	Gas	Electricity	Telecom
Commoditization	Yes: commodity	Yes: commodity	No: continuous development of new and different products
Market maturity	Mature market	Mature market, however: Possibility of paradigm changing developments	Developing market: increasing demand, decreasing prices, high innovation
Market structure	• Ownership unbundled • Supply: Oligopoly • Transmission: Monopoly • Distribution: Monopoly • Downstream: Increasing Competition	• Ownership unbundled • Supply: Imperfect Competition • Transmission: Monopoly • Distribution: Monopoly • Downstream: Increasing Competition	• Vertical integration • Supply: Full Competition • Transmission: Oligopoly • Distribution: Duopoly • Downstream: Full Competition
Cost structure	• Volatile product price • Transmission costs $\approx 1\%$ total costs • Entry and exit capacity tariffs	• Very volatile product price • Transmission costs $\approx 1\%$ total costs • Non-cost reflective consumer tariffs	• Highly differentiated product costs • Transmission costs $< 1\%$ total costs • Route specific capacity tariffs

Table 7.3: Institutional context

	Gas	Electricity	Telecom
Price regulation	Yes: tariff regulation (volume risk for TSO)	Yes: revenue regulation (no volume risk for TSO) and substantial investment policy	No: competition is deemed adequate
Quality regulation	Yes: performance publications, quality standards and compensation payments	Yes: performance publications, quality standards and compensation payments	No: however, quality standards are safeguarded in product and service agreements
Public service regulation	GTS acts as supplier of last resort, connection policy and small fields policy	Connection obligation, TenneT has a coordinating role in emergency supply	Interconnection obligation
International dependence	- Increasing dependence on import - Increasing dependence on international flows	- Decreasing dependence on import - Increasing dependence on international flows	- Increasing international traffic - However, peering reduces impact on data transport

7.1.2 Assessment

Table 7.4 gives an overview of the assessment of reliability in the different infrastructures, based around the classification of reliability in three levels, as introduced in chapter 2.

As can be seen, the assessment of reliability in gas and electricity infrastructures shows large similarities on all three levels, while the telecommunications infrastructure is almost completely different. While both the gas and electricity infrastructure show an astonishing level of reliability (dependability of more than 99.99%), the fact that the gas infrastructure is slightly more reliable can mainly be attributed to the technical characteristics and the higher controllability of gas network, especially the inherent delay of gas flows and the ability to buffer. However, the fact that the reliability in the gas infrastructures is so high also makes it vulnerable, because of its invisibility to consumers and decision makers. Thus it is tough to continually safeguard reliability in a comprehensive way.

On the other hand, the fast technological and societal developments and large product differentiation in telecommunications infrastructure have led to a very different perception of reliability. Unlike gas, electricity, which are treated as commodities, internet access has evolved from an luxurious oddity to a necessity in the last 20 years. Therefore the public value attached to internet access has been lower than in other infrastructures. Overall the reliability is significantly lower than in the other infrastructures and can differ enormously between different services and providers. However, the fact that average reliability has been increasing steadily over the last decades and that very high reliability can still be seen as a luxury, also enables differentiation based on reliability and quality levels and thus to better determine and match the reliability levels required by consumers.

Table 7.4: Assessment of reliability

	Gas	Electricity	Telecom
Dependability			
Average interruptions per year	$\approx$ 1 minute	$\approx$ 30 minutes	Hours/days
Large Interruptions	Occur: once every couple of years Affect: more than 1,000 consumers	Occur: 3-4 times a year Affect: more than 20,000 consumers	Size and frequency of large interruptions differ per service
Intrinsic Quality			
	Strictly specified quality	Strictly specified quality	Product differentiation based on quality: statistical vs. guaranteed quality, overbooking
Perceived Quality			
Public good	Yes	Yes	No
Public value	Very strong	Strong	Limited, but increasing
Hardness of value	Very soft	Soft	Average
Risk aversion	Very strong	Strong	Determined by the market

7.1.3 Treatment

As addressed in §3.2.4, the treatment options available to and employed by the TSO in a given infrastructure are very dependent on the technical, economic and institutional context and the business goals of the TSO. As a result, the individual options are often very specific and a comparison of all individual options here would be very extensive and of limited use. However the options can be categorized in four more generic high-level strategies, which can be compared among infrastructures.

Thus it has also been analyzed how the treatment options identified in the case studies, contribute to the treatment strategies in each individual infrastructure. Aside from a high-level strategy being able to contain multiple options, individual options can also contribute to multiple strategies at once. Using a structured approach, this analysis results in a indication of the potential of and the emphasis placed on the different treatment strategies. It is important to stress that this is a highly simplified and subjective approach, which is aimed more at creating an effective visualization of general considerations and a starting point for the more in-depth discussion below, than providing an analytic framework to assess and compare individual options. The steps in the approach are the following:

1. Important options are identified in the individual case studies.
2. For each option it is determined to which high-level strategies they contribute: larger infrastructures (L), smarter infrastructures (Sm), supply responsiveness (S) and demand responsiveness (D).
3. For each option it is determined how much emphasis this option gets in planning and investment decisions: High (H, 3 points), Medium (M, 2 points) or Low (L, 1 point).
4. For each option it is determined how much potential this option has to improve reliability: High (H, 3 points), Medium (M, 2 points) or Low (L, 1 point).
5. For each option, the scores for emphasis and potential are multiplied resulting in a feasibility score on a scale from 1 to 9.
6. The feasibility scores of the high-level strategies are aggregated and normalized per infrastructure.

The scoring of individual options in the different infrastructures is displayed in Tables 7.5 through 7.7. Figure 7.1 shows the aggregated scores per treatment strategy for all three infrastructures. It is clear that there are significant differences in treatment strategies between the infrastructures. Some of these differences can be related to the differences in context and assessment in the different infrastructure, and will be discussed now. Some differences are more difficult to explain on the other hand. Why, for example, is investing in larger infrastructures so prominent in gas infrastructure? Of course, the large seasonality and transport distances require much transport capacity but the growth potential in the gas infrastructure is significantly smaller than in the other infrastructures. These and other less obvious results form input for the discussion in the next section.

Larger infrastructures

Investing in larger infrastructures is a relatively prominent strategy in gas and telecommunications infrastructure, but much less so in electricity infrastructure. In gas infrastructure, this can primarily be ascribed to large seasonality and long transport distances from foreign supply sources, which both require large transport capacity. In telecommunications, the most important cause seems to be the rapid growth of traffic flows and the related increasing penetration of broadband connections. Also the increase of services that require a minimum guaranteed bandwidth instead of the traditional best-effort approach stimulates investment in larger networks.

While the electricity network is confronted with moderately growing demand and increasing international flows, the investment in larger infrastructures is not as prominent. Investments in additional transport capacity are mostly made as a response to actual physical bottlenecks, and network development thus follows the development of generation facilities.

Smarter infrastructures

Investing in smarter infrastructures is the prominent strategy in telecommunications infrastructures, and is much less prominent in electricity and gas infrastructures. This difference can for the most part be explained by the difference in technological development of network equipment. In telecommunications industry this development is very fast, resulting in a rapid succession of newer, faster and cheaper equipment. As a result, existing equipment quickly becomes outdated and insufficient to meet increasing traffic demands and thus quickly becomes obsolete and loses its value. In the other infrastructures there is much less technological development, especially in the gas infrastructure. In the electricity infrastructure there are potentially significant technological developments, but these will not radically change the design and planning principles in the short or midterm.

While from a viewpoint of reliability and experience it is sensible and defensible to invest in proven technology in gas and electricity infrastructures, the question is how much opportunities are missed to develop more effective and efficient solutions. It is a known fact that R&D expenses in gas and electricity are noticeably lower than in information technology (Hekking, 2009; Pollitt, 2009), while the returns are not. Moreover, there is a concern that the R&D investments in energy infrastructures are redirected from long-term projects with high public value to short-term research aimed at immediate, private needs of companies (Egenhofer and Legge, 2001).

Supply responsiveness

Supply responsiveness is a central strategy in ensuring reliability in gas and electricity infrastructures. Because the demand exhibits strong fluctuations, which can only be predicted and controlled to a limited extent, the supply naturally has to follow demand, either directly or through intermediary storage. Maintaining enough supply responsiveness is a major theme in both infrastructures, given the decrease in supply responsiveness of the Groningen field in the gas infrastructure and the additional demand for supply responsiveness in electricity infrastructure due to the growing share of intermittent, renewable electricity generation.

In the telecommunications infrastructure supply responsiveness is typically not a central strategy. For suppliers, the flexibility of their services is for a large part determined by the level of reliability they want to achieve and the costs they want to make. Given the best effort nature of internet and the modularity of server and transport capacity, investment in new capacity is often postponed until the limits are approached and the quality is decreasing notably (of course, this is not the case for critical and/or high-quality processes). Expanding capacity only when the limits are approached is attractive because it can often be done at relatively short notice and the costs are constantly decreasing due to technological developments.

Demand responsiveness

Demand responsiveness has significant potential in all three infrastructures. However, it is not a central strategy for TSOs for two reasons. First, they are faced with aggregated traffic flows and thus experience less of the fluctuations of individual demand patterns. Furthermore, they have no direct contracts with consumers in which to include incentives for demand responsiveness. In electricity infrastructure, demand responsiveness forms a relatively strong strategy, because balancing supply and demand is crucial and delicate at all times and both large and small consumers can adjust their demand to some extent. In gas infrastructure, the requirements for balancing are less strict due to the buffering effect in the network and especially small consumers are less able to adjust their demand, because of the stable driving forces behind gas consumption.

In telecommunications, ISPs are able to curb demand flows through overbooking of capacity¹, which acts as a form of demand responsiveness. When the network is highly used,

¹ Overbooking is the sale of access to a service, which exceeds the capacity of the service. For example, an overbooking ratio of 2:1 means that two consumers who each have an overbooked 1 Mbit connection, share a physical 1 Mbit connection. With overbooking consumers can get a cheaper and faster connection, if they use their connection unsimultaneously.

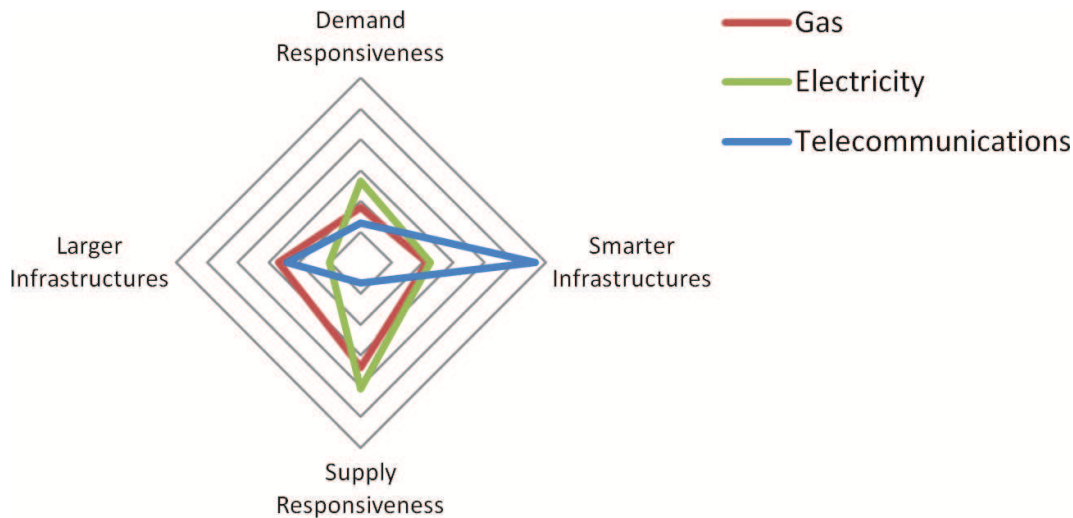


Figure 7.1: Feasibility of treatment strategies

the maximum bandwidth of users with overbooking is automatically decreased with a maximum factor equal to the overbooking ratio. The maximum demand for network access by these users is thus made responsive to network conditions. Overbooking is strongly applied by ISPs in local distribution networks, however in the transmission networks overbooking is not applied because of high quality requirements. As a result a TSO cannot directly apply overbooking on its own transmission network, but it can acquire ISPs that do so because there are no requirements for vertical unbundling in the telecommunications infrastructure. Given the increasing quality demands and usage of internet access, it is questionable if the current levels of overbooking can be sustained in the future and thus if the current level of demand responsiveness can be maintained.

7.2 Discussion

In this section we delve deeper into the interaction between context, assessment and treatment of reliability in network infrastructures. In the first two subsections we reflect on the assumed trade-off between reliability and network capacity (first introduced and discussed in §1.1) and the issues that cloud this trade-off. The third subsection contains a critical reflection on the dominant instrument of price regulation and the possible (unintended) effects of this instrument.

7.2.1 The complexity of reliability

Throughout the cases we have seen that the perception of (the same level of) reliability can be very different in different infrastructures and between different users. A dependability of 99.99% (or an equivalent average interruption of 53 minutes per year) is at the same time extremely reliable from the perspective of an internet user and totally unacceptable from the perspective of a TSO in gas or electricity infrastructure. Thus the perception of reliability cannot be determined based on numbers alone, but is rather determined by the historical developments and context of the infrastructure. Reliability can be seen as a social construct, that is seen through the 'eye of the beholder'; every stakeholder can have a different perception of reliability (Chester, 2010), that can also change over time. We will discuss this consideration and the impact it has on TSOs in the different infrastructures.

Gas and electricity infrastructures have been treated as vital infrastructures over the last few decades. Accordingly, the networks have been designed and managed in such a way that interruptions were held to a minimum. In the hierarchical controlled and vertically integrated public utilities, this was achieved by very sophisticated planning methods and risk averse design; the networks were able to meet all but the most extreme supply and demand

Table 7.5: Treatment options gas infrastructure

Option	Categories	Emphasis	Potential
Increasing transport capacity	L	H	H
Increasing storage capacity	L,S,Sm	M	H
Smart metering	D,Sm	L	L
Balancing system	S,D	M	M
Interruptible contracting	S,D	L	L
Local feeding: LNG and green gas	S,Sm	M	M
Smarter grid controls	Sm	L	L
Increasing market liquidity	S,D	M	M

Table 7.6: Treatment options electricity infrastructure

Option	Categories	Emphasis	Potential
Increasing transport capacity	L	M	M
Increasing storage capacity	L,S,Sm	L	L
Smart metering	D,Sm	L	M
Balancing system	S,D	H	H
Interruptible contracting	D	M	L
Congestion management	S,Sm	M	M
Smarter grid controls	Sm	M	M
Stimulating complementary generation	S	M	H

Table 7.7: Treatment options telecommunications infrastructure

Option	Categories	Emphasis	Potential
Increasing transport capacity	L	H	M
Network coupling	Sm	H	H
Overbooking of capacity	D,Sm	M	M
Network technology	Sm	H	H
Network design (All-IP)	L, Sm	H	H
Prioritizing traffic	S,D,Sm	M	M

situations. Even after liberalization, which reduced the hierarchical control and introduced uncertainties about network flows and utilization, the planning and design paradigms have remained relatively unchanged (Scheepers, 2008, p. 15).²

In the telecommunications infrastructure, we see a wholly different development. From the PSTN, an infrastructure that was managed as a public utility, much in the same way as gas and electricity are still managed, this infrastructure has seen tremendous change over the last decades. With the development of data communication, a whole new service next to the existing voice communication was introduced. This service was initially considered a luxury, and because of the switched nature of the telecommunications infrastructure it could be differentiated on quality aspects. As a result we have seen connections of different quality being offered next to and in competition with each other. From cheap, low-quality connections that are very prone to supply interruptions to dedicated lines that are able to equal or even surpass the reliability of gas and electricity networks.

Another important characteristic of data communications is the fact that reliability and quality in data communications are on a gliding scale; a packet loss (supply interruption) has much the same effect as transport delay (a quality aspect) because of the ability to immediately resend a packet that gets lost. Thus in the perception of the user there is no real difference. Because of these characteristics and the capacity constraints of some parts of the network,³ the concept of capacity overbooking has become common practice, both to increase network utilization and offer higher peak bandwidth to users.

Another important development in the telecommunications sector was the large scale penetration of information technology, with its wholly different design paradigm. Where the original telecommunications sector had the same philosophy as the gas and electricity network to thoroughly test changes before implementing them in the network, the information technology sector, with its high drive for innovation, is used to replace components of a network in real-time. As a result failures and downtime are integral to upgrading the system and so are supply interruptions in the total network.

These developments have had a profound impact on the current reliability in the infrastructures and the value different stakeholders attach to this reliability. In gas infrastructure, interruptions are very rare and relatively small, resulting in little risk awareness of users and almost no valuation of reliability. In electricity infrastructure, the level of reliability is also very high. Given the uncontrollability of the electricity infrastructure however, every user is confronted with small interruptions from time to time and large scale interruptions happen at least a couple times per year and can have a large impact on society. As a result, users have a little more risk awareness and multiple efforts have been made to value reliability. However, due to the public good characteristic of electricity supply and the lack of a market for reliability, these valuations often remain very coarse and speculative.

In telecommunications infrastructure, we have seen internet access develop in under 20 years, from a little used oddity to a daily necessity for many people. In this time the quality and reliability of internet access also grew tremendously, notwithstanding the failure of some service providers to deliver quality services. So, users have been confronted with unreliable and slow connections and have been offered newer, faster and more reliable connections on a consistent basis. As a result, an effective market for reliability has emerged and reliability can thus be valued reasonably well.

One viewpoint that is often found in literature, and that formed one of the starting points for the larger research project this study was part of (as discussed in Chapter 1), is that there exists some "optimal" level of reliability, such that the value of extra reliability just matches the costs of providing this extra reliability. It is further assumed that this

² However, we see some developments here. In electricity infrastructure, it is being acknowledged that investing in additional network capacity to deal with uncertain flows might be inefficient and unsuitable to reduce certain interruption risks. Special interest is given to more comprehensive ways to deal with uncertainty, for instance active network control (Ilic et al., 2005). In gas infrastructure, the change in philosophy is slower, partly because the risk of critical conditions is much smaller, due to the technical (buffering) characteristics of the gas network, and partly because of the safety risks associated with an interruption (e.g. leakage/explosion). However, the planning of new capacity has changed from hierarchical controlled optimization to scenario studies.

³ Most notably the distribution network, or local loop, where the existing copper lines can only be replaced at high cost.

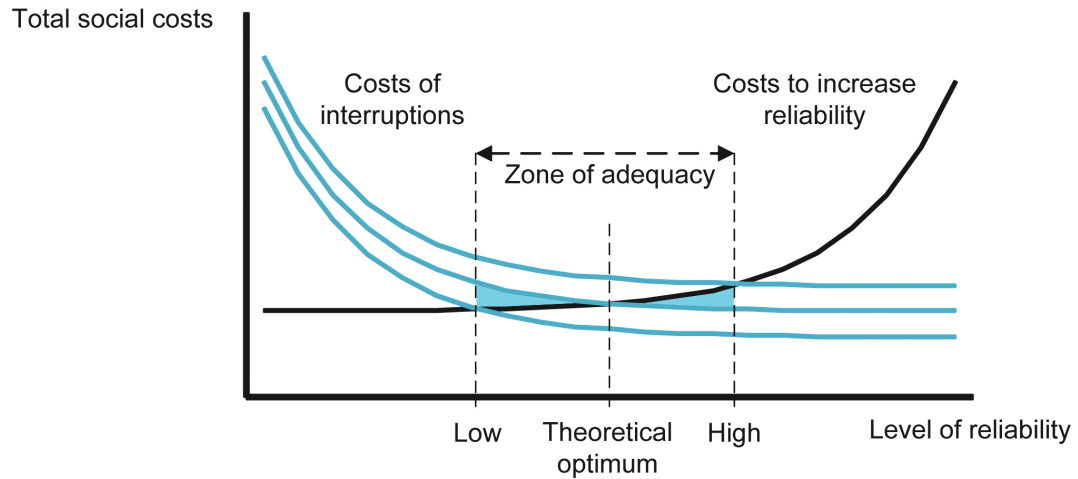


Figure 7.2: Zone of adequacy as a result of the complexity of reliability
 Source: based on National Economic Research Associates (2002), Figure 3.2, p. 12

optimal level can be estimated within a relatively small bandwidth, when the willingness to pay for extra reliability and the costs of providing reliability are determined. In reality, obtaining information to determine these values is very difficult and subjective, especially in gas and electricity infrastructures where there is no market for reliability, reliability has strong public good characteristics and consumers can have different willingness to pay but no way to express this (National Economic Research Associates, 2002, p. 12). And even with the effective market for reliability in internet access, willingness to pay for reliability is hard to determine because individual consumers often buy contracts that seem not appropriate for them (Pollitt, 2009; Levinson and Odlyzko, 2008).

Also, in an infrastructure reliability is not the only value stakeholders are interested in. Other values, such as affordability (including low transaction costs), accessibility and sustainability, also play a role in the deliberations of stakeholders. So instead of optimizing all those individual values, the goal in infrastructures is often the satisficing⁴ of those values. Determining the adequacy of public values is thus likely to be a political process rather than an analytical process.

Combining the facts that exact information to optimize reliability is hard or impossible to come by and that optimizing reliability might not be a sensible goal, we should perhaps rather look at realizing an adequate level of reliability. National Economic Research Associates (2002, p. i) argues that there exists a "zone of adequacy" where both the valuation of security and the extra costs of providing it will be relatively stable (see Figure 7.2).

The goal of policies (both from the TSO, the regulator and other stakeholders) should be to remain within that zone of adequacy. Choosing for this satisficing goal is even more sensible if we take into account that (the perception and valuation of) reliability is prone to change over time.

Firstly, when infrastructures are faced with large interruptions, the fungibility and the importance of reliability increases almost immediately as can be witnessed by the political and societal responses. For instance, the large electricity interruption at Haaksbergen prompted demands for network investments and regulatory standards, where the reliability was regarded as being adequate before (DTe, 2006). Similarly, after another large interruption in mobile telephony in November 2009, demands for government supervision and emergency planning in case of large internet and telephony interruptions arose (Volkskrant, 2009).

Secondly, current reliability levels may be inappropriate in the future. For example, considering the continued increase in quality and usage of internet access in critical processes, the "adequate" reliability could well approach that in gas and electricity infrastructures.

⁴ Satisficing is a decision-making strategy that attempts to meet criteria for adequacy, rather than to identify an optimal solution.

Conversely, the reduction of flexible production in gas infrastructure or the strain of intermittent power generation in electricity infrastructure, might make current levels of reliability only attainable at very high costs in the future. This will require a new deliberation on "adequate" reliability.

7.2.2 Relating reliability and network capacity

Determining the adequate level of reliability is not the only complex issue in the trade-off. The complexity of network infrastructures also makes it very difficult to clearly relate reliability to network capacity. As we have seen in the case studies, most interruptions are not caused by a lack of network capacity, but by failures during maintenance or digging operations or failure of individual components. Therefore, the empirical evidence of the relation between network capacity and reliability is limited. Also the relation between reliability and network capacity is often non-linear, especially in the electricity infrastructure with its risk of cascading failures (TenneT, 2008a; Dobson et al., 2007).

The complexity and redundancy in network infrastructures also make it hard to directly relate network capacity to infrastructure costs. Due to redundancy, the contribution of a single pipe or line to the functioning of the network is hard to determine, because the removal would have almost no effect in normal operation, while it might cause the difference between continued operation and total collapse in critical situations (Perez-Arriaga and Smeers, 2003). The fact that physical and contractual flows often do not follow the same path in gas infrastructure and especially in electricity infrastructure (due to loop flows), also limits the possibilities to determine the exact infrastructure costs of a certain transaction.

It is often contended that an efficient network is a network that has a high utilization rate. In fact, price regulation in electricity and gas infrastructure is often justified by the remark that the utilization rate of the networks is low, which would suggest "gold-plated" networks. While increasing the utilization rate in networks, especially by alleviating contractual congestion, indeed improves the efficient use of the infrastructure, simply equating utilization rate with efficiency is an ill-informed proposition given the complexity of those infrastructures. First of all, the infrastructures have to accommodate fluctuations in supply and demand, and especially if the required reliability is high this already significantly restricts the utilization rate.

Secondly, low utilization rates cannot always be viewed as a waste of network capacity, because the users of those networks often value other aspects besides the costs of transport capacity. For instance, in the gas infrastructure having ample transport capacity on multiple routes, allows parties to manage their supply portfolios. In the US, which is considered to have a more liberalized gas market than the Netherlands, the utilization rate of networks has decreased and a higher utilization rate can be regarded as "a misleading yardstick for the success of market liberalization" (Correljé et al., 2009, p. 43).

In telecommunications, having ample transport capacity on multiple routes, ensures adequate bandwidth and quality and is "not a sign of waste, but of the value of high quality data communications and of the complexity of running networks" (Odlyzko, 2000, p. 10). In fact, broadband QoS regulation in Singapore does not require service providers to increase the utilization rate, but rather to expand their capacity if the peak utilization exceeds 90% for 3 consecutive months (Wattegama, 2008), clearly illustrating the value of reliable broadband internet access.

Given these difficulties in establishing a relation between network costs and reliability, the cost curve of investment costs to increase reliability can only be estimated to a certain extent. Analogous to the multi-dimensionality and ambiguity of reliability itself, this leads to a zone of adequacy in which optimizing investment costs is very difficult and the results are limited and dubious (See Figure 7.3). Furthermore, given the complexity of infrastructures, it is also very difficult to compare utilization rates among infrastructures, as the utilization rate is influenced by a large number of infrastructure specific factors.

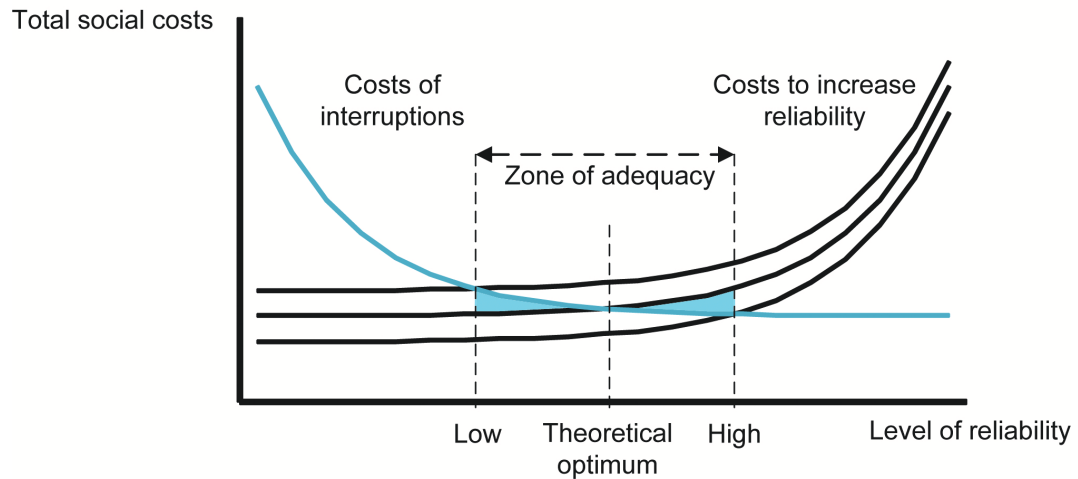


Figure 7.3: Zone of adequacy as a result of uncertain investment costs

7.2.3 Price regulation of transmission networks

The goals of liberalization have been to increase customer choice, affordability and efficiency in infrastructures. Because of the monopolistic characteristics of gas and electricity transmission networks, liberalization had to be accompanied by regulation. There is less regulation in telecommunications transmission networks, because the competition is deemed appropriate. Because the TSOs were regarded as inefficient, the initial focus of regulation has been on price reductions. By incorporating price regulation, the regulators were able to 'trim the fat' of the former public monopolists (Wetenschappelijke Raad voor het Regeringsbeleid, 2008). In this respect price regulation can be regarded as a success, as the transmission tariffs in gas and electricity networks have decreased significantly as a result of regulation (Energiekamer, 2009a).

While the current regulatory regime is deemed effective in solving 'type I' market failures (i.e. improper market functioning), its influence on 'type II' market failures (i.e. failure to realise long-term public values) is a cause for concern (van Dijk, 2008; Wetenschappelijke Raad voor het Regeringsbeleid, 2008). Because price regulation focuses purely on efficiency, it creates incentives to reduce investments in infrastructure which in turn can reduce the reliability of the infrastructure. In theory, this negative effect of price regulation on reliability is compensated by additional quality regulation. As has been shown in the case studies however, the current impact of quality regulation on the behaviour of TSOs is limited. This ineffectiveness might be partly explained by the relative inexperience with quality regulation, but the softness of reliability as a public value might also well exclude the possibility to develop quality regulation on an even footage with price regulation. Unless reliability unexpectedly decreases, its visibility and immediacy is bound to remain limited. While the Energiekamer, as the regulator of electricity and gas infrastructures, also acknowledges the concern on 'type II' market failures, it argues that regulation has increased efficiency without having a negative effect on reliability (Energiekamer, 2009a).

Next to this broadly recognized concern around price regulation, we have identified two more concerns on price regulation that, while less visible, may have harmful effects on the further development of infrastructures. The first concern is caused by the limited share of transmission costs in the total costs, which typically is less than 1% in all three infrastructures. Thus any improvement in the efficiency of TSOs has only a minor impact on the overall costs. This is further strengthened by the fact that transmission networks have high fixed costs and the TSOs have little control over those costs; often the only way to reduce them is to hold off maintenance and replacement investments.⁵ Furthermore, price regulation and the uncertainty it creates frustrate the investment climate for expansion investment in transmission networks, which in turn hinders the development of the product markets.

⁵ However, some stakeholders argue that more sophisticated asset management by TSOs should still result in significant and permanent cost reductions (Interview with EK1, held December 14, 2009).

Given that the development of these product markets has a much larger potential influence on consumer choice and affordability than the development of the transmission costs, the current focus of regulation is questionable (Correljé et al., 2009).

The second concern is the narrowing effect stringent price regulation seems to have on the scope of TSOs for (new) solutions and developments. In the unbundled gas and electricity infrastructures, the income from transport tariffs has become the dominant source of income for TSOs. By aggressively decreasing these tariffs through price regulation, the regulator directly threatens the profitability and vitality of TSOs, a practice which is bound to elicit a strong defensive reaction. While reducing costs further and further is attractive, it is important to ensure that regulated TSOs remain profitable and receive a reasonable return on investments given their vital role in the infrastructure.

During the case studies, we identified this risk of narrowing scope for both the gas and electricity TSOs.⁶ It was especially strong in the case of the gas TSO, which is subject to a more stringent form of price regulation than the electricity TSO (respectively tariff regulation and revenue regulation). In the gas infrastructure, we see a discussion that is focused sharply on the capacity of transport networks. On the one hand, the TSO has strong incentives to increase capacity as this is their primary source of income, while on the other hand the regulator focuses heavily on the “low” utilization rate and the presumably inefficient use of current capacity. As a result, the debate is a back and forth of attacks and defenses on the rather one-dimensional issue of capacity, while a problem like the reduction of production flexibility, which is both more pressing and extensive is often left to the “market”. This disparity becomes clear both in documents describing the strategy of the TSO (e.g. in GTS, 2007a, 2009c) and the conducted interviews. The argument is that the TSO and the regulator currently have limited control mechanisms to stimulate investment in production flexibility. However, this should not be seen as a restriction, but rather as a challenge to address this problem. While the revenue regulation in electricity has a less narrowing effect on the scope, we also see a large amount of the debate being centered around the acceptability of investments.

7.3 Dealing with reliability in vital infrastructures

In this section we discuss the consequences of the analysis for dealing with reliability in vital infrastructures and the gas infrastructure in particular. First of all, we focus on a development that has taken place in all three infrastructures, the fragmentation of the institutional environment after liberalization. This development has had an immense impact on managing infrastructures. From top-down controlled infrastructures, where the TSO knew and designed everything, the infrastructures have evolved to market places, where every participant acts according to his or her own plan. As a result, the flows in the network are not predictable anymore and the TSOs are confronted with great uncertainty.

The easiest way for a TSO to deal with this uncertainty is to create more transport capacity to meet the most extreme cases. Especially when the TSO is risk averse and wants to guarantee high reliability and network users are willing to buy the extra capacity (because transport costs are relatively low), this is defensible strategy. From an efficiency perspective this is of course very unattractive as the average utilization of the network will be much lower; liberalization achieves just the opposite of what it was intended to (at least for network utilization, the dependent product markets might become more efficient). Instead of building additional transport capacity to deal with this uncertainty, TSOs can also employ more proactive methods to efficiently and effectively utilize existing and future transport capacity, which would be much more effective. Already we see some of these pro-active methods being employed in the different infrastructures.

In telecommunications infrastructure, parties that book firm capacities with network operators, use overbooking to efficiently allocate capacity between their users and reduce the need for transport capacity. This works especially well in the distribution networks, as transport capacity is limited and hard to increase. Also, parties that own capacity on one

⁶ In telecommunications we identified a similar problem in the regulated distribution network (the ‘local’ loop)

network, optimize the use of this capacity by peering with parties that own capacity on other networks, creating a large and effective secondary market for capacity.

In electricity infrastructure, the congestion management scheme employed by the TSO TenneT is an innovative way to allocate transport capacity in case of imminent congestion on the network. This scheme is both effective and necessary, given the bottlenecks in some parts of the transmission network. The gas infrastructure on the contrary has neither a dynamic capacity allocation mechanism nor an effective secondary market for capacity. The current lack of sophisticated methods to deal with uncertain network flows, can lead to an overestimation of the needed transport capacity. This can in turn cause a large financial risk for the TSO (and thus indirectly for society), especially with the large investments following from the gas-roundabout strategy and the open season procedures. The development of a more sophisticated capacity allocation mechanism in gas infrastructure can help reduce those risks.

For instance, the congestion management scheme used in the electricity transmission infrastructure can be a promising mechanism as it seems adaptable to the gas infrastructure and it alleviates contractual and physical congestion without an immediate increase of physical capacity. However, there are also a number of characteristics specific to the gas infrastructure, which might limit the functionality of such a mechanism. First of all, the scarcity in transport capacity in gas infrastructure is most likely less frequent but for longer periods than in electricity infrastructure, because the gas demand is strongly temperature dependent. Therefore the mechanism will be inactive for long periods of time, while in winter shippers face the risk of long interruptions. This reduces the potential gains of the system and makes it less attractive. Furthermore, while GTS offers interruptible capacity and allows the secondary trade of capacity, users have expressed a strong preference for firm capacity. Thus the market potential of capacity allocation based on interruptible capacity is uncertain.

Second, TSOs need a way to determine and achieve an adequate level of reliability. As discussed before, trying to determine the optimal trade-off between reliability and network capacity, while a cognitive appealing concept, is not likely to produce sensible results. Neither the value of reliability nor the costs of total capacity can be determined unambiguously and/or uncontested in a system as complex as a network infrastructure. If we combine these findings in the consideration of total social costs, it indicates the existence of a very broad and diffuse zone of adequacy even if we only look at the trade-off between reliability and investment in network capacity (see Figure 7.4).

In reality, network investments are just one of several solutions to ensure and improve reliability in vital infrastructures. In this report, we identified three other treatment strategies to ensure reliability: i.e. investing in smarter infrastructures, supply responsiveness and demand responsiveness. Incorporating multiple treatment strategies increases the robustness and efficiency with which reliability can be safeguarded. To make a good decision on the adequate level of network capacity, these other treatment strategies should thus also be part of the equation.

Thus it might be wise to abandon the mirage of an economic optimal trade-off between reliability and network capacity and accept the inherent political nature of reliability. Instead of an optimal level of reliability, networks should be designed to provide an adequate level of reliability. The telecommunications infrastructure, with its functioning market for reliability, shows that most consumers are willing to overpay for guaranteed reliability, instead of choosing a contract that exactly suits their needs. We expect that this will be no different in gas and electricity infrastructure if consumers get the chance, especially given the essential character of these products. With the enormous importance of vital infrastructures for the functioning of society, it might be more sensible to embrace the current risk averseness, than to strive for an abstract economic calculation based on risk neutrality and the unknown risks it poses.

Especially when considering long-term reliability, there are a lot of uncertainties for TSOs. It is hard to predict the conditions and preferences of the future. Considering the political and complex nature of reliability, it is necessary to develop instruments to achieve long-term reliability in cooperation with other stakeholders. By developing effective technologies and institutions, in cooperation with market parties, governments and academia, the goal of reliability could be achieved both in a more robust way and at a lower cost.

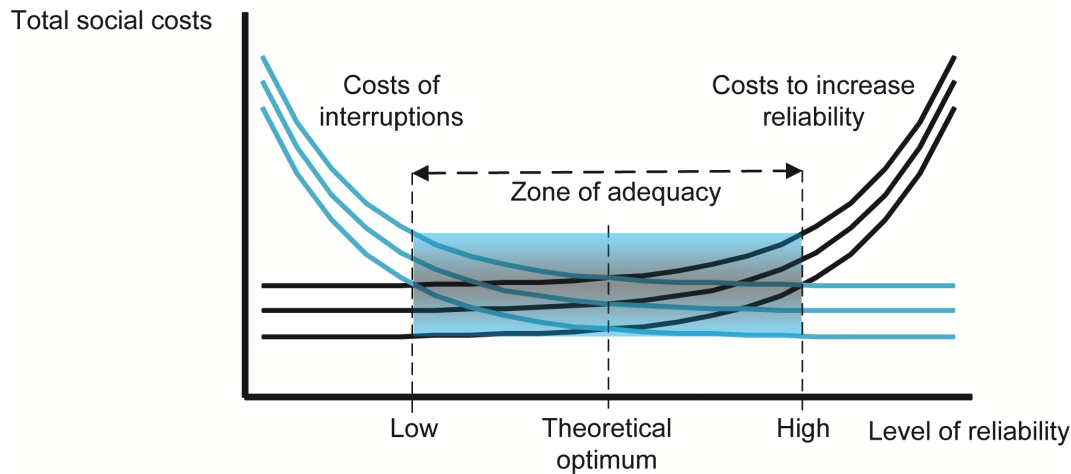


Figure 7.4: Zone of adequacy for transmission networks

Finally, we would like to address the impact of regulation on dealing with reliability, especially considering the effects of price regulation we described above. Steenhuisen (2009) discusses the problem of fragmented regulatory oversight, where different authorities put pressure on specific public values, instead of addressing the conflicts between different public values. This decoupling of public values can lead to uncoordinated and conflicting interventions, resulting in a vicious circle of ever increasing efficiency requirements, over regulating as a result of incidents and evasive maneuvers by regulated organizations. To allow for more effective solutions to improve reliability, regulation should be more holistic, better safeguarding reliability and other public values. In this light, the recommendation of the Energy Council (Energieraad, 2009) that the State rather than the regulator should look after the public interest in the national transmission networks is interesting. By allowing a broader consideration, the deadlock between conflicting public interests can be broken.

Chapter 8

Conclusion and reflection

In this chapter we will discuss the research question and the implications of our results. Furthermore, we will reflect on the research project and possible future research.

8.1 Conclusions

The goal of this research was to identify how the context in a vital network infrastructure influences the assessment of reliability and the feasibility of treatment options available to transmission system operators in that infrastructure. The research consisted of a comparative case study of three vital Dutch infrastructures: the natural gas infrastructure, the electricity infrastructure and the telecommunications infrastructure. We developed an analytical framework, as an extension to the ISO31000 Risk management framework, to structure and analyze the case study. The framework identifies the most important parts of the risk management process (i.e. context, assessment and treatment), the concepts that constitute these parts and the relations between them.

An important remark to make here is that reliability is neither a simple nor an unambiguous concept for multiple reasons. First of all, there are different notions of reliability. Reliability can relate purely to the availability of the product or service but also to additional quality parameters, like throughput and delay. Second, reliability risks can occur on different time-scales and in different parts of the supply chain. Third, in vital infrastructures the public interest in reliability has a large influence on the perception of reliability. If and when reliability has strong public good characteristics and/or is considered an important public value, this has profound impact on assessing and dealing with reliability. Finally, the discussion on reliability is often embedded in a specific infrastructure. The central concepts (e.g. security of supply in energy infrastructures and quality of service in telecommunications infrastructures) consider infrastructure specific issues and are not readily translated to other infrastructures.

To deal with the complexity of reliability, we have developed a new conceptual model that not only takes these issues into account but also is generic enough to be applied to all analyzed infrastructures. This conceptual model distinguishes different levels and dimensions of reliability, which enables us to frame the analysis on the specific responsibilities and capabilities of the TSO in any given infrastructure. Next to this conceptual model, we also developed a general infrastructure paradigm, which was extended for all analyzed infrastructures. This paradigm allows us to quickly identify the most important components and stakeholders in an infrastructure, which helps develop a structured analysis of the infrastructure context.

The analysis resulted in a set of technical, economic and institutional context factors that was both relevant, parsimonious and complete. This set captured both the most important similarities and differences between the infrastructures. It was found that the context and the public interest of reliability have a strong influence on the assessment of reliability. For instance, the high controllability of gas and telecommunications infrastructures has a positive influence on the reliability compared to the electricity infrastructure. Furthermore, the strong public good characteristics and the public value attached to reliability in gas and electricity infrastructures have resulted in a very high (required) reliability. In the

telecommunications infrastructure however, with its continuing technological development and possibility to differentiate between reliability levels, the assessment of reliability is much more market-based and considerably lower for many services.

During the research we identified multiple treatment options available to and employed by TSOs in the different infrastructures. However, the options often were very infrastructure specific and thus incomparable between infrastructures. Therefore, we identified four high-level treatment strategies by which the treatment options can be categorized: larger infrastructures, smarter infrastructures, supply responsiveness and demand responsiveness. It can be concluded that there are significant differences in the treatment strategies employed in the different infrastructures and that these differences have strong relations with the technical, economic and institutional context and the assessment of reliability in the infrastructures. For instance, in the gas infrastructure investing in larger infrastructures and ensuring supply responsiveness are dominant strategies. Because of the high (expected) level of reliability and the large seasonal fluctuation in demand, the transport networks and supply sources are expected to accommodate these fluctuations at all time. On the other hand, demand responsiveness is not a central strategy for TSOs for two reasons. First, they are faced with aggregated traffic flows and thus experience less of the fluctuations of individual demand patterns. Furthermore, they have no direct contracts with consumers in which to include incentives for demand responsiveness.

However, because of the complexity of network infrastructures not all relations between context, assessment and treatment are so clear-cut. Some relations are complex, ambiguous and possibly contradicting each other. For example, we have shown that reliability is a multi-faceted and complex concept and that it is very difficult to directly relate reliability to network capacity. At the same time, the trade-off between reliability and efficiency is sometimes mistakenly simplified and over rationalized in the discussion between regulators and regulated TSOs. Considering that the costs of reliability risks and the investment costs to reduce these risks can be estimated, it is contended that this trade-off can be analytically optimized. However, given the multidimensionality and subjectivity of reliability and the complexity of transmission networks, this optimization is most likely false and extremely difficult. Especially considering the increased uncertainty in institutionally fragmented infrastructures, it seems wise to abandon the theoretical notion of an optimal trade-off and instead focus attention on developing technologies and institutional arrangements that can adequately satisfy multiple values.

Furthermore, we argue that fragmented regulatory oversight and the decoupling of public values lead to conflicting interventions and suboptimal decisions by the TSO. Especially when the regulation of a specific value is very stringent compared to other values (e.g. efficiency by price regulation) and the regulated TSO has only specific responsibilities and capabilities, the risk exists that the scope of the TSO is narrowed only to those responsibilities and capabilities, instead of developing and encouraging new solutions. Thus, regulation should be more holistic and should explicitly address conflicts between different public values instead of decoupling them.

8.2 Implications

The results of this research have several implications for multiple stakeholders and further research on reliability in vital infrastructures. The contribution of this research to the larger research project within GTS is twofold. By identifying and comparing multiple treatment strategies in different infrastructures, it provides insights for dealing with reliability in a broader scope. It indicates the (im)possibilities of the different treatment strategies, but also suggests the overemphasis on one particular treatment strategy, namely investing in larger infrastructures. Given that this overemphasis creates a risk of overinvestment, specific attention should be paid to this issue and additional research should be performed on potentially more effective treatment options.

Furthermore, the study provides an elaborate discussion and challenge of the initial problem analysis of the larger research project. The issue of reliability in vital infrastructures

has shown to be way too complex to be rationalized into a quantitative economic trade-off, especially in current institutionally fragmented infrastructures. By accepting that the trade-off between values is a satisficing rather than an optimizing game, GTS can develop more politically feasible solutions and more effective research. That is not to say the quantitative analyses of the larger research project are not valid in their own right. Rather, their results can be very valuable for future research as long as they are not overgeneralized or overemphasized.

This research also provides considerations for regulatory and/or governmental institutions on dealing with reliability, especially in competition with other public values. The research has clearly shown the complexity of reliability and the risks of treating reliability as a one-dimensional issue. How to safeguard multiple and possibly conflicting public values should be a political and coordinated decision and regulation should both be effective and balanced.

We believe that this study makes three contributions to research on reliability in network infrastructures. First of all, it captures the multidimensionality of reliability and the fundamental impact this has on dealing with reliability in different infrastructures. The conceptual model of reliability developed in this study provides both a generally applicable and detailed framework for future analysis. Secondly, this study made a novel and explicit link between context, assessment and treatment of reliability in vital infrastructures by extending the ISO91000 risk management framework. This framework can easily be extended to include more and different vital infrastructures.

A final contribution is in the case studies provided. To our knowledge, this study is one of few integral case studies on reliability in multiple infrastructures. Considering the novel conceptualization of reliability that is employed, both the individual and combined case studies can provide valuable analytical material.

8.3 Reflection

"Satisfaction is the death of desire" - James Shanahan

8.3.1 On methodology and research process

In the chapter on methodology we argued that case study research was the most suitable research strategy based on the characteristics of the research questions and the research subjects (i.e. vital infrastructures). During the research, the validity of this assessment became clear as the strategy allowed adjusting of the problem analysis and the inclusion of a large number of data sources and literature from a broad range of research fields. During the case study it became clear that the initial problem analysis was too narrow and rigid to grasp the full complexity and multidimensionality of reliability, especially when considering multiple infrastructures. Thus it was a conscious decision to broaden the scope of the problem analysis. This required additional iterations in the research process and the analysis of more material, but did not require fundamental changes in the case study approach.

Using both a new and unproven analytical framework and conceptualization of reliability in a first-time research of this magnitude and complexity, makes it difficult to impartially assess the validity of individual aspects of the research. While we believe that this approach produced some good results, an independent assessment of the validity and effectiveness of the individual aspects is needed before they can be used in further research. Another concern is the selection of data sources and literature. We purposefully used a very open and intuitive approach to acquiring information, which has led to unexpected and useful information and considerations. However, this approach makes it difficult to assess the validity and completeness of all information on face value, especially in research subjects where the researcher has limited affinity and experience. While this has been dealt with by triangulating multiple information sources, a certain level of arbitrary selection and bias is unavoidable.

Given the iterative nature of the research and the analytical framework, it was very helpful to perform the case study on the gas infrastructure while being embedded in the organization of GTS. The possibilities to have continuous formal and informal discussions on the research subject, as well as the daily routine in the organization, helped nuance and

strengthen the analysis. Ideally and without the restrictions of the master's thesis project, this would be done for every case study in the research to balance the analysis.

8.3.2 On interviews

The interviews provided important input both as information sources and for refining and testing the analysis. The interviewees were very open to discuss not only their own experience, but also parallels with other infrastructures and reflecting on the problem analysis of the researcher. By discussing nuances and considerations that do not show up in final decision making, the interviews proved indispensable as an addition to and critique of official documentation. While the interviewees sometimes allude to imperfections in current planning and decision making and identify possible solutions, they tend to support the status quo and are critical of unproven changes. The current reliability performance is typically seen as more than satisfactory and threats are attributed to other organizations.

Given the time restrictions of this research, every interviewee was interviewed only once. Considering the explorative and iterative character of the research and the impact this had research process, in a longer research project it would be preferable to have multiple interviews. In this way, assumptions can be checked and fed back to the interviewees in a more consistent manner. Another point of attention is the decision to use voice recording or literal transcripts during the interviews. Not using those during this research project helped conduct very open and informal interviews. However, this resulted in a differing structure between the interview summaries. This wasn't a problem during this research, as there was no intention to directly compare the interviews. However in a longer research project with multiple interviews as proposed above, it seems essential to compare interviews and thus have more structured transcripts.

8.3.3 On results

As discussed in §3.1, the complexity of vital infrastructures and their embeddedness in technical, economic and institutional context allows only the identification of a limited set of relations. Given the developments during the research process, the analysis is a black box process to a certain extent. Not all deliberations and decisions have been documented and thus the transparency of the process and the reproducibility of the results are low. We acknowledge that the relations and results presented are a partial, temporary and personal selection, which can be contested. Nevertheless, we believe that by applying triangulation of information sources and inviting discussion on the results, we have assured relatively unbiased results.

This study focused on TSOs. While this delineates the research in some ways, due to the complexity and interrelations within the infrastructure, it was often necessary to also analyze other segments and stakeholders involved in the infrastructure. Given the differences between the infrastructures, this results in a less strict and more ambiguous delineation which hinders a "pure" comparison between TSOs. During the integration of cases we tried to limit the deviations in delineation as much as possible and ensure that the comparisons were balanced.

It was originally intended that the study compared individual treatment options and indicated how feasible they were in a given infrastructure. As discussed before, the treatment options were too infrastructure specific and only more generic high-level treatment strategies could be compared between infrastructures. Additional research, preferably in a single infrastructure, is needed to determine the feasibility of individual treatment options. In this case, the general considerations of this research can be used as a starting point.

One last remark concerns the dynamics of infrastructures and the impact it has had on this research. Even while this research was performed in a relatively short period of time, we can see changes in the infrastructures that have a profound influence on this research and would result in significantly different results even a year from now. Currently, in gas infrastructure a new balancing regime is developed and introduced while in the electricity infrastructure the TSO is dealing with the intricacies of the congestion management scheme. During the research, we established that there was no supplier of last resort mechanism in telecommunications infrastructure and wondered when this would be deemed necessary enough, given the increasing importance of reliable connections. Weeks later, there were

large interruptions in the mobile networks, and there was a sudden demand for emergency arrangements and more government intervention to avoid interruptions in telephony and internet connections (Volkskrant, 2009).

8.3.4 On generalisation

How representative are the results obtained in this case study to other vital infrastructures? And how applicable is the analytical framework in analyzing other vital infrastructures? The analytical framework explicitly deals with the differences in technical, economic and institutional characteristics of the studied infrastructures. The analysis shows how these differences lead to other possibilities and decisions in the different infrastructures. On the other hand the analysis also indicates some general trends and considerations that apply in all three analyzed infrastructures.

It is clear that the tension between reliability and efficiency is not limited to these three infrastructures and neither is the discussion on the adequacy of capacity. The reliability and risk of large scale failures in road and rail infrastructures is a continuous source of debate, and since the credit crisis even finance and banking are submitted to much of the same scrutiny. The building blocks of the analytical framework (the technical, economic and institutional context; the levels of reliability and the four treatment strategies) are generic and largely infrastructure independent. If handled diligently, the analytical framework should thus be applicable to other physical network infrastructures or even other vital infrastructures, as long as they contain a clear supply chain.

8.3.5 Further research

During the research process we have identified a number of knowledge gaps that can be interesting for future research. First of all, the conceptual model for reliability and/or the analytical framework developed for comparing infrastructures should be validated in future research. This can be done by comparing the models with others or by applying and assessing them in new case studies. Secondly, the research can be extended to analyze other infrastructures. For instance, one could compare the same technical infrastructures between different countries. Or one could analyze other technical infrastructures. In the latter case, other vital and physical network infrastructures (e.g. drinking water supply, railways and other telecommunications infrastructures, such as RTV cable infrastructure or mobile telephony) likely provide the most suitable subjects when starting from this research.

Thirdly, the analytical framework can also be extended to analyze individual treatment options. This can be important for TSOs that wish to evaluate their current strategies or implement new ones. Fourthly, the research illustrated the complexity of reliability and the difficulties in satisficing multiple conflicting public values. This requires continuous attention and research from TSOs, regulators, governmental organizations and academia. Not only to develop more understanding but also to develop more sophisticated mechanisms and institutions to ensure an adequate safeguarding of these values.

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Appendix A

Scientific Paper

This appendix contains the scientific paper that was written as part of the master's thesis project. It is based on the same research performed for the master's thesis, however it should be viewed as an independent work. Based on the research subject and content of the paper, the author's guidelines of the Energy Policy journal have been followed for the structure and lay-out of the paper. This paper is not intended for external publication and in a relative preliminary state. Before publication, the paper should go through an additional review and refinement process.

Reliability and efficiency in transmission networks: a wicked trade-off

G. van de Schouw¹

Delft University of Technology

Abstract

The trade-off between efficiency and reliability is a central theme in regulated vital infrastructures. While vital infrastructures can be regarded as very complex systems, this trade-off is sometimes mistakenly simplified and over rationalized in the discussion between regulators and regulated transmission system operators. Based on a case study in three vital infrastructures in the Netherlands, we show in this article that this rationalization is not only incorrect but also counter-productive. First, we demonstrate that the multidimensionality and subjectivity of reliability prohibit the determination of an "optimal" level of reliability. After that, we argue that the complexity of transmission networks hinders determining the efficiency based on network utilization. Given the complexity of the trade-off, we argue that the "adequate" level of reliability can only be determined in a political, rather than an analytical, process. Finally, we discuss the implications of these findings for TSOs and regulators.

Key words: vital infrastructures, reliability, transmission networks

1. Introduction

The functioning of vital infrastructures is crucial to society. The provision of products and services such as energy, telecommunication and transport should not only be affordable, but also reliable, sustainable and accessible. However, these values are often contradicting and should be safeguarded in an environment that is constantly changing and becoming increasingly more complex. Thus constant trade-offs between different values and different stakeholders have to be made to ensure the adequate functioning of infrastructures. One trade-off that is especially interesting, is the trade-off between efficiency and reliability in price-regulated electricity and gas transmission networks. Recently, this trade-off has become more and more complex as a result of the liberalization and internationalization of the gas and electricity markets.

Transmission networks form the backbone of vital infrastructures in more than one way; they allow for (inter)national transport, connection to other markets and provide additional reliability. In light of the liberalization process, the gas and electricity transmission networks in the Netherlands have been unbundled from up- and downstream activities and opened up to third parties. Given

the natural monopolistic characteristics of the transmission networks, they have been subjected to various forms of regulation. Because of the perceived low efficiency of former public monopolies, the regulation has initially mainly been focused on reducing transmission tariffs through price regulation. This focus carries the risk of overemphasizing efficiency over other values such as reliability.

To determine adequate levels for multidimensional values like efficiency and reliability, these values should be rationalized and operationalized in factors. For example, determining the efficiency with which a transmission system operator (TSO) manages and operates a transmission network is difficult, given the complexity of the system. Different approaches have been used to help determine the efficiency of a TSO, for instance by analyzing tariffs (e.g. in (ETSO, 2008)), productivity (e.g. in (Reckon, 2008)) or network utilization rates (e.g. in (Energiekamer, 2009)). Reliability of transport networks is often determined by assessing customer-based interruption indicators and/or analyzing large-scale failures.

When analyzing the transport capacity of transmission networks, typically a relation between network utilization, efficiency and reliability is assumed. The network utilization rate provides a measure of the average usage of the transport capacity available in the network. It is often assumed that a low utilization rate is related to bad market functioning or monopolistic inefficiency. After all, a low utilization rate can indicate that the network capacity is too large compared to demand (overinvestment) or that network capacity is not available to all interested parties. On the other hand, as a crucial part of a vital infrastructure, the transmission networks should guarantee reliable

Email address: gvandeschouw@gmail.com (G. van de Schouw)

¹ Guus van de Schouw is a graduate student in System Engineering, Policy Analysis and Management at the faculty of Technology, Policy and Management of Delft University of Technology. This paper is based on his master's thesis "Keeping connection: A comparative case study on reliability in vital infrastructures"

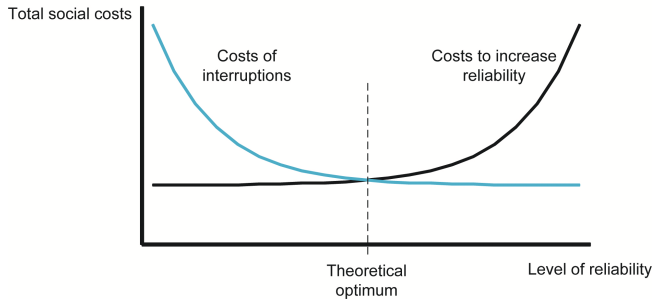


Figure 1: Theoretical optimal level of reliability

Source: based on National Economic Research Associates (2002), Figure 3.1, p. 10

delivery even in extreme demand conditions and be resilient to failures in the network. As a result, the network should be dimensioned to meet all but the most extreme and unlikely scenarios, resulting in a low network utilization in average conditions.

The different requirements that the values of efficiency and reliability pose on transmission network capacity, lead to a debate between regulators and transmission system operators, for instance in the Dutch gas infrastructure. The *Energiekamer*, the regulator of gas and electricity transmission networks in the Netherlands, argues that the utilization rate in some parts of the networks is too low and should be improved (Energiekamer, 2009). On the other hand Gas Transport Services B.V., the TSO of the gas transmission network in the Netherlands, argues that the current (utilization of) network capacity is adequate, because the transmission network should not only be efficient, but should also safeguard reliability and enable proper market functioning (GTS, 2008).

This debate often considers an optimal level of network capacity, where the total costs to society (including among others the network investment costs, the costs of supply interruptions and the costs of market imperfections) are minimal. When considering the trade-off between network investment costs and the costs of supply interruptions,² additional network investments will typically increase network reliability and thus decrease the total costs of supply interruptions and vice versa. As the marginal costs of increasing reliability are continuously rising, there exists a level of reliability where the costs of increasing reliability are higher than the benefits (see Figure 1) and the total social costs are minimal.

Theoretically, the optimal level of capacity can be determined analytically by constructing cost curves for both the costs of supply interruptions and for network investment costs. Because of information problems the cost curves cannot be determined precisely, and the optimal level can only be estimated within a certain range. When

this range is determined and compared to the current level of capacity, it is possible to assess the adequacy of the current network.

However, we believe that this particular trade-off cannot be isolated from other value trade-offs and that complex concepts such as reliability and network capacity should not be simplified and rationalized into a simple economic equation. We argue that there is no singular optimum level of capacity and that over rationalizing the trade-off between reliability and network capacity in this way is not only incorrect but also counterproductive. This paper is based on a comparative case study on three vital infrastructures in the Netherlands: the gas, electricity and fixed line telecommunications infrastructure. The case study consisted of literature review and interviews with infrastructure professionals and regulators (van de Schouw, 2010).

This paper is structured as follows. In Section 2 we will discuss why optimal reliability cannot be determined. In Section 3 we will discuss why the complexity of transport networks hinders calculating and interpreting utilization rates in a whole network. In Section 4 we discuss the consequences of these complications for determining an adequate level of reliability for transmission networks. We also analyze the Dutch gas transmission network as a particular case study. Finally, Section 5 concludes with recommendations for TSOs and regulators and potential future research.

2. Reliability in vital infrastructures

Vital infrastructures serve a large and diverse group of stakeholders. Each of these stakeholders has its own expectations and requirements for the functioning of the infrastructure. The reliability of a vital infrastructure is thus not a simple system property but a social construct, that is seen through the 'eye of the beholder': every stakeholder can have a different perception of reliability (Chester, 2010), that can also change over time. To determine an adequate level of reliability for an infrastructure, one has to assess the preferred level of reliability of different users. Typically there is a trade-off between reliability and costs; higher levels of reliability can only be achieved at higher costs. It is assumed that every stakeholder has a willingness to pay (WTP) for reliability, which indicates the amount of money a user is willing to pay to increase reliability. Theoretically, when we determine the WTP for all users and determine cost to provide extra reliability, we can determine an optimal level of reliability. In reality however, determining users' WTP poses at least three requirements:³

- Reliability is a private good that can be offered to individual users.

² In the rest of this paper we do not focus on other costs. If anything, the inclusion of more costs will only make the trade-off more complex and strengthen our argument.

³ Derived from (National Economic Research Associates, 2002)

- Users can express their preferred level of reliability and do so rationally.
- The relation between the perception of reliability and actual reliability is relatively stable and linear.

Typically vital infrastructures, and in particular energy infrastructures do not meet these requirements. Gas and electricity infrastructures lack metering and switching equipment to offer different levels of reliability to most users. Telecommunications infrastructure offers advanced metering and switching equipment and thus it allows to offer different levels of reliability to users, which has resulted in products and services with wildly varying levels of reliability and an effective market for reliability. But even in this effective market for reliability, it is hard to determine consumers' willingness to pay for reliability because individual consumers often buy contracts that seem not appropriate for them (Pollitt, 2009; Levinson and Odlyzko, 2008). This mismatch might be attributed to several causes: risk averseness of the consumer, rationally over dimensioning (a consumer is more interested in the top speed of his connection, than the average usage), avoiding transaction costs by choosing a standard instead of a tailored solution and the intransparency of the market (also referred to as a "confusopoly"). This broadness of causes influencing individual judgment and the reliance on intuition and anecdotes, also make it hard, if not impossible, to aggregate individual willingness to pay (Renn, 1998).

Two examples can be used to illustrate the volatility of the perception of reliability. Normally the reliability of transmission networks is so high, that users do not notice a change in reliability. The reliability is marginal and as a result the willingness to pay for additional reliability is low. However, when infrastructures are faced with large interruptions, the importance of and the willingness to pay for reliability increases almost immediately as can be witnessed by political and societal responses. The large electricity interruption at Haaksbergen prompted demands for network investments and regulatory standards, where the reliability was regarded adequate before (DTe, 2006). Similarly, after another large interruption in mobile telephony in November 2009, demands for government supervision and emergency planning in case of large internet and telephony interruptions arose (Volkskrant, 2009).

Combining the facts that there are different users with different valuations of reliability, which are difficult to determine and also change over time it is impossible to determine an "optimal" level of reliability. At best we can identify a range of reliability levels that are adequate for a large majority of users. In this "zone of adequacy" (see Figure 2) a change in reliability has a relatively limited impact on the total social costs. Given the difficulty and ambiguity of estimating a more optimal solution within this zone, the costs and efforts of doing so would be very great, while the results would be limited at best (National Economic Research Associates, 2002).

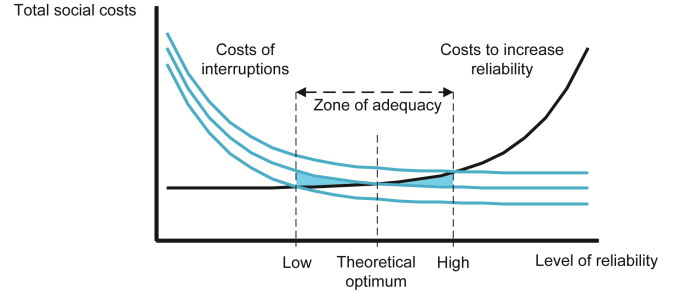


Figure 2: Zone of adequacy as a result of the complexity of reliability
Source: based on National Economic Research Associates (2002),
Figure 3.2, p. 12

3. Network Complexity

Determining an "optimal" network capacity not only requires determination of an "optimal" level of reliability, but also the establishing of a clear relation between network costs and reliability. In this section, we will discuss the difficulties in meeting this requirement.

First of all, the case studies showed that most interruptions are not caused by a lack of network capacity, but by failures during maintenance or digging operations, failure of individual components or failures in up- or downstream activities. Therefore, the empirical evidence of the relation between network capacity and reliability is limited. Also the relation between reliability and network capacity is often non-linear, especially in the electricity infrastructure with its risk of cascading failures (TenneT, 2008; Dobson et al., 2007).

Second, in institutionally fragmented infrastructures, where the users of the network instead of the TSO determine the flow in the transmission network, it is difficult to assess the theoretical maximum demand for transport and thus if a network is capable of meeting this demand. As research commissioned by GTS showed, even for a small part of the transmission network the maximum utilization rate cannot be determined unambiguously (Verlinden, 2008, p. 46). Determining this for the network as a whole is thus extremely difficult.

Third, the complexity and redundancy in network infrastructures also make it hard to directly relate network capacity to network costs. Due to redundancy, the contribution of a single pipe or line to the functioning of the network is hard to determine, because the removal would have almost no effect in normal operation, while it might cause the difference between continued operation and total collapse in critical situations (Perez-Arriaga and Smeers, 2003). The fact that physical and contractual flows often do not follow the same path in gas infrastructure and especially in electricity infrastructure (due to loop flows), also limits the possibilities to determine the exact network costs of a certain transaction.

Finally, low utilization rates cannot always be viewed as a waste of network capacity, because the users of those

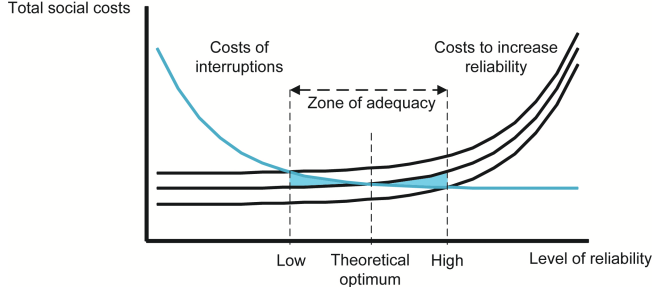


Figure 3: Zone of adequacy as a result of uncertain investment costs

networks often value other aspects besides the costs of transport capacity. For instance, in the gas infrastructure having ample transport capacity on multiple routes, allows parties to manage their supply portfolios. In the US, which is considered to have a more liberalized gas market than the Netherlands, the utilization rate of networks has decreased and a higher utilization rate can be regarded as "a misleading yardstick for the success of market liberalization" (Correljé et al., 2009, p. 43). In telecommunications having ample transport capacity on multiple routes, ensures adequate bandwidth and quality and is "not a sign of waste, but of the value of high quality data communications and of the complexity of running networks" (Odlyzko, 2000, p. 10).

Given these difficulties in establishing a relation between network costs and reliability, the cost curve of investment costs to increase reliability can only be estimated to a certain extent. Analogous to the multi-dimensionality and ambiguity of reliability itself, this leads to a zone of adequacy in which optimizing investment costs is very difficult and the results are limited and dubious (See Figure 3).

4. Implications for transmission

In the previous two sections we have discussed the multi-dimensionality of reliability and the complexity of transmission networks and the difficulties this creates for analytically determining an adequate level of reliability. If we combine these findings in the consideration of total social costs, it indicates the existence of a very broad and diffuse zone of adequacy even if we only look at the trade-off between reliability and investment in network capacity (see Figure 4).

In reality, network investments are just one of several solutions to ensure and improve reliability in vital infrastructures. In (van de Schouw, 2010), we identified three other treatment strategies to ensure reliability: i.e. investing in smarter infrastructures, supply responsiveness and demand responsiveness. Incorporating multiple treatment strategies increases the robustness and efficiency with which reliability can be safeguarded. To make a good decision on the adequate level of network capacity, these other treatment strategies should thus also be part of the equation.

Table 1: Quality Indicators Gas Transport 2005-2008

	SAIFI ⁴	Availability
Transmission	0.0004	99,9999%
Distribution	0.005	99,9999%
Total	0.005	99,9998%

Source: based on van de Schouw (2010), Table 4.2, p. 39

In many ways, the trade-off between reliability and efficiency is thus a wicked problem; a problem "not amenable to traditional linear, analytical approaches or resolution by the systematic application of technical expertise" (Chester, 2010, p. 893). Trying to determine an optimum in such a problem not only results in an unsolvable problem, but is also counterproductive as it draws the attention away from other solutions and narrows the solution scope. Instead, the adequate level of reliability should be determined in a political process between TSOs, regulators and other stakeholders, where the trade-offs between different values are made explicit and decisions on how to safeguard these values are made.

Case Study

We will now analyze the consequences of this wicked trade-off for determining an adequate level of reliability in a specific case: the Dutch gas transmission network operated by Gas Transport Services B.V. (GTS). First of all, we should consider if the current situation of the transmission network falls within the zone of adequacy. Considering the extremely high reliability of the gas transmission network (on average only 1 in 2500 consumers per year experienced an interruption caused in the transmission network from 2005-2008), it seems safe to say that transmission network reach the minimum reliability level in the zone of adequacy.

Especially if we consider that consumers are dependent on the reliability of the entire infrastructure, and other parts of the infrastructure have a significantly lower reliability.

⁴ SAIFI stands for System Average Interruption Frequency Index and indicates the average number of interruptions a consumer would experience in a year.

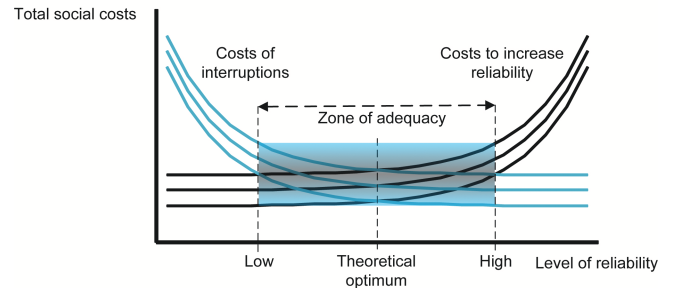


Figure 4: Zone of adequacy for transmission networks

Open Season procedure

In an open season procedure, a TSO inventorizes the need for transport services and the willingness to make long-term capacity reservations from interested market parties. This is done by identifying the demands, refining the design and increasing the commitment in several pre-determined stages. By making this an open and non-discriminatory process, the TSO is able to attract and combine many request from market parties. This helps create an optimal scale for new investments, which is necessary given the large economies of scale of pipeline investments (Correljé et al., 2009).

The Open Seasons of GTS are succesful and show an market-based need for transmission capacity (Correljé et al., 2009; GTS, 2009a). To ensure the effectiveness of Open Seasons, GTS takes into account the Open Seasons in neighbouring transmission networks (GTS, 2009b).

Determining the high end of the zone of adequacy on the other hand, seems less straight-forward. Transmission networks are designed to deal with all but the most extreme situations. However, these situations rarely occur and thus there is no empirical data to validate the design. Thus it is impossible to establish the exact reliability of transmission networks in these conditions, especially when there are unforeseen contingencies.

When determining the adequacy of the transmission network, it seems sensible to focus on expansion and replacement investments. The adequacy of the existing networks is less relevant, as these networks were developed under a wholly different regime and with different perceptions on capacity usage and reliability. To determine the need for new expansion investments, GTS employs an Open Season procedure (see box for more information). New expansion investments thus result from capacity bottlenecks in the transmission network identified by market parties and the proposed solutions of the TSO. The decision on these expansion investments is made in consultation between the TSO, the regulator and parties interested in additional transmission capacity. As a result, the approved expansion investments in the Open Season procedure can thus be deemed adequate, when other treatment strategies are also included in the decision making process.

Considering that the current situation of the gas transmission network thus seems to fall within the zone of adequacy, what does this mean for assessing the current level of reliability and investments? As argued before, given the difficulty and ambiguity of estimating a more optimal solution within this zone, the costs and efforts of doing so would be very great, while the results would be limited at best. The current system of using minimum reliability standards and design criteria to determine needed network capacity seems a more unambiguous and robust way to ensure an adequate solution. Of course, these standards

and criteria should be updated and tailored in consultation with the TSO, regulator and market parties to suit new requirements and developments.

However, we have to consider the relatively low costs of transmission networks compared to the rest of the infrastructure and the crucial role transmission networks play as the backbone of the infrastructure. Thus it seems appropriate to keep higher reliability standards for transmission networks, than required from an economic perspective given the low additional costs. With the enormous importance of vital infrastructures for the functioning of society, it might be more sensible to embrace risk averseness, than to strive for an abstract economic calculation based on risk neutrality and the unknown risks it poses.

5. Recommendations

In this paper we have shown the complexity of the trade-off between efficiency and reliability in transmission networks. This complexity should be addressed in the discussion between TSOs and regulators individually and within the individual organizations. To contribute to this discussion, we provide some recommendations for both parties.

TSOs fulfill both the roles of network operator and market facilitator. In a fragmented infrastructure, where the TSO has limited influence and insight in the actual networks flows, TSOs should make and communicate a clear risk assessment on the reliability of transport capacity. Do they adhere to strict capacity calculations that are always guaranteed, or do they allow cost savings by introducing and accepting a statistical risk that capacity might be overlooked? And how are these risks transferred to users?

As a market facilitator, the TSO should offer services and information to the users, which enable them to decide on an adequate level of reliability, e.g. interruptible contracts and capacity allocations mechanisms. It is the task of the TSO to make these services adequate and available, not to ensure that users use them. The final decision on reliability should be made by the market, the TSO should only safeguard an adequate level of reliability.

The regulatory regime should safeguard an adequate trade-off between efficiency, reliability and other values by the TSO. As such, the regulator should ensure that the TSO offers enough and transparent services at reasonable tariffs for users to make effective decisions. This requires a regulatory framework with a tariff structure that puts the risk of new investments with the TSO and parties interested in new transport capacity, and not with existing customers. Furthermore, the regulator should also enable investments to ensure the long-term reliability, which cannot be determined objectively and unambiguously. Given the public interest is typically represented as risk averse to interruptions, regulation should enable the TSO to recover the costs of keeping a safety margin for capacity (Helm, 2002). Therefore, a supportive and lenient approach seems

preferable over a hard economic approach, especially considering the relatively low costs of transmission networks.

This paper indicated some implications and recommendations for dealing with the complex trade-off between efficiency and reliability, e.g. to include multiple treatment strategies in the decision making process. However, it did not address the design of such elaborate policy and decision making processes. Additional research is thus needed to design processes that include multiple stakeholders, values and treatment strategies in a holistic and balanced manner.

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