Natural gas networks in the Netherlands

An analysis of technical & institutional developments in relation to the network's integrity

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Acknowledgments

Throughout my time as a bachelor and master student of the TU Delft, there is one quote that always kept me moving: "*Dedication makes dreams come true.*" by Kobe Bryant. Even though the fact that when I was younger I did not know how, I always wanted to understand the world a bit better than the day before. Now, becoming an engineering in the field of complex socio-technical systems, it is the perfect way to keep learning and hoping to make an impact in a better future. I can honestly say the dedication and hard work were all worth it in the end to make my dream come true, and so my late grandpa's greatest wish.

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Executive summary

In the Netherlands, households and industries are highly dependent on the supply of natural gas through underground pipeline networks. Homes are warm, food is on the table, and factories are running. However, the natural gas pipelines have mostly been laid over 60 years ago and its environment has gone through some changes. Over time various trends have emerged in the network infrastructure. Examples can be the aging of the infrastructure which causes the increasing risks of gas leaks and pipeline breaks, the separation of Gasunie's transmission services from their economic market activities after 2000, or the introduction of LNG and biogas into the pipelines. In addition, the Dutch population has grown and the changing climate has sparked national goals about phasing out natural gas.

The infrastructure together with its direct environmental and parties involved is called the natural gas system. All these trends and changes have made an impact on the utilization, governance, and innovation within the natural gas system. And may have influenced the system's integrity over time. Therefore this study aims to gain more insight into the relation between technical and institutional developments in the Dutch natural gas system and their impacts on the system's integrity.

Within this research, the technical and institutional developments have been studied in the national high-pressure transportation network of natural gas for a period of 30 years. This was done through desk research, several interviews, and a small case study. To structure the analysis the Alignment Perspective framework by Künneke, Groenewegen, and Ménard has been used (2010). As well as the specified version of the framework for the natural gas system by Künneke and Scholten (2016). The Alignment Perspective framework follows the philosophy that technical and institutional aspects of a system need to be coordinated/aligned for the system to be operating at its expected quality level.

One system analysis has been performed on the technical side of the natural gas system, as well as a system analysis of its institutional background. Here the technical and institutional analysis of the two-sided framework can each be separated into three layers which show the complexity of a socio-technical system. Putting it more straightforward, the three layers can be identified as: 1) design & national law, 2) organization and control, and 3) transactions and investments.

The third and final analysis in this research combined the two sides of the framework to try to see which alignments or misalignments could be identified between the technical and institutional development analysis previously performed. This information then was compared to the integrity timeline of the natural gas system which consisted of perspective changes, but also quantitative data on incidents in the system. The case study was used to see whether the same integrity issues and possible misalignments would be found when using the Alignment Perspective framework on a smaller-scale system. For this case study, a new-build construction project in Zaanstad was analyzed where Gasunie and the municipality of Zaanstad were not on the same page about this project initially. For this case, both the technical and institutional sides of the project were studied to see whether the layers of the Alignment Perspective framework were aligned and whether this was the cause of the integrity issues found.

The Alignment Perspective analysis of the Dutch natural gas system led to the following findings. The integrity perspective has changed multiple times, from only covering work place safety, to including environmental effects, to ensuring the external safety of the network within its direct physical space. Within the technical side of the system, Gasunie began to focus more on risk analysis, outsourcing of maintenance and control tasks, and investing in renewable energy transport projects. While on the institutional side of the network, due to these integrity perspective changes, the supervision and organization of the network also changed. First, in 2000 with the introduction of the Gas Act, the technical operation of the network and the economic market of natural gas were separated into two companies. The Authority for Consumers & Markets gained supervision over Gasunie's technical and coordination practices for the gas transmission operation. Soon after in 2006, the State Supervision of Mines (SodM) was assigned the supervisory task to look at the system's safety regulations and environmental law compliance.

The SodM already was the supervisor of the low-pressure regional distribution networks. Their expertise in natural gas transport and safety procedures helped them to identify that integrity procedures and interventions were not clear and formally formulated in the system. What started with research projects on risk awareness and gas leak reporting, the SodM found ways to improve the regulatory sector-specific processes that would be beneficial for the natural gas system. With more of these theme-based projects, they investigated the environmental effects of the network as well as how renewable energy transportation projects were implementing safety routines. This is to avoid integrity issues in their projects and the natural gas networks close-by. The advice following these research projects was then incorporated by the government in sector-specific laws like the Gas Act, the Decree on external safety of pipelines, and guidelines for reporting gas leaks

However, it was recognized that the sector-specific institutional developments were a reaction to integrity issues found in the research projects by the SodM, instead of being proactive in the prevention of such issues in the first place. This reactive behavior showed up in miscommunication between actors and delays in construction projects, occasional overlap in the tasks of supervisors, and uncertainty about which aspects of the system are supervised and which are left to Gasunie itself. This has led to an ongoing gas leak and gas leak reporting problem, and the SodM expanding its supervision portfolio despite it not being their responsibility or scope of control legally.

In addition, the Zaanstad case study confirmed that the communication between local governments like municipalities and national utility companies is not routine and focused on collaboration. This led to miscommunication is safety requirements and risk definitions for natural gas network assets in spatial planning projects. The case study has also provided insight into the fact that the Alignment Perspective framework is useful for analyzing national socio-technical systems as well as smaller components or events within these systems.

In light of the study's conclusions, the following recommendations can be formulated. As the natural gas system is preparing itself for the energy transition, identifying technical safety requirements and protocols to facilitate this transition is necessary to implement new technologies and energy sources that might perform chemically differently than natural gas. In addition, the changes that have to be made in the external environment of the system have to be incorporated into the national and regional spatial designs. Including municipalities in this development is crucial to ensure the collaboration between municipalities and utility service companies is strengthened and made into a routine practice in case of future spatial plans around the natural gas system. A proactive approach to establishing these requirements and routines is advised to prevent integrity issues related to miscommunication, misalignment of risk definitions, and knowledge sharing.

This research is however still limited in identifying other aspects than technical and institutional developments causing integrity issues in the natural gas transmission system, and how the security of assets and technical ICT systems are related to the integrity of the system. Therefore future research should address which other 'pillars' (economic, social, etc.) can be influential on the system's integrity perspective, and how data security has evolved.

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1
Introduction

1.1 Context & motivation of this research

In the Netherlands, several million tons of hazardous materials are transported under the ground every year. This is done via the pipeline infrastructure networks that have been serving the country ever since the 19th century, which started with transporting coal gas and oil gas (Waszink, 1996). The pipelines transport many different materials for industries and households. This can be for example crude oil, gasoline, kerosene, or other chemical products. However, the main part of the national infrastructure network is used for the transportation of natural gas (Ministerie van IenM & Ministerie van ELenI, 2012). Industries depend on this network for their supply of energy and raw materials. Households mostly depend on natural gas to have a warm home during the colder months, hot running water, and the ability to turn on the stove. As society and the industry are highly dependent on this natural gas network, the criticality of this network and its safety management is also high. If pipelines are not handled with care and safety at the forefront of all interacting activities, catastrophic events might occur which can range from small gas leaks to people being injured or killed (Viana et al., 2021). The national high-pressure natural gas pipeline infrastructure will be the focus of this study, first and foremost for the societal dependency and industrial economic aspect.

Over the past few decades, a variety of developments have occurred in the Dutch natural gas pipeline infrastructure. Examples of such developments are the growth in uses with the introduction of hydrogen, biogas, and LNG into the network, the partial liberalization of the network, but also the aging of the infrastructure as a whole (Gasunie, 2022b; Reinders & Spoelstra, 2022; Rolande, 2020; Shin et al., 2018; Stellinga, 2012). To elaborate on these developments, first off is the aging of the infrastructure. The first Dutch long-distance natural gas pipeline was constructed over 70 years ago when the gas field was found in Slochteren (Ministerie van IenM & Ministerie van ELenI, 2012). With corrosion and excavation damages being the two main safety risks associated with the aging of the infrastructure, aging can introduce safety risks to the infrastructure itself (i.e. breakage, leakages, increase in maintenance), but also its surroundings (i.e. soil and air pollution, explosion risk) (Shin et al., 2018).

Secondly is the partial liberalization of the natural gas industry. This started in 2000 with the introduction of the National Gas Act (NMa, 2000; Gaswet, 2000). In this Act, it is arranged that the consumers of natural gas are free to choose their own gas supplier. The Gas Act was implemented in phases: 1) big consumers in 2000, 2) middle large consumers in 2002, and 3) small businesses and citizens in 2004). In addition, it was arranged that the exploitation of the gas network is performed by independent network operators which need a license from the minister. The exploitation was previously done by a "*50/50 joint venture between the Dutch government and two oil companies*" (Riemersma, Correljé, et al., 2020, p. 148). With the Gas Act, the high-pressure transportation network operator Gasunie was transforming from a 50/50 public-private participation venture into a fully state-owned transportation system operator. With this transition, the gas market (supply) has been liberalized while the transportation system itself has become fully state-owned. The thought behind the partial liberalization was to lower energy costs and provide better service quality in the face of the envisioned competition (R. W. Künneke et al., 2005), and facilitate international competition by opening up the network to all European gas suppliers (Riemersma, Correljé, et al., 2020; Zeniewski, 2021). For the safety of the network, the security of supply is the most important task of Gasunie (Gasunie, n.d.-c, n.d.-a). However, with the liberalization of the gas buying market and the regional distribution networks not being state-owned, is the safety of supply ensured throughout the whole natural gas network. The objective of safety and maintenance is put alongside making profits and gaining market share by these private gas suppliers and regional network operators (Correljé & de Jong, 2009; A. F. Correljé, 2005; Riemersma et al., 2020). Their focus is divided over safety, strategic economic choices, as well as climate obligations imposed by the state. How could this have influenced and is influencing the efficiency and overall safety of Dutch the natural gas network? The national network in focus in this study is at all times linked to the regional networks, physically and in infrastructure project collaborations (GTS, n.d.-b; Netbeheer Nederland, 2023).

Besides internal developments in the infrastructure, the surrounding environment has also changed since the construction of the network. A third development is seen in the physical surroundings of pipelines in the Netherlands. The Dutch population has grown and many people moved out of villages into cities which has caused cities to expand and merge together (De Groot et al., 2010). These now residential areas used to be remote open areas with little or no building structures that could affect the pipelines in the ground.

The fourth and final development that will be discussed here is the energy transition to more sustainable energy sources in relation to the changing climate. In the Netherlands, society and nature are increasingly experiencing effects of the extreme weather conditions due to climate change (NPO Kennis, n.d.). In addition, the discussion on whether natural gas is future-proof has increased (Girgin & Krausmann, 2016; Sever, 2020). The Dutch state has the task of organizing and stimulating an energy transition to lower greenhouse gas emissions (Rijksoverheid, n.d.-a; United Nations, 2023), to transition to sustainable and climate-proof energy sources. The natural gas network therefore will be affected as natural gas will eventually be switched out for more climate-friendly options like wind and sun energy, and the use of hydrogen in transport (i.e. car).

The described developments have made a difference in the utilization, governance, and/or technical characteristics of the high-pressure natural gas transmission network. Due to its criticality for the societal and industrial functioning of the country, the natural gas network has to be safe, reliable, and stable in terms of the probability of incidents being low. In this research, the safety of the network will be evaluated in the level of integrity. For this, the following definition will be used:

> *The integrity of the system is on a continuum scale* (Redmill, 2000)*, and can also be called the safety of the system. It says something about 'how well' the system is operating and will operate in the future. This means that the consequences of future unexpected events in the environment of the system or to the system itself are considered* (Peculis & Shirvani, 2017).

To use this definition, the natural gas network will be viewed from a system perspective: the natural gas system will refer to the physical pipelines underground and the infrastructure facilities above ground (i.e. compression stations which will be discussed in Chapter 3), as well as the direct physical environment of the network, the parties involved/affected, and the institutions concerning the transport of natural gas. Here, institutions include formal and informal rules and agreements that regulate behavior, how a society functions, or how a system's functioning is organized.

The above definition encapsulates the belief that integrity is a range and not a binary attribute (safe or unsafe). Therefore this definition is suitable for this research: every complex system has different safety requirements for different subsystems within it. The high-pressure natural gas system has this complex character due to the integration of its many technical components, its surrounding environment, and different specialized parties that are involved in the system's operation (i.e. technicians, policy makers).

The importance of pipeline integrity has come to light very recently, close by in Europe and in the Netherlands itself. At the beginning of this year, there was a big gas leak in the municipality of Nunspeet (Ververs, 2023). During construction work, a natural gas pipeline was hit. One of the maintenance workers said that with one spark the whole place would have been up in the air. This of course was a dangerous situation, especially as it was near a train station.

In the European Union (EU), the integrity of natural gas pipelines also has gained more interest, especially over the last 2 years (Abnett, 2023; European Parlement, 2017). The Norwegian national oil and gas company Equinor is investing in the safety of its infrastructure (van Dijk, 2023). As they are the biggest supplier of natural gas in Europe, the critical nature of their infrastructure follows with great responsibilities to ensure the gas supply stays at the required level. The reason for these investments in safety and security came in response to the explosions of the underground natural gas pipelines Nord Streams 1 and 2, which seemed to be part of the war between Ukraine and Russia (Berglund, 2022). This brought even more light to the importance of integrity within natural gas transport. There The EU supported the investments of Equinor, through research on risk assessment, disaster recovery plans, and surveillance collaboration (Abnett, 2023; Habibic, 2023).

When previously discussing various types of developments in recent decades, the question arises to what extent the Dutch gas pipeline infrastructure is robust, both in terms of the integrity of the network itself, and also in combination with the environment (external integrity). Therefore this research aims to gain insights into the relationship between technical and institutional developments in the Dutch natural gas pipeline infrastructure and their impacts on the system's integrity. The results can be used to develop strategic & tactical plans to ensure integrity in the natural gas system for future technical & policy changes.

1.2 The knowledge gap

As the environmental, institutional, and technical developments in the system seem to appear side by side, their relation to the integrity of the system seems to be a knowledge gap within the understanding of the system's integrity itself. To better understand this knowledge gap, a literature review was performed before the start of this research. (Which can be found in Appendix A.)

The synthesis of the articles in the literature review resulted in two main findings. Firstly, in the found articles of the preliminary literature study, the focus area for integrity research in pipeline structures was mostly centered in Northern America, especially in the USA (Gong et al., 2018; Parfomak & Folger, 2008; Suarez Suarez et al., 2020). Europe was not mentioned at all in the found articles. This indicates that the topic of integrity and pipeline infrastructure development is not yet a popular topic of discussion in European academic literature.

The second finding has to do with the incorporation of all three themes: technology, institutions, and integrity. Within the literature review, no study was found that had incorporated all three themes in their research. The primary focus was either on technological developments/innovations (Burton, 2014; Gong et al., 2018; Suarez Suarez et al., 2020), or on the safety of the network (Brogan, 2017; Hayes et al., 2021). When talking about institutions and regulations, the connection was with the implementation of a technology, and not regarding any safety measures, issues, or improvements.

With recent incidents and developments that were mentioned before in mind, it is questioned whether the Dutch natural gas infrastructure is still working and regulated level as it should, to ensure high standards of system integrity. Especially in combination with the two findings from the preliminary literature just described. The relation between technical and institutional developments in the pipeline transport systems and their impacts on the integrity of the system has not been studied before where all three themes are incorporated together. Therefore in this study, all three themes will be combined to better understand their relationship to each other, especially technological & institutional developments on the system's integrity. In addition, with the help of the Alignment Perspective framework by Künneke, Groenewegen, and Ménard (2010), the adequate coordination between the technical and institutional developments is further researched. This matching of the technical regulation needs and its actual institutional settings is what will be defined as 'alignment'.

1.3 Research questions & demarcation

Following the knowledge gap discussed above and the aim of this research, the main research question of this master thesis is formulated as follows:

What insights do we take when reflecting on the influence of technical and institutional developments on the integrity of the natural gas system in the Netherlands?

To answer the main question, a set of sub-questions has been identified together with the research methods that will be used for each of these sub-questions:

1.	*What physical & technical system aspects and stakeholders are of importance when analyzing the integrity of the Dutch natural gas transmission system?*	Desk research
2.	*How have the institutions that manage the Dutch natural gas transmission system changed over the last 30 years?*	Desk research Interviews
3.	*How have technological developments in the Dutch natural gas transmission system changed in the last 30 years?*	Desk research Interviews
4.	*Which insights do we gain from looking at the level of alignment between technical and institutional developments in the Dutch natural gas transmission system from the last 30 years?*	Desk research Content analysis gathered data
5.	*What insights can be obtained from the alignment framework applied to a specific Dutch natural gas pipeline case study?*	Case study

The boundaries of this study can be summarized as follows:

- Within this research, the focus will be on the national higher-level (high-pressure) transportation network as the natural gas transport system. This is the midstream process of the natural gas provision. The natural gas economic market will therefore not be part of this study, the regional (lower pressure) distribution network will be discussed when relevant to the working of the higher national network.
- The time horizon is set at 30 years (1990-2020) so that the time before and after the partial liberalization can be properly analyzed. This will give insights into how well this has played out for the system's integrity.

1.4 The scientific and societal contribution of this research

Starting from a scientific perspective, the inclusion of technical AND political developments in the analysis of the system's integrity will contribute in three ways. First off, the technical academic field of pipeline infrastructures will advance from the insights on what the connection between technology and regulation means for the working of a technical system. Secondly, the other way around in the field of policy studies, the emphasis on the integrity of the pipeline system will add knowledge on safety consequences from policy changes in the technical field. Finally, by placing integrity requirements and policies besides the technical needs of the system, this research adds to the understanding of the used Alignment Perspective framework (Chapter 3) within a real-world application. But also in how this framework might help to understand the integrity of the Dutch natural gas infrastructure better for any future research into new technological or institutional changes that occur in the network.

When it comes to a societal perspective, the research will contribute to the evaluation of current and the decision-making process for future policies & regulations within the natural gas system. At the governmental level, the insights from this research could help Dutch policymakers when making or adjusting gas network policies and when designing strategies for the energy transition. Possible missteps or delays in the past can be taken as an example to prevent them in future pivotal transition moments in the natural gas infrastructure.

1.5 Link to MSc Complex Systems Engineering & Management program

Analyzing the integrity of the Dutch pipeline infrastructures from a combined perspective of technical and political directions aligns with the socio-technical vision from the master's program Complex Systems Engineering and Management (CoSEM). The pipeline infrastructure is a multidisciplinary system that involves technology, governmental, societal, and environmental impacts. As none of these elements is acting in solidity, changes in the governmental perspective or outside environment have an impact on how the pipeline network is regulated, utilized, and measured in performance. The system's complexity is shown in external unpredictable events, like climate change regulations from the European Union, the social aversion to the dangers of new pipelines near cities, or environmental studies falling short (Process Control, 2019).

Also, developments in negotiations between public parties and private parties can cause friction that may not be beneficial for the utilization, profitability, and integrity of the Dutch pipeline system. Therefore, the system in focus can be described as a complex socio-technical system that is closely related to the CoSEM master's program.

1.6 Thesis outline

This thesis is structured as follows. First, the research design will be discussed, and how the Alignment Perspective framework will be used in this research. Chapter 3 will elaborate on what the natural gas system entails and will give a more detailed integrity definition that is used. Chapters 4 and 5 respectively will present the technological and institutional developments analysis of the natural gas system. Hereafter, in Chapter 6 the alignment between these two previous analyses will be studied. In this chapter, the case study and the discussion of the results will also be presented. In the last chapter, Chapter 7, the conclusions of this research will be given with recommendations for the natural gas sector and future research following these conclusions.

2

Research design

Before the analyses can be presented, the design of this research will be presented. In Section 2.1 the Alignment Perspective framework that will be leading in these analyses will be discussed. Sections 2.2 and 2.3 respectively, the research approach and the used research methods will be discussed. The reliability and validity strategy is next, whereafter the research flow diagram in Section 2.5 will complete this chapter.

2.1 The Alignment Perspective framework

In this study the Alignment Perspective framework will be used to structure the analysis of the technical and institutional changes in the natural gas transmission system, and how this has effected the integrity of the system over time. In this subsection, the basics of the Alignment Perspective will be discussed, as well as how the framework will be used in the analysis of this study.

2.1.1 The Alignment Perspective framework basics

The critical functions in the natural gas pipeline system (i.e. transportation, storage, maintenance, proportional mixing of chemicals) depend upon the right governance and coordination (Künneke et al., 2010). But what is the right governance or coordination for the natural gas system? The technical and institutional aspects of the system need to be 'aligned' / coordinated to have the system operating at its expected quality level. Here, the expected quality level refers to the integrity of the Dutch pipeline system.

The Alignment Perspective by Künneke (2013) combines two separate fields of study: technical functions and institutional design elements for complex socio-technical systems. A social-technical system combines both the social and technical factors that influence the functionality of a system (Baxter & Sommerville, 2011). Here the system is the high-pressure natural gas network, and the functionality of the system is viewed as its level of integrity to maintain the desired level of natural gas supply security.

The Alignment Perspective was further elaborated on in 2016 by Scholten & Künneke when analyzing system designs for energy infrastructures in general. The version used for this research is shown in Figure 2.1. Here the institutional field refers to '*the rules & regulations under which the system can be operated*' or the '*rules of the game*' (Künneke, 2013; North, 1990), and includes elements like values & norms, jurisdiction, & contracts.

Before the creation of this Alignment Perspective, the design perspectives for infrastructures mostly have been fragmented (Scholten & Künneke, 2016). In the field of control engineering the technical elements of the infrastructure would be studied to secure and improve the desired operational degree of the technical system (Burns, 2001). On the other hand, market design and economic perspectives focus more on the desired market outcomes, and regulations to realize the desired behavior from actors connected to the infrastructure, in other words, the institutional side of the alignment perspective. The combination of the technical engineering and market design perspectives was found limited and underexposed.

Starting with the right side of the Alignment Perspective (Figure 2.1), three layers of institutions are presented which are related hierarchically. Choices on the governance layer (2) should be in line with the layer above with norms and traditions of the system's environment. Layer 1 is about the informal and formal constitutive rules (norms, law), the second layer represents governance and organization rules of the system, and layer 3 focuses on market and business-related activities. These three layers are based on the economics of institutions by Williamson (2000). The presented layers are a more simple representation of the economics of institutions in New Institutional Economics which focusses on the institutions that underlie economic behavior (Rutherford, 2001).

On the technical side on the left of the Alignment Perspective, there are also three layers representing the hierarchical setup of the technical transport system. Layer 1 describes the key technological functions of the system, layer 2 represents the infrastructural design, and the third layer focusses on the business-related control mechanisms to ensure the infrastructure is functioning as it should. Also here the lower levels need to be conform to the characteristics defined in the layers above. Table 2.1 gives some examples with regards to the technical and institutional layers of the framework.

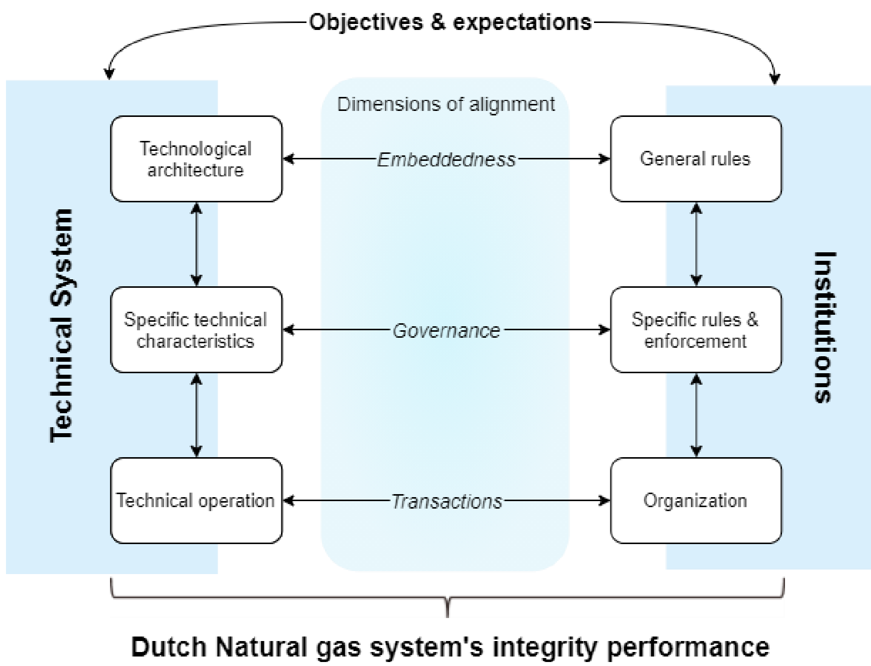

Figure 2.1: Alignment perspective (based on Künneke (2013) and Scholten & Künneke (2016).[1]

When combining the two sides of the framework, three system design alignments become apparent to ensure the effective and efficient function of the natural gas transmission system. First off, the systemic and institutional environments of the network have to be aligned to ensure the functioning and social energy provision of the system on the generic design level (Künneke, 2013; Scholten & Künneke, 2016).

Secondly, the governance of the system refers to specific technical and regulatory arrangements that focus on the control & intervention task division (Scholten & Künneke, 2016). Importantly, the local conditions (physical, surrounding sectors, users) and performance parameters are leading in this process of monitoring and adjusting (Künneke, 2013). The general design choices of layer 1 area a given in the operation and decisions made on the second layer.

The third layer represents the interaction and coordination of operational activities between different stakeholders in the natural gas system (R. Künneke, 2013; Scholten & Künneke, 2016). The criticality of the coordination is based on the scope of the subsystem they are involved in (i.e. production, regional distribution) and the reaction time for necessary system intervention (Künneke et al., 2010). This results in different modes of organization between these stakeholders. Layers 1 & 2 are a given for the operation of the third layer. The playing field of stakeholders will be discussed in detail in Chapter 3.

[1] 'Infrastructure performance' at the bottom has been changed to 'System's integrity,' in line with this research.

Table 2.1: Three layers of critical alignments (based on Scholten & Künneke (2016)).

Alignments	Technical System	Institutions
Embeddedness	Technological feasibility + Design perspective *Knowledge, system architecture, asset aspects*	Informal institutions + Formal institutions *Traditions, norms, values, judiciary, polity, national law*
Governance	Design principles + Control mechanisms *Network topology, capacity, planning, storage, ownership rights, operational coordination, routines*	Governance + organization *Sector laws, ownership, industry standards, access & tariffs, contractual arrangements, transaction costs*
Transactions	System activities *Firm decision-making on asset management, investments, disturbance response*	Market activities *Firm decision-making on prices & quantities, business models, operation & maintenance*

2.1.2 The application of the Alignment Perspective framework

For the analyzes of this study, the Alignment Perspective framework will be taken as a basis. As seen above, the framework has a technical and an institutional side. These two sides will also be analyzed first on there own in Chapters 4 and 5 respectively. The developments from the past 30 years will be discussed for each of the three layers. After this, the interaction between these layers is also explored. As Layer 1 is a given for Layer 2, and Layers 1 and 2 are a given for Layer 3, the layers are not isolated from each other. Technical access to the natural gas system (Layer 1) is a given for the way monitoring and control are organized by the involved stakeholders (Layer 2). The technical coordination of daily activities (Layer 3) is determined by the tasks and responsibilities of the stakeholders (Layer 2).

After the analyzes of the technical and institutional developments individually, the actual alignment between the two sides is next. With the integrity of the system taken as the critical function for the Alignment Perspective, the evolutions within the technical and institutional analyses will be evaluated to see if the developments were aligned throughout the 30-year period and if they have affected the integrity of the system. The data about the system's integrity will be presented in this synthesis chapter (Chapter 6), as well as how this was collected. In addition, a practical case study will be used to see if the (mis)alignments found in the general synthesis can also be identified on a smaller scale section of the system.

By using the framework to thoroughly analyze a specific infrastructure system the usability of the framework itself will be tested. The framework will be tested to see whether the conclusions from using this framework are in line with what experts in the field say during interviews. But also when there is a misalignment found between the technical and institutional developments at some point in the studies period, but the integrity data is not showing any problems or hiccups, can it be that the Alignment Perspective framework is enough to evaluate a system's critical function?

2.2 Research approach

With the Alignment Perspective framework in mind, the aim is to combine the technical and institutional developments in relation to the integrity of the Dutch transmission system. This research has a qualitative research design and will use methods like desk research and interviews to gather the necessary data. As information about regulations and policies is qualitative, while information about safety incidents and technical innovations is quite quantitative, this research will use both types in an inductive approach. Observations, regulations, and theory are used to identify possible patterns in the data (Business Research Methodology, n.d.; Neuman, 2020), where the quantitative data is analyzed qualitatively.

Following the Alignment Perspective framework there are three main steps to this research:

1. A technical system analysis focused on the technical developments in the transmission system;
2. An institutional system analysis focused on institutional and regulatory changes the pipeline infrastructure system is affected by and which are embedded into the system;
3. The alignment analysis of the two previous aspects with the use of the Alignment Perspective framework as the basis.

The information from steps 1 and 2 above is used inductively with the help of the framework perspective to gain insights into the integrity of the Dutch natural gas transmission system.

2.3 Research methods

2.3.1 Desk research

The research method called desk research was used to gather all the necessary information for this study. The method was selected to gain knowledge on the technical and institutional developments of the last 30 years that have occurred in the natural gas system. In addition, information about the integrity of the system and different perspectives on this integrity were gathered as well.

The sources used in this desk research could be literature from scholarly databases that were searched for academic literature. The information from such sources is used to analyze the technical developments within the system, the construction of the system itself, and the Alignment Perspective.

In addition, non-academic literature was used to gain more practical knowledge and information about the institutional background of the natural gas system. Dutch legislation is always announced in the Official Gazette (the legal newspaper of the country), and societal trends are more often found in news articles, research reports, policy papers, industry communications, etc.

The inclusion of both academic and non-academic literature for the desk research allows for combining a variety of sources from a wide range of disciplines (Houghton et al., 2014), and perspectives.

A limitation of desk research is that the researcher is limited by the material available at the time of doing this research. Some sources may give limited answers or the data is from a considerable amount of time back. Also, the researcher had to be aware of potential biases (Waśko, 2019). See Section 2.4 for the reliability and validation strategy to mitigate these disadvantages.

2.3.2 Interviews

With the knowledge in hand from the desk research, interviews were held to validate the information. But also with the idea of seeing if the participants would indicate different knowledge that was not yet found in the literature. The setup of these interviews can be categorized as semi-structured. This way the interviews allowed for more room for discussion and knowledge sharing about the topic (Kallio et al., 2016). As well as the opinion and overall view of the Dutch pipeline system from the participants themselves.

For each of the interviewees, a list of questions was prepared following their expertise and points from the technical and institutional literature that were still unclear or missing. The interviewees, therefore, did not get the same set of questions. In Table 2.2 some example questions are presented.

During the interviews, the participants were asked if they were comfortable with being audio recorded. For all interviews, the interviewer took hand-written notes to prepare follow-up questions, and in case an audio recording was not possible. Possible audio recordings, transcriptions, and hand-taken notes of the interviews have been stored during the research on the TU Delft One Drive. This was in line with the approved Data Management Plan of this research.

Interviews have some downsides to them, as the knowledge acquired depends on both the interviewer and the interviewee. The uncertainty is minimized by performing the desk research first to gain a good understanding of the Dutch pipeline system and which knowledge gaps are open to discuss during the interviews. In addition, the interviewer has to be careful to stay neutral during the interview, to minimize potential bias in the responses of the interviewee. The pre-made questions list helped to manage this.

In Table 2.3, a list of the interviewees is given with their roles at the company they work at. It was decided to gather information from the public and private sectors utilizing interviews, as well as from both the technical and institutional sides of the system. The interviewees were selected based on their role within the company, with the company either coming up within desk research or being found influential within the stakeholder analysis (see Chapter 3).

On the technical side of the network, it was possible to interview an asset manager of the GTS (Gasunie Transport Services) who is part of Gasunie which is the manager of the natural gas transmission network. For the institutional side, a senior inspector was interviewed to verify incident data and regulatory changes that were found in the desk research. Lastly, three private sector companies have participated in this research which either are involved in technical engineering consultancy or are part of the maintenance and construction of the network itself (Heijmans N.V.).

Table 2.2: Example questions for each interviewee type.

Interviewee type	Example questions
General questions[2]	• How would you define 'Integrity' from your professional position in the natural gas transmission system? • Looking forward in time, which issues need to be addressed to ensure a safe energy transition for the upcoming energy transition?
Governmental institution	• How is the process built to create and change norms and industry standards? • What is the collaboration like on the international level for asset inspection? • Have changes in international safety standards & norms influenced the way pipeline safety is viewed in the Netherlands?
Technical consultancy	• What consequences have you seen as a result of the shift of responsibility from more national to regional? For example, the introduction of the Gas Act in 2000. • How are problems or bottlenecks defined and explored within projects that involve natural gas pipelines? And which stakeholders are involved in the management of these bottlenecks? • Which aspects are important for pipeline safety in the energy transition? Are these the same as when the step from town gas to national natural gas was made?
Private sector	• Have there been technical developments within the natural gas sector that have had great difficulty establishing in the pipeline network? Or the opposite, that there was little to no friction at all? • How is the safety management system established and revised over the years? Have there been major changes and if so, why were these made? • What could be the reasons for the fact that despite a KLIC notification being mandatory, it is not always done carefully?

[2] These general questions were ask during every interview, no matter the interviewee type.

Table 2.3: Interviewee list.

Interviewee	Company	Role	Date of interview
Mr. J. Aardema	Inspectie Leefomgeving en Transport (ILT) *(part of Ministerie Infrastructuur en Waterstaat)*	Senior inspector, Department chairperson Bevb	May 9, 2023
Mr. R. Hermkens	Kiwa Technology B.V.	Senior project manager for Energy & Building Technology	May 10. 2023
Mr. M.T. Dröge	Gasunie Transport Services B.V.	Senior adviser Asset Management	May 15, 2023
Mr. R. Frinks	Heijmans N.V.	Commercieel Manager Kabel en Leidingsystemen	June 26, 2023
Mr. J. Driessen	Sweco Nederland B.V.	Senior Adviseur Ondergrondse Infrastructuur	June 30, 2023

2.3.3 Case study

In Chapter 6, a small case study will be performed to use the Alignment Perspective framework on a practical smaller-scale case besides the general analysis which looks at all 30 years. The case will capture the complexity of the situation at hand (Johansson, 2007), as well as how this fits in the overall Dutch natural gas transport system. All three layers of the Alignment Perspective will be discussed, the interaction between them, and what insights can be gained from using the Alignment Perspective within a case study.

A case study bridges the gap between qualitative and quantitative research. It investigates the found general insights within a specific context (Yin, 2009). The integration of a practical case will deepen the understanding of the Dutch natural gas transport system within the Alignment Perspective. In addition, the utility of the Alignment Perspective will be evaluated from a more general and practice side.

2.4 Reliability and validation strategy

Where reliability is about the consistency of measures, validity is about the accuracy of the measures (Golafshani, 2015; Roberts & Priest, 2006). To gain reliable research outcomes, certain actions were taken. For example, all interviews are structured in the same way, with room for the interviewees to go in-depth about their reasoning. As well as keeping the subjective statements from the interviewer to a minimum to not affect the interviewees' professional perspective on the topics discussed.

When it comes to data collection via desk research, the reliability of the sources is examined for their credibility (Golafshani, 2015). This was done by evaluating the origin of the data (say journal or author reputation), and via the way the information was generated. For the academic literature, when the sources were peer-reviewed it showed that the source was credible and could be added to the collection of knowledge. Questions about how well is the research method executed, and is the author transparent about the boundaries of their outcomes, indicated the quality of the resource as well.

To make sure that the methods used are executed with accuracy, during the desk research, the information was collected from a variety of sources, and with the help of cross-referencing this information was checked for validity. When two sources were conflicting, a third was consulted to ensure that the correct information was used within the analyses. In addition, the interviews that were conducted after the desk research phases, act as validity opportunities besides gaining even more knowledge from experts in the field.

2.5 Research flow diagram

In Figure 2.2, the research flow diagram is shown. Here the connections between all chapters and research methods are visualized. Also, all chapter outputs are presented, which are used as input by lower sections of the research.

The figure shows that there are four sections to this study. First off is the *research background*, here the system in focus is presented, the research approach, and the context of this research. The first sub-question will be answered here as well.

The second part of this research is the system analysis, here the technical and institutional developments of the transmission system are presented and analyzed with the help of the Alignment Perspective. The data used will be gathered with desk research and interviews, and sub-questions 2 and 3 will be answered.

In the third part, the system analysis of the second part is used to analyze the integrity of the natural gas transmission system in the form of a synthesis. The full 30-year timeframe of this research will be evaluated based on the technical & institutional system evolution. Ultimately the fourth sub-question will be addressed through Section 6.1. In Section 6.2 the practical case study will be presented. Lastly in the third part of this research, the results will be discussed concerning their meaning, importance, and relevance for the system itself, the stakeholders involved, and the future of the network.

The fourth and final part of this research will present the formal conclusions based on the results and discussion of part 3. Also, a list of recommendations and a research agenda proposal will be given based on these conclusions.

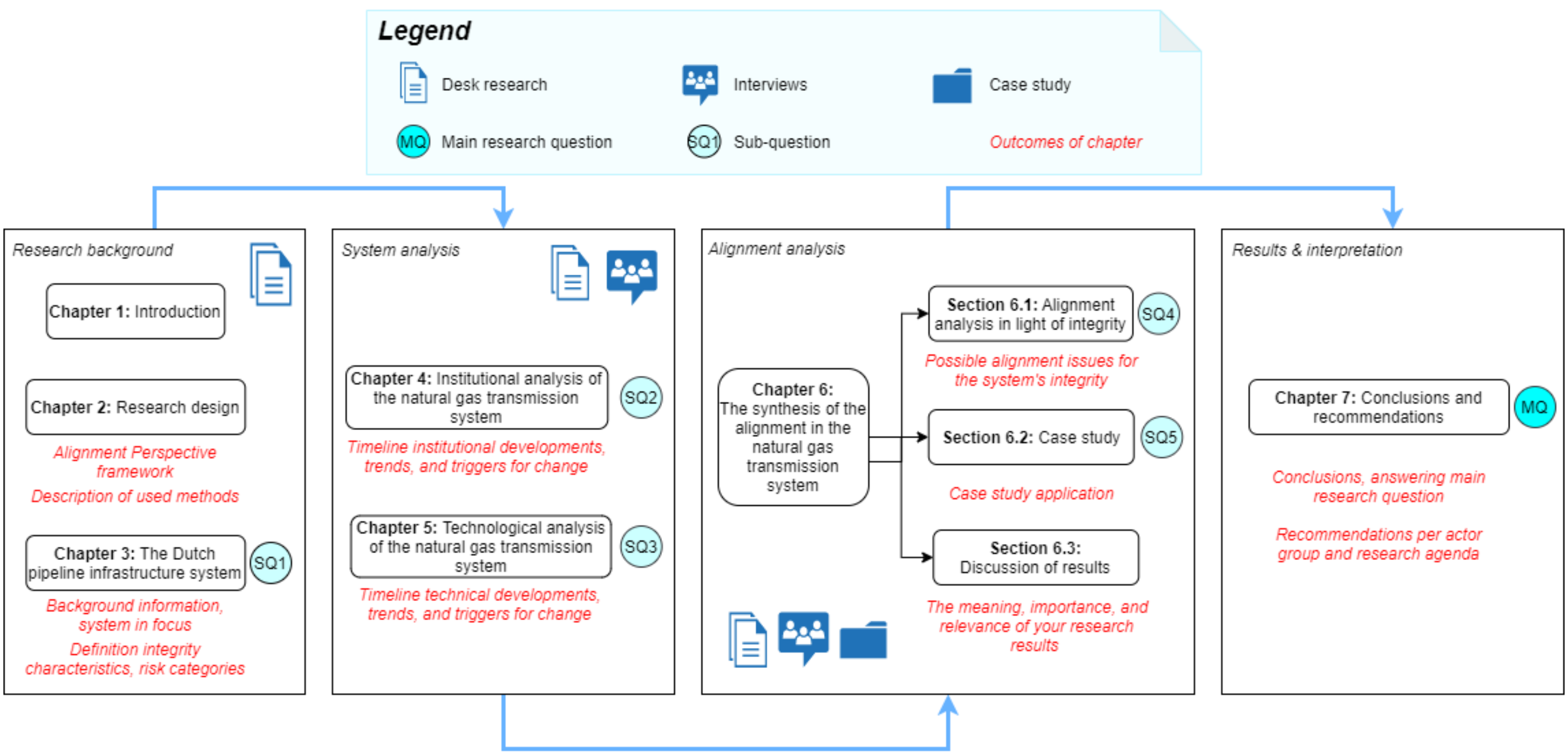

Figure 2.2: Research flow diagram.

3

The Dutch natural gas transmission system

In this third chapter, an overview will be given of the natural gas transmission system in question. The technical elements, its surrounding environment, connecting sectors, and the involved stakeholders will be discussed. After this, the link between the system, integrity, and the Alignment Perspective is explained.

3.1 The technical transmission system of natural gas in the Netherlands

Even though gas has been transported ever since the 19th century, the beginning of the modern Dutch natural gas infrastructure started in 1959 when in Slochteren a natural gas field was discovered (Eskes, 2021). Within a rapid 10 years, the Netherlands was nearly fully connected via high-pressure pipelines to this natural gas supply. The gas was mainly used for heating houses, warm water supply, and cooking food on the stove (Centraal Bureau voor de Statistiek (CBS), 2019), the consumption of gas by electricity production, industry, and agriculture grew rapidly and increased to nearly the same level as household consumption in the 1990s.

Besides the convenience and cleanliness benefits of natural gas in comparison to using coal and oil for energy, the discovery of the natural gas bubble also had immense economic advantages. The natural gas bubble was also beneficial for other European countries, and therefore there were export incentives to gain state money. The export of the natural gas found, already started in 1964, even when not every Dutch household was yet connected to the network (CBS, 2023b). Around this time there were about 3,000 km of infrastructure underground. Nowadays, the network consists of approximately 18,000 km of pipelines (Ministerie van IenM & Ministerie van ELenI, 2012).

Before the integrity analysis of the system that will be discussed later in this study, some technical characteristics of the Dutch natural gas transmission system will be discussed that are important for the operation and safety of the system.

The full Dutch natural gas network can be split into two main parts: the national transmission pipeline network (HTL) and the regional distribution network (RTL) (GTS, n.d.-a). The gas is fed in at the entry points of the HTL network. This can be from a national production facility, storage facilities, gasified gas for an LNG terminal, or via the networks of neighboring countries.

The exit points of the HTL network are the transfer points to the RTL, connection points to neighboring countries' networks, and national natural gas storage facilities. The end users of the national HTL network are big consuming industries and companies, as well as power plants (CBS, 2023c).

Even though this study only looks at the HTL network, it is important to understand that the integrity of RTL sections near the HTL network can influence the integrity of the HTL network due to their connection point as well as the sometimes small physical distance between them. The HTL and the RTL are connected via delivery points which are called 'Measure- and regulation stations'. The gas is between 60 – 80 bar in the HTL, and with the help of compression stations the desired pressure is maintained (Gasunie, 2015). Within the Measure- and regulation stations the pressure is lowered to 40 bar which is suitable for the pipelines of the RTL. In this process, the well-known mercaptan smell is added as a safety measure in case of gas leaks, as natural gas itself is odorless. The natural gas is delivered to the small consumer via a gas receiving station (Dutch: Gasontvangstations (GOS)). Here the pressure is lowered to between 3 and 20 bar depending on the receiver's installation characteristics (Gasunie, 2015). The end users of the regional part of the pipeline infrastructure are households and smaller businesses. A conceptual representation from production to end user is given in Figure 3.1.

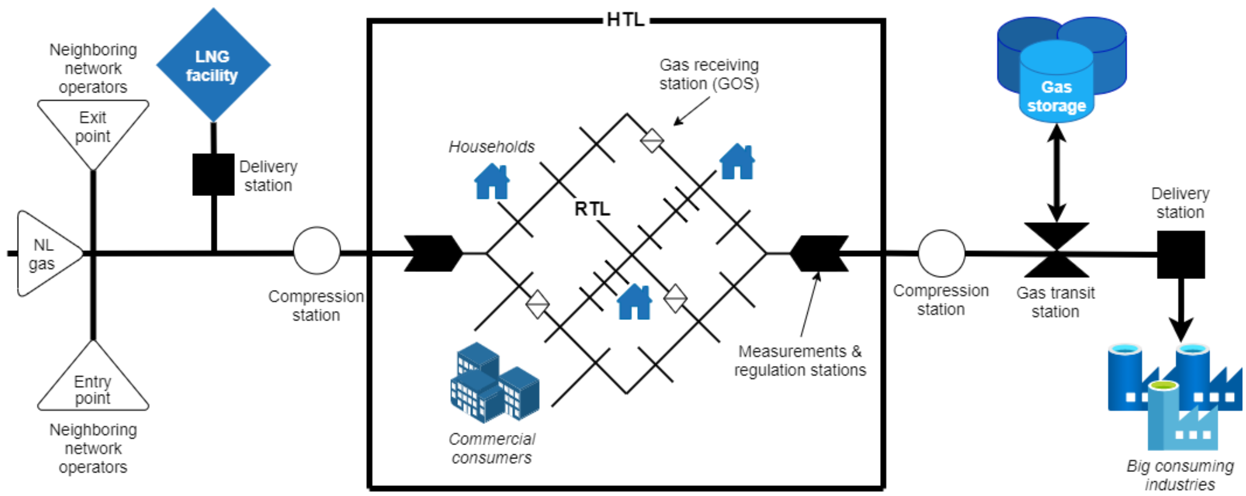

Figure 3.1: Conceptualization of essential elements in the Dutch natural gas infrastructure (based on Riemersma et al. (2020)*).*

Figure 3.2 contains a map of the Dutch national pipeline infrastructure with all important elements. It can also be seen that the rational network is connected to other countries' national network operators: Belgium (*via Limburg & Zeeland*), England (*North-Holland*), Norway, and Germany (*Groningen*). The connection to Norway is only an entry point, while the other national network operators are connected with a bidirectional import/export facility.

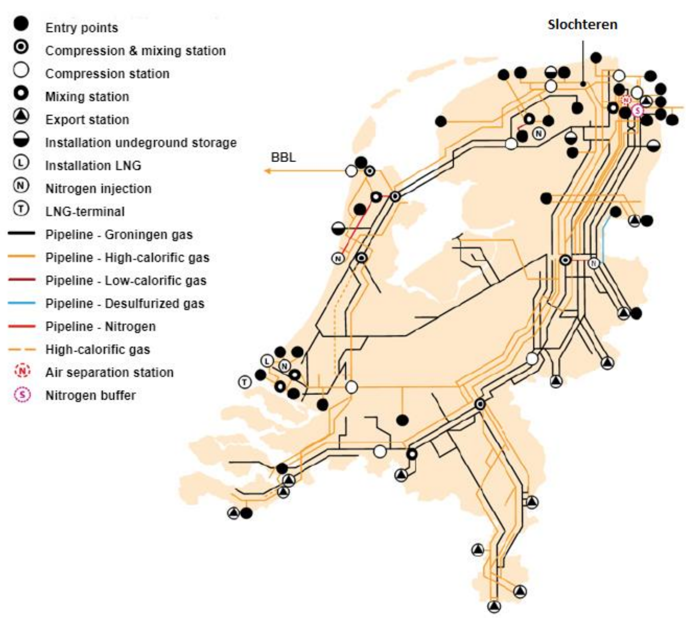

Figure 3.2: The Dutch gas network (based on Netbeheer Nederland (n.d.)*).*

Table 3.1: Material characteristics of natural gas and future energy sources.

Characteristic	Natural gas (LC)	Natural gas (HC)	LNG	Biogas	Hydrogen
Calorific value	9,5 – 10,7 kWh/m3[a]	10,8 – 12, 8 kWh/m3[a]	10,8 – 12, 8 kWh/m3 [a]	4,28 – 5,42 kWh/m3[b]	39,40 kWh/m3[c]
Natural form temperature (°C)	Room temperature [f]	Room temperature [f]	-162 maximum [d]	34[e]	Room temperature [f]
Flammability	0 [i]	+ [i]	**–** [i]	0 [h]	++ [h]
Color	none [g]	none [g]	none [g]	none [h]	none [h]
Smell	none [g]	none [g]	none [g]	none [h]	none [h]
Minimal pipeline wall thickness (diameter)	12 – 15 mm [g]	12 – 15 mm [g]	*Gasified before going into the HTL*	5 – 12 mm [g]	*> 12 mm [f]*

Note: Data from Geertsma (2013)[a], Erol et al. (2010)[b], Quakernaat, 1992)[c], Kumar et al. (2011)[d], Babaei & Shayegan (2019)[e], Miller et al. (2022)[f], Energiebuffer Zuidwending (n.d.)[g], Energie van Noordoost Twente (n.d.)[h], Bijkerk (2020)[i].

In Table 3.1 some safety-related characteristics are listed of natural gas, as well as some popular energy sources/carriers for the future that are being explored or executed for the energy transition. In the analysis of the technical developments in the natural gas transmission system of Chapter 5, these newer energy sources/carriers will be further discussed. Here natural gas is divided into low-calorific (LC) and high-calorific (HC). The natural gas produced in Slochteren is categorized as low-calorific, the Dutch gas installations in homes and the industry are designed to be able to run on low-calorific natural gas. The gas coming from international sources is all high calorific, which also holds for LNG. Therefore the calorific value of LNG is considered the same as HC natural gas. To be able to use HC natural gas in the Netherlands, the imported gas is mixed with nitrogen (RVO, 2015b).

The calorific value of an energy source indicates the energy value of this source (Erol et al., 2010). This means how much heat a certain amount of this energy source can provide.

For '*flammability*', natural gas (LC) was taken as the base level of flammability. The energy sources indicated with a + are more flammable than LC natural gas due to a higher share of menthane in the gas mixture (VAJO, 2019). Energy sources that are less flammable than LC natural gas are indicated with a **–.**

When it comes to the pipeline wall thickness requirements of biogas and hydrogen, their implementation point in the network is leading. As biogas is injected into the national *and* regional natural gas network, the minimal pipeline wall thickness is the same as the wall thickness of the regional network (RTL). For hydrogen, this is aligned with the national (HTL) network as the modern higher network is sufficient to transport hydrogen (Miller et al., 2022), although this would be with a higher pressure.

3.2 Surrounding environment and connecting industries

3.2.1 The physical surrounding environment of the infrastructure

With most of the infrastructure located underground, the visible features (i.e. compression stations, maintenance- & regulation stations) stick out in this infrastructure. But this does not mean the pipelines themselves do not have an impact on their surroundings and vice versa. Pipelines are included in zoning plans with a matching barrier strip for environmental safety, therefore the environment of pipelines is also relevant when analyzing the integrity of the transmission system (ILT, n.d.).

Most of the natural gas transmission pipelines were laid during the 60s and 70s. With the aging of the network, the chance of gas leaks is increasing as the pipes are more prone to breakage due to wear and soil pressure. These pipelines have to be replaced ideally after approximately 40 years (SodM, n.d.). During their lifetimes, they are monitored by various sensors and control mechanisms with the help of pigging technology (M.T. Dröge, personal communication, May 15, 2023). Here, an elongated device filled with sensors and maintenance equipment is sent through the pipeline without having the stop the gas flow (Esmaeilzadeh et al., 2009; Sölken, n.d.).

The effects of these older pipelines can be seen in the surrounding layers of ground. Gas leaks can release a high concentration of benzene which dies down plants, infects soil, and affects groundwater when there is little to no air circulation (Andere Tijden, 2019; Polma et al., 2018). On the other hand, land shifts and heavy traffic loads on top of the network can cause friction and can damage the old pipes.

Although the pipelines are underground, they are made visible above ground for inspection. The national network manager Gasunie has placed little yellow indication posts along the whole HTL network. The purpose of these posts ('*vliegpalen*') is to indicate where the network is located and to ensure the safety of the network when there are plans to do construction work or dig near a pipe (van der Kooi, 2022).

Lastly, urbanized areas can have a different effect on the HTL network than more rural areas. Within the urbanized areas, the pipelines are located under streets and parks. To ensure safety for the environment and the pipeline structure itself, there is a spatial reservation for the barrier strip of the network of five meters on each side (Ministerie van I&W, n.d.-a).

At the ends of the pipeline sections, most facilities or connecting stations are located (as seen in Figure 3.1). The compression stations are mostly located in the rural areas of the country (Gasunie, 2022b; GTS, n.d.-a). There is lots of space around the facility and it is secured with a fence and entrance gates. Exit & entry point facilities are also located in more open areas at the borders of the Netherlands. When it comes to the delivery stations, measure- and regulation stations, and gas receiving stations, the facility is located near the edge of a city or industry park and is recognizable by the stand-alone building with a security fence around it (Gasunie, 2022b). And the same as with pipelines, the distance around these facilities to housing and nature is considered in case of calamities.

As mentioned, the pipelines are also located in more urban areas. With safety measures about digging & building restrictions, and changing zoning plans & heavy traffic flows, the pipeline network is integrated into today's society and nature landscaping (Gasunie, 2015; Smith, 2018). The result is that changes on either the technical or societal side also affect the other side. An example of this could be the recent increase in natural hazards like earthquakes, flooding, and extreme heat periods (Girgin & Krausmann, 2016). This can change the ground density and structure around the pipes. Or network replacement projects that require construction work in neighborhoods and industrial parks.

3.2.2 Other industries linked with the Dutch natural gas pipeline system

Besides the environmental connections in the physical space, there are also links between the Dutch natural gas transmission system and other industries. Whether they are dependent on natural gas, or the pipeline system cannot operate without them. Statistics Netherlands (CBS) has mapped out the natural gas consumption from the biggest users and industries of the country, which is represented in Figure 3.3. This figure shows that the dependency on natural gas is widespread across Dutch society *and* economy.

The big natural gas consumers are the *Built Environment* and the *Industry*. Here, examples of what is included in the sector *Industry* are the chemical industry, paper production, and building materials production (CBS, 2023a). For *Built Environment*, this includes residential heating, commercial services, and public services. In Figure 3.1 these industries are presented at the far most right of the figure.

One other thing to note is the low consumption of the *Transport* sector. A simple explanation for this is the use of natural oil (in benzine and diesel) and electricity (trains) (Anandarajah et al., 2013), as well as the integration of transport companies into the commercial services of *Built Environment*.

As the transmission network is a technical network that requires maintenance, repair, and innovation over time, the right knowledge and tools are needed to fulfill these necessary tasks. The network itself cannot do this on its own. Technical knowledge in sectors like mechanical engineering, civil engineering, or measurement and control technology is much needed to keep the network running and developing.

In addition, as policies change over time plus the societal connection of the network, industries like management, jurisdiction, environmental development, and economics are involved in the operation of the network. This can be in terms of financial advice for innovation plans, property management of facilities, or changing zoning plans for the old pipeline replacements. Section 3.3 will elaborate on this.

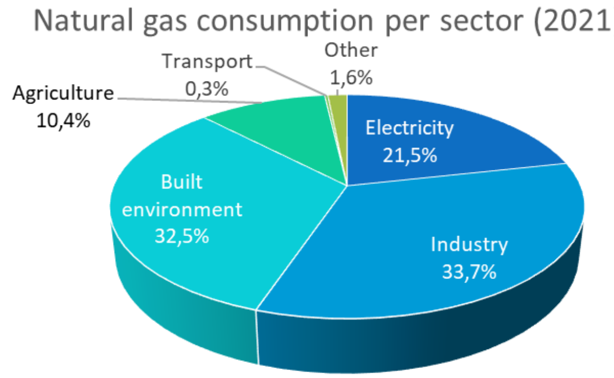

Figure 3.3: Natural gas consumption by the major industry sectors (data by CBS (2023a)).

3.3 A stakeholder analysis of the natural gas transmission system

The transmission network enables natural gas to be transported and stored. In Figure 3.4 an overview is created of all stakeholders involved in the Dutch natural gas system. Some stakeholders are essential for the safety transmission of the gas and are directly involved. These will be called actors. Other stakeholders who are affected by or have a passive position within the system will be called stakeholders.

Gasunie and its subsidiary Gasunie Transport Services (GTS) are actors. Respectively, they are responsible for the maintenance, construction & development of the network, and the management of the gas transport (Gasunie, n.d.-c). Their tasks are controlled by the Authority for Consumers and Markets (ACM) and the Dutch government (especially the Ministry of Economic Affairs and Climate) (Gasunie, n.d.-a). The ACM is responsible for the creation and supervision of gas codes which are rules the natural gas industry has to follow. While there are multiple types of codes, the technical gas codes are important for this research and describe the responsibilities and duties of network managers, gas suppliers, and network operators (ACM, n.d.-a).

The government is also responsible for the decision-making process about the gas extracted from national fields which is done by the NAM. In addition, they impose regulations and legislation on the other actors and stakeholders to enforce the effective and safe operation of the system (Gasunie, 2022b; Rijksoverheid, 2023b). This can be done through lower governmental bodies like provinces and municipalities or via inspections like the SodM. The government itself is obliged to create national legislation within the EU legislation frameworks. An example of this is the Natural Gas Act based on the 98/30/EG directive by the European Parliament and Council of the European Union (Gaswet, 2000). This concerns common rules for the national natural gas market and the use of the transmission infrastructure.

In addition, the national government creates a national spatial structural vision that contains the features of new spatial developments in the country (Ministerie van I&W, n.d.-c). New spatial policies are needed for these developments and projects to be implemented by municipalities. Safety regions in this situation as responsible for the incident response and its preparation in case of a gas leak for example (Tonnaer, 2018). The provinces and municipalities implement the structural vision in their regional spatial integration and zoning plans respectively (Ministerie van IenM & Ministerie van ELenI, 2012). Here the safety barrier strips of natural gas infrastructure are planned for.

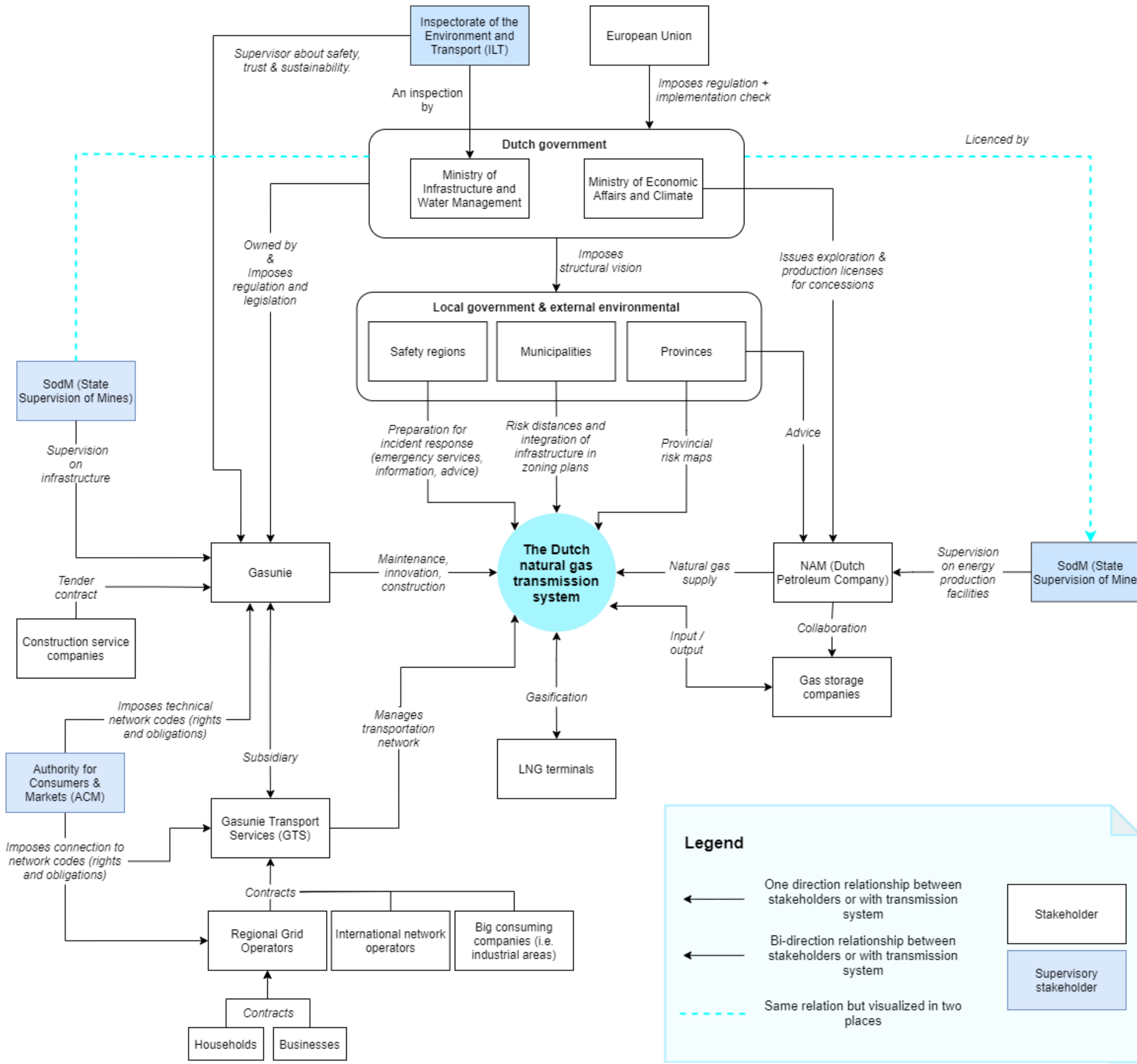

Figure 3.4: Stakeholder overview of parties involved in the Dutch natural gas transmission system.

The modes of organization

Within Layer 3 of the Alignment Perspective framework, the scale of coordination and the time to intervene are important to determine the right mode of organization for an actor. This was recognized by Künneke, Groenewegen, and Ménard in 2010. For this research, the real positioning of the network's supervisors within the scheme of Künneke et al. will be determined (visualized in Appendix B), as well as their appropriate placement in relation to their task and the time available to intervene. In Figure 3.5 a timeline is created of who was responsible for which part of the institutional constraints of the natural gas system. In the stakeholder overview of Figure 3.4, the current stakeholders were presented.

The State Supervision of Mines (SodM)

The SodM is responsible for the compliance of safety requirements and regulations within the system, this is for the pipelines, compression stations, GOSs, and maintenance and regulation stations (SodM, n.d., 2007, 2016). This involves therefore the whole system. As a controlling and advising party, they are not involved in daily activities. Therefore, their mode of organization is categorized as compulsory monitoring and enforced adjustments. To enforce the adjustments recommended they are allowed to administratively enforce the Gasunie to make the adjustments. The price for not making the changes is first a warning and for a second time a fine (SodM, 2019).

The Inspection of Living environment and Transport (ILT)

The ILT is the inspection of the compliance of the Bevb. Their scope is on the subsystem of the pipelines within the system. The Bevb involves requirements and protocols to ensure the integrity of these pipelines, which indicates the mode of organization to be Mutual monitoring and simulated adjustment. They are allowed to give a fine when Gasunie does not take their recommendations into practice. This is not inline with their mode of organization based on their scope and intervention time. The time to intervene is not immediate, as their inspections are once a year (Mr. J. Aardema, personal communication, May 9, 2023).

The Authority for Consumers & Markets (ACM)

The ACM is the technical and coordination supervisor of the Gas Act and is therefore involved in the whole natural gas system. They are monitoring the system continuously through inspections and processing complaints by consumers (ACM, n.d.). When the gas codes are violated, they are allowed to give a fine. Their mode of organization based on the scope and monitoring approach is categorized as compulsory monitoring and enforced adjustment.

Gasunie (specifically GTS)

Gasunie is the system operator of the natural gas system. They own the technical physical system as well as they balance the gas flow daily. When it comes to their renewable energy and hydrogen projects, this is different. The hydrogen system of Gasunie is still in the planning and experimenting phase, here their mode of organization can be categorized as Directive planning. They work together will private companies that coordinate the balancing and the utilization of the network. But Gasunie looks at innovation and system transformation. “Gasunie is working on the question of how we can get these energy carriers to work together smartly and is investing in energy infrastructure to make this possible.” (Gasunie, n.d., 2022).

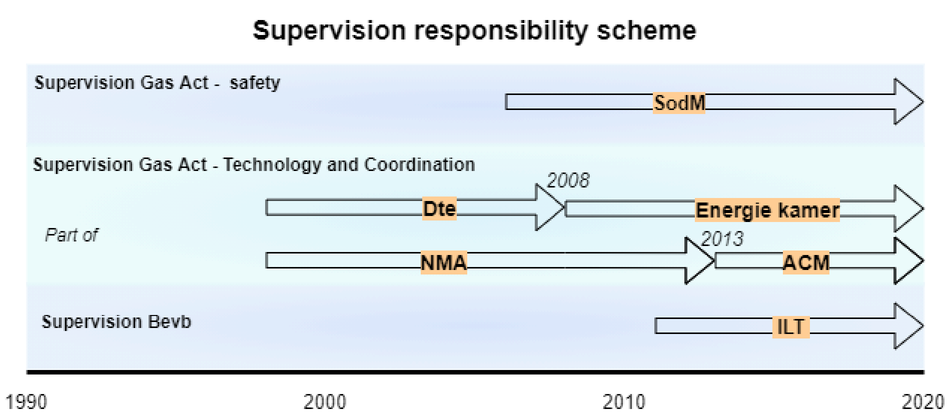

Figure 3.5: Supervision responsibility scheme.

3.4 Integrity characteristics of the system's functionality: natural gas transmission

The topic of integrity is of huge importance within the natural gas transmission system. For the country itself, the safety level of the transmission system is critical for the country's functioning (Ameziane El Hassani et al., 2015). Without a reliable supply of natural gas in a safe manner, society would not be able to work as sufficiently as it is. Buildings would be cold, and people would have to find alternative ways to have a warm meal and hot water supply. On the other hand, an unsafe network will have a higher changes of gas leakages with the consequences of air and soil pollution. This affects our surroundings, one can think about people's health, risks of explosions nearby buildings and other important infrastructures, but also the quality of nature around the incidents.

When looking at the natural gas industry itself, the safety level of the pipelines and other components (as seen in Section 3.1) is what influences the security of the natural gas supply for its customers. But also, their reputation and the overall societal perspective on natural gas in general. Private companies connected to the network can be affected by gas supply disruptions due to the closing of a particular section of the network. They will have a lack of access to energy which can increase the costs of production and transport processes, with negative consequences for other economic sectors (Urciuoli et al., 2014).

To ensure the natural gas system is integer, certain functions and components are viewed as essential (or critical) for the proper functioning of the transport system. For this research, the following components are regarded as essential: pipelines, entry- and exit points, delivery stations, compression stations, and measurements & regulation stations (all visualized in Figure 3.1). These components are needed to transport the produced natural gas from its production facility to its end users. Without one of them, the transmission system would not be working in a technically correct way. The natural gas would not be in the pipes with the right pressure appropriate for the pipeline material and its surroundings.

To ensure the integrity of the natural gas system, there are different technical components and different stakeholders involved as seen before. A commonly used way of doing this is to start with the facts. This can be numbers about incidents and unsafe events, or how much maintenance had to be done within a year. With this knowledge, the old procedures and regulations can be evaluated and changed if needed. However, there is a step that is left within this process (Kokx & van Kempen, 2010). Different people and stakeholders will have different perspectives on these 'facts' and will want to improve differently. In addition, people's perspective is also influenced by others, economic perspectives, and the spirit of the times at that time (Bradbury, 1989; Ling et al., 2007). In Figure 3.6 this relationship is shown.

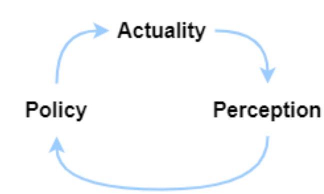

Figure 3.6: Relationship between the actual state of the system and how policy is designed.

Perspective (or perception) of the situation within the natural gas system can be seen as questions like '*are we still happy with the way the system is working,*' '*is this issue a priority at this moment in time*,' or '*do we have the means at this moment to improve the situation*'. Based on these prioritizations and issue comparisons, the stakeholders can evaluate whether or not their policies need to be changed. The outcomes of the policy evaluations create a new framework to work with for the future with desired outcomes to tackle certain issues and to improve the working & safety of the system. However, it is important to note that desired outcomes may not have to materialize in reality or may be disappointing. This in turn changes the future facts measured or experiences within the system.

The next two subsections will discuss what is included in this definition, as well as how integrity fits into the Alignment Perspective framework. Here the terms *integrity* and *safety* are used interchangeably.

3.4.1 Characteristics that are included in the integrity evaluation

The definition of integrity described in the introduction is still quite broad in the sense that it is not a tangible (quantitative) description of what will be evaluated within the natural gas system. Therefore, some decisions were made to maintain the focus on the transmission network itself (HTL), its connections to facilities and other networks, as well as its physical surroundings. This means that personnel safety in natural gas production plants is not incorporated within this study, as well as integrity issues at the level of natural gas pipelines near houses as this is the distributing network (RTL).

Another big topic that is associated with natural gas within the Netherlands is ground movement. This encapsulates for example earthquakes and ground subsidence. However, this is associated with the production of natural gas from gas fields underground and not with the transport of this gas.

What is included in the integrity evaluation of the natural gas system are the following topics:

- Asset management — *pipelines, stations, connections to other networks and facilities*
- The condition of the network — *materials, external influences, age*
- Risk management systems — *computer information systems to aggregate risk data*

These topics are focused on the technical and procedural side of the system which directly influences the condition and therefore integrity of the system. With these the essential components are covered as well as the critical function of the network to the stable supply of natural gas from production to regional customers (= network managers within the RTL).

3.4.2 Integrity placed in the Alignment Perspective framework

Traditionally, energy infrastructures are implemented as public monopolies with vertical integration of all responsibilities and tasks (Scholten & Künneke, 2016). The government would be controlling all investments, planning, and operating the technical system. However, since the partial liberalization, the ownership of the Dutch natural gas system has changed. This change initially came from layers 1 and 2 on the institutional side of the Alignment Perspective, which has influenced the third layer with the increase of actors and parties involved in the operation of the system (Künneke et al., 2005).

On the other hand, the technological evolution in this transportation network did not stop. An example from the introductory chapter (Chapter 1) is the growth in network use cases due to the energy transition moving towards the use of more renewable and sustainable energy sources (i.e., connecting LNG storage facilities to the network which has other characteristics than natural gas).

In short, institutional changes and technical evolutions occur beside each other but are also in a dependent relationship. Understanding such dynamics of transitions and interconnection can help policymakers in the future to address societal problems like environmental harm, pollution, and human risk exposure (Berkhout, 2002). This calls for multi-perspective analysis, like the Alignment Perspective.

The increasing number of parties involved, and technical expansions of the network make the system constantly evolving. Whether this is in the production processes of natural gas, transportation flows, or the maintenance of the technical and regulatory systems. The complexity of the socio-technical pipeline system increases, as well as the interrelation between the technical innovation evolution and the institutional and economic changes for natural gas. Looking at theories around safety and integrity, in the notion of the Normal Accidents Theory (NAT), some accidents are inevitable due to this system's complexity and tightly coupled technical & organizational components (Giikalp, 1992; Perrow, 1999; Rijpma, 1997; Sammarco, 2005). The network is very unlikely to be one hundred percent accident-immune. The complexity and size of the system indicate that developments are slower. The technological architecture will rarely change, but when changes occur it is most likely under pressure from society or economics, i.e., changes in societal values or law enforcement (Giikalp, 1992).

Besides the NAT, there is also the High-Reliability Theory (HRT) created around the same time by Californian Scholars (Shrivastava et al., 2009). The HRT looks for organizational factors and processes that play a part in reliability, were the NAT looks at organizational properties that cause accidents (Shrivastava et al., 2009). The factors found by the HRT would be the opposite of those properties of the NAT as these would steer away from causing incidents within the system. Risk mitigation and risk identification, therefore, are two different but both particularly important when assessing safety issues.

In addition, the high-level natural gas transmission system experiences besides technical also external complexity with its physical surroundings and involved stakeholders. In resilience engineering, these types of systems need to have the necessary adaptations to adjust to real-world complexity to ensure their performance (Dekker et al., 2008). Organizations and individuals need to anticipate changing risks and hazardous situations to avoid damage, failures, or major accidents. Gas leaks in rural areas with no one around need different safety perspectives than gas leaks within densely populated areas.

As later the layers of the alignment framework will be analyzed, it would be useful to discuss how integrity plays a part in each of these layers. Starting on layer 1, here national law & norms should come together with the system's architecture and technical design. The bigger picture of the infrastructure is focused on, and therefore the general safety outside of the natural gas system should be on the level with the national sense of safety and security. Looking from the technical perspective, this also applies to the technical knowledge about the system. Looking at the current state and the future of the system. The complexity in the architecture of the network, as related to the Normal Accidents Theory, affects the network's integrity.

For the second layer, the integrity is mostly related to the surroundings of the network. Nature, society, and connecting industries should not be paying a harmful price for homes and industry facilities to get natural gas supply. In addition, maintenance and technological implementation processes carry a lot of safety risks, as the employees and surroundings are exposed to a different state during maintenance work or even a new (possibly more complex) version of the network after technical updates.

Lastly, on the third layer of the framework integrity is integrated in the way procedures are designed and who are involved in which parts of the network. But also, in which collaborative relationships have been formed to manage & control the network operations to ensure the lowest possible risk levels throughout the infrastructure (pipelines & the different stations). The communication processes and alignment of perspectives are the mechanisms upon which integrity mostly depends.

From making changes within the natural gas system over time, the consequences can be used to learn for future changes. This incremental learning can be within actor behavior and regulatory process, or in the implementation process of new technologies. This process is exactly the aim of this research where the Dutch natural gas system is analyzed over the last 30 years. With the societal function of natural gas supply, this co-evolution of both sides of the framework is important to analyze to ensure the integrity of the system, from the perspective of the system as well as from its environment. This means that the technical developments and the institutional developments from the last three decades will be mapped out to compare them in the end. Questions that can be investigated could be whether the right institutional arrangements were chosen for the technical state of the infrastructure, or if certain innovations should have been implemented in a more incremental way to ensure the full implementation was able to run effectively based on the institutional and social perspectives.

The Alignment Perspective framework will help to explore these relations in a structured manner. In addition, possible misalignments or delays can be taken as examples for future decision-making processes or technical changes in the pipeline system. Technical design & governance options as well as trade-offs about performance & integrity within the natural gas system will be easier to investigate.

4

The technological system analysis

In this chapter, the technological developments within or affecting the natural gas transmission system will be analyzed on each of the three framework layers. In addition, the interaction between these layers will be discussed: are the developments in each layer connected, influencing each other, or are there even contradiction directions found in the technical evolutions? With the help of interviews, a literature review, and yearly reports by the SodM and the ILT (Inspection of Living environment and Transport), an overview of these developments was made.

4.1 Alignment Perspective layers analysis

In Figure 4.1, an overview is presented of the different technological developments that have occurred within the natural gas system over the past 30 years. Here the three layers of the Alignment Perspective framework are visualized in different colors of blue with Layer 1 at the top in the darkest blue color. For Layer 1 the academic literature is presented in grey boxes with a dark blue color for the border to visualize this group better.

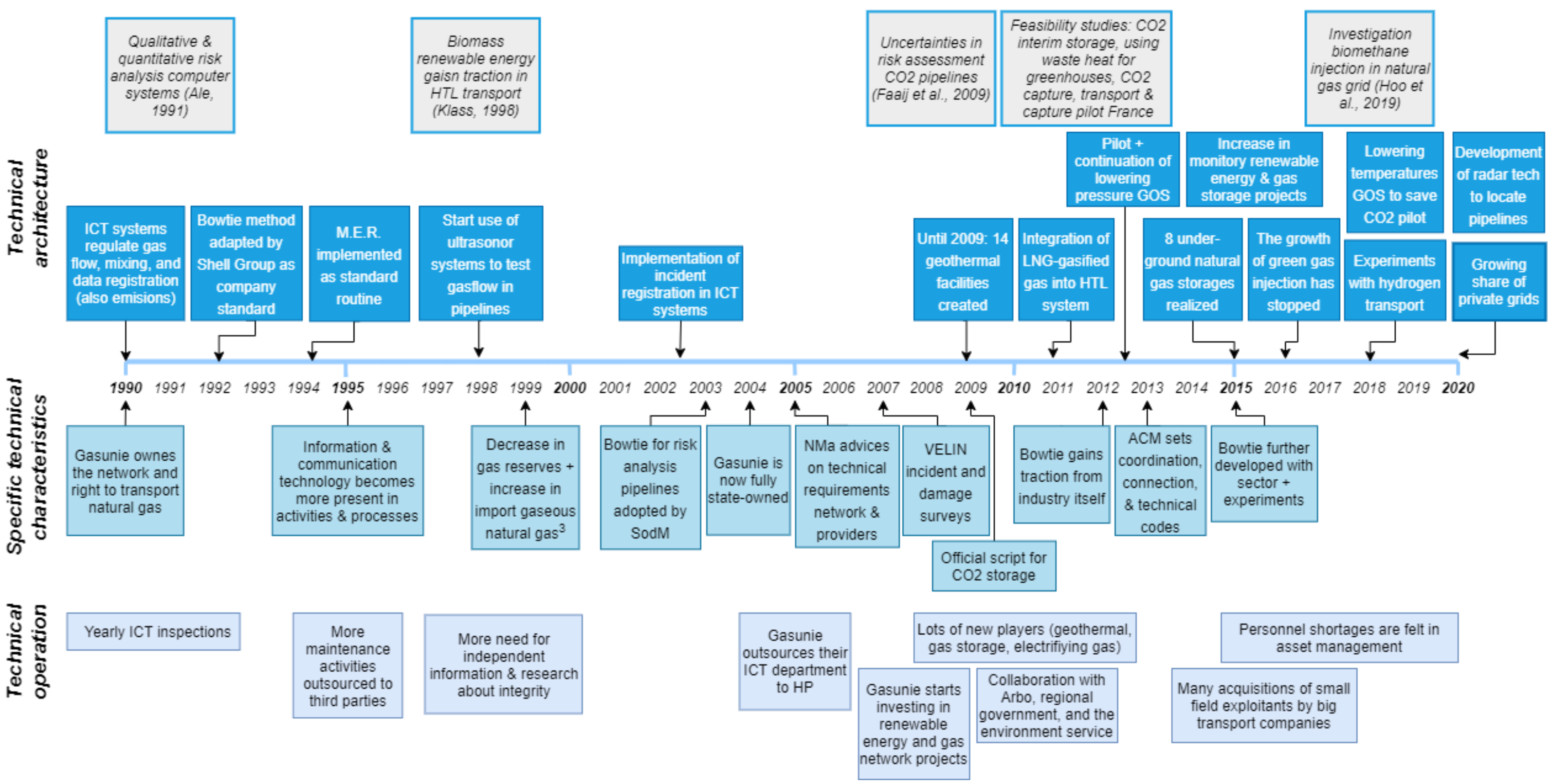

Figure 4.1: The technological developments timeline of the Dutch natural gas transmission system.

[3] The Netherlands had to import more natural gas as the reserves & production decreased. https://opendata.cbs.nl/#/CBS/nl/dataset/00372/table

In the following subsections, the three layers will be individually discussed on general trends and noteworthy changes. Hereafter, the interaction between the three layers is analyzed on several different aspects which will be presented in Section 4.2.

4.1.1 *Layer 1: Technical architecture*

The first technical layer of the Alignment Perspective framework encapsulates the available technical knowledge and the natural gas system's architecture meaning what is the design and asset elements. To start with technical knowledge, academic literature was used together with the conducting interviews to establish an overview of the changes in the knowledge evolution. In Appendix C, the full search strategy and results of the literature review can be found. The interviews also helped to verify this review on time indication and technical implementation level.

Over the 30 years, the academic literature early on made a shift from analytical methods for risk analysis (Ale, 1991), to performing feasibility studies and in-depth applicability analysis of renewable energy sources and new use cases for the natural gas network (Andrews & Pearce, 2011; Farhat et al., 2011; Koornneef et al., 2009). As the studied literature is just a handful of the total body of literature on renewable energy and gas transport systems, it indicates that the technical knowledge on for example CO_2 storage, waste heat transport, and biogas injections are well researched. It was found however that most of these technical developments are still in the simulation phase.

In Figure 4.1 it is also seen that the actual natural gas system has been through some changes. The first 15 years were mainly focused on updating their ICT systems and making sure that the monitoring and control of the system could be done more efficiently. This could be with the help of new ICT-subsystems to monitor incidents, gas leaks, and gas emission registration (Mr. R. Hermens, personal communication, May 10, 2023) or with ultrasonic systems to evaluate the gas flow with more precision (SodM, 1999).

In the second half of the studied period, the physical network was evolving. The original natural gas network in the 90s can be categorized as a closed-access network, with some production facilities and foreign neighboring gas networks on the input side, and big consuming industry facilities and regional distribution networks (RTL) on the output side. The network is rigid and pre-determined. However, on a regional level, projects for renewable energy sources and network uses (i.e. geothermal technology, CO_2 transport) were starting to develop (Gasunie, 2022a; ILT, 2016; SodM, 2010). The view on the natural gas network was changing, and with the Paris Climate Agreement greenhouse gasses need to be limited where natural gas is one of the biggest sources (Shell Global, n.d.). Gasunie has been monitoring these projects and experiments. This way they can collect information on design and safety requirements that are needed to develop a network on a national scale when these projects are perceived as successful and future-proof (Gasunie, n.d.-d, 2022a; SodM, 2020). In addition, their interest in these types of projects is also to protect their natural gas network from any possible risks of these projects that could harm the HTL network.

The developments just described in academia and in the network's design indicate that the academia and technical knowledge are ahead of what is happening in the network's design. The future of the natural gas network has mostly been explored in the last 10 years by Gasunie publicly, whereas academia has been researching this topic since the late 90s.

4.1.2 *Layer 2: Specific technical characteristics*

For the second technology layer of the Alignment Perspective framework, the focus is on the organization and control mechanisms in the network. One can think about planning, routines, and ownership rights. These practices and organizational structures are presumed to follow from Layer 1.

The development in safety evaluations and data collection found in layer 1, is also seen in Layer 2 with the most impacting development being the use of the Bowtie methodology. The Bowtie model is a diagram that visualizes an event/hazard that could occur with various potential causes and various potential outcomes (Figure 4.2) (Wolters Kluwer, n.d.-a). It is mostly used to structure risk and safety problems, the approach identifies the system elements that generate considerable risk and aims to improve their reliability to reduce these risks (Riemersma, Künneke, et al., 2020). The method was adapted by Shell Group in 1992 as a company standard (Wolters Kluwer, n.d.-b), which was for 25% the owner of Gasunie (Riemersma, Correljé, et al., 2020). Whereafter the SodM started to use the model for risk analysis in RTL networks, and later in HTL networks as they gained the supervisory responsibility on HTL safety in 2006 (SodM, 2004, 2007).

In addition to the development of the Bowtie method, the organization of the network further focused on the technical requirements and coordination procedures to ensure the network would be on par with the set-out industry standards and safety routines. Firstly, this was done by the NMa (Netherlands Competition Authority) as the technical design and specification advisor of the HTL system (*Gas* Act, 2005). In the next chapter, these industry standards will be discussed in more detail. However, in 2013, the ACM (successor of the NMa) changed the approach from advice to setting technical requirements in the form of Gas Codes that were mandatory to follow (*Gas Act*, 2013).

Figure 4.2: A simple representation of the Bowtie method (Wolters Kluwer, n.d.).

Also in Layer 2, the ownership rights of the network operation and assets have changed from a 50/50 public-private partnership to a fully public operational network when Gasunie became state-owned in 2004 (A. F. Correljé, 2005; SodM, 2005).

4.1.3 *Layer 3: Technical operation*

The day-to-day operations, collaborations, and problem responses are located in Layer 3. The specific technical requirements from Layer 2 are managed as well as the technical architecture of the system from Layer 1. In layer 3 it is important to discuss the technical operation coordination, and the complexity of the network when it comes to the time to react to different hazardous events and the scope of these events. This will first be discussed for Gasunie as the technical operator of the system. After this, some developments in Layer 3 will be highlighted.

As the technical operator of the system and the owner of the natural gas system, Gasunie controls and maintains the whole system: from entry point to compression station, from pipeline to gas receiving station. When a disturbance occurs in the system, direct intervention is needed. The whole system can be disrupted when the intervention does not consider the effects on other parts of the system. Most of the time an intervention starts with closing off one subsection of the pipeline network via gas valves in the pipes (Gasunie, n.d.-b; Mr. M.T. Dröge, personal communication, May 15, 2023). The gas flow and supply will not be disrupted.

Due to its social and economic dependency, and the dangerousness of the natural gas itself, immediate intervention is required. In other words, the natural gas system requires continuous control to ensure one hiccup cannot damage the function of the entire system but rather be contained to its very local problem area.

Looking at Figure 4.1, the technical developments in Layers 1 and 2 have affected the way the technical system is coordinated. The introduction of a more complex ICT system for operational and registrational purposes requires a reliable and safe system. Therefore, Gasunie incorporated a yearly inspection as well as regular upgrades to be able to rely on and evolve the system (Mr. R. Hermens, personal communication, May 10, 2023). When the integration of incident data was made in 2003, the computer systems were getting overly complex to inspect and improve. Therefore, Gasunie decided to outsource its ICT administration and calculation departments to Hewlett-Packard in 2005 (Sanders, 2005).

Despite the ICT outsourcing, during the 90s Gasunie already started to slowly outsource some of their day-to-day tasks in network maintenance and control. This cleared capacity to increase work on risk analyses and the expansion of the network (SodM, 1993, 1998). But also increased the collaborative relationships that had to be maintained and controlled to ensure the right execution of the operational and control activities within the network (Mr. M.T. Dröge, personal communication, May 15, 2023).

4.2 The interaction between the different layers

In Chapter 2 the Alignment Perspective framework was presented, here the link between the different layers was explained as that an upper layer is a given (background) for a lower layer. In this section, the interaction between the three technical layers will be discussed. The following aspects were looked at: influence from other layers, consequences between layer developments, and developments supported by other layers.

Within the first layer, renewable energy and other use cases of the natural gas infrastructure have been researched already since the 90s. However, this knowledge is not implemented in the actual physical infrastructure (from 2011), or system requirements on Layer 2 (from 2009), very rapidly. During one of the interviews, a potential reason for this delay was given. As Gasunie does not have the academic knowledge right away, and the feasibility of these new technological changes is not directly applicable to their specific infrastructure, further research has to be done into the feasibility (Mr. R. Frinks, personal communication, June 26, 2023). The first hydrogen pilots and the script for CO_2 storage are perfect examples of this delay.

When it comes to risk analysis, the integration of computer systems to do this task was first found in Layer 1 with a study done by Ale (1991). During this time, the implementation of ICT systems at Gasunie and SodM had also ready started, but were more focused on administrative, business-related, and gas flow data registration. (SodM, 1993; Mr. R. Hermkens, personal communication, May 10, 2023). With the yearly ICT system reviews and updates, Gasunie slowly coordinated the integration of calculations and analysis tasks into the computer systems. After the ICT department was outsourced to Hewlett-Packard in 2005, Gasunie did not report any significant changes to its systems as it wanted to focus on its core task of natural gas transmission (Sanders, 2005).

Risk analysis looks to be a continuous evolvement. Starting with the Bowtie methodology adapted by Shell Group in Layer 1, which later was further developed specifically for the HTL networks by the SodM in Layer 2. Here also the risk definitions and causes of excavation damages were questioned with the help of a yearly routine by VELIN (the Association of Pipeline Owners in the Netherlands). They reach out to all their members with an incident survey (VELIN, 2009). The growing use of the Bowtie method in 2012 shows that Gasunie and SodM both saw the results of the method as a benefit in their risk analysis toolbox and its benefits to clarify definitions (GTS, 2023; SodM, 2013). This toolbox is used within the company itself, but also in their communication to their third-party contractors who perform the outsourced activities like excavation works.

Mr. J. Driessen of the consultancy company Sweco also confirmed that the method is frequently used in calculations and analyzes for energy transition-related issues, which became essential around 2010 for Gasunie: what if we transfer hydrogen in natural gas networks? How can biogas be injected into the network without or with fewer fluctuations in the calorific value of the gas mixture? (Personal communication, June 30, 2023).

The technical architecture characteristic of the natural gas transmission system that describes the network as a simple input-to-output rigid design with only a few actors is indirectly seen in Layers 2 and 3. In Layer 2, the need for control and interest in other regional pilots and experiments after 2015 indicates that the transmission does not have control over these developments. They are not involved in the execution, but the dangerous effects if something goes wrong during these projects can affect the operation and integrity of the HTL. Mr. R. Frinks also called this one of the reasons that Gasunie became an investor in such types of projects (personal communication, June 26, 2023).

In Layer 3 this closed-access design is seen in the outsourcing of maintenance and control activities by Gasunie. In the case of open access, the danger of unsafe entry points would be too high to outsource these activities and not keep them internal in the organization. There would be less control over quality and knowledge levels.

When it comes to support between the layers, the technical requirements for implementing renewable energy projects and alternative use cases for the physical network were not clear from the specifications in Layer 2. This was also recognized by the SodM in 2011 and 2016 for biogas and green gas injections (ILT, 2012; SodM, 2012, 2017). The calorific value was affected by this lack of technical requirements as big fluctuations were seen in its value. As these fluctuations are dangerous for the integrity of the network and natural gas devices of consumers (RVO, 2015a), the injection of green gas was stopped (SodM, 2017). The stop on green gas was confirmed by the SodM due to the lack of coordination and control on this calorific value. However, the efforts to make these specific technical requirements are shown to be there. When interviewing Mr. M.T. Dröge and Mr. R. Frinks, the involvement of Gasunie in the implementation strategy of these new projects and use cases of the natural gas network is in contradiction to the lack of publicly available requirements for these developments. In addition, Mr. R. Frinks and Mr. J. Driessen argued that the technical requirements mostly are a reaction later on instead of preparation earlier for new technologies. Whether these are industry standards or formal legislation (see Chapter 5).

4.3 Conclusions from the technological development evaluation

In this chapter, the technological side of the natural gas transmission system has been analyzed with the help of the Alignment Perspective framework. Each layer individually, but also the interconnection between these layers. It was seen that the technological developments throughout the 30 years have evolved from focusing on risk analysis to uniformity in risk definitions to renewable energy technologies that might replace natural gas in the future. Industry surveys and the Bowtie methodology both helped to gain more knowledge on the technical requirements for the evolving system.

The organization of the network focused on the further development of network risk analysis and registration overall in Layer 2. In Layer 3, the coordination of the maintenance and control of the system evolved from a simple streamlined Gasunie that did everything itself to a network of third parties and government bodies. They are involved in the maintenance, control, and further development of the network for the future. Here not only is looked at the internal workings of the network but also into effects on the environment and how regional projects can affect the network operation safety.

When looking at the interaction between the layers, it was found that the technical system requirements that are the basis for operating the system in Layer 3 did not reflect the same trends or developments that were found in the other two layers. For the renewable energy projects, CO_2 transport pilots, and the injection of green gas into the network, the technical requirements to coordinate and control these changes were not made explicit. Whether this has affected the way the system is regulated and the integrity of the system, will be seen in Chapters 5 and 6 respectively.

5

The Dutch institutional and regulations analysis

In this chapter, the Dutch legislation and regulations associated with and connected to the natural gas transmission system are presented and analyzed. For this analysis, the legislation overview made by VELIN was used as a basis (VELIN, 2018)*. VELIN emphasizes that this overview is not complete and changes over time. In addition, knowledge from the SodM year reports, interviews, and the official Dutch legislation website[4] was used to establish a more complete understanding of how institutions have changed over time for the natural gas transmission system and its integrity.*

5.1 Alignment Perspective layers analysis

5.1.1 Layer 1: General rules

In Figure 5.1, the first institutional layer of the Alignment Perspective framework is presented. As certain institutions and regulations have been replaced over time, this is visualized by the matching colored stripes above them. In Appendix D a short description of each law/regulation/norm is given.

In Layer 1, the relevant general rules and national institutional background of the natural gas system are positioned. The specific institutions, regulations, and organizational structures for the transmission of natural gas itself are found in layer 2. Looking at Figure 5.1, it can be seen that from early on the emphasis on environmental effects from society and industry has been important in the Netherlands. Throughout the years more environmental impact regulations and institutions have been added, all to protect and preserve our environment. Analyzing the environmental impacts of big construction projects has been in practice since 1979 and legally binding since 1994 with the introduction of the Environmental Impact Assessment Decree (Ministerie van I&W, n.d.-b). The Dutch legal system also has incorporated the conservation of nature (1998), the protection of soil (1986), and water (1991) into their strategy to protect the environment (Ministerie van I&W, n.d.-e). For the supervision of industry and businesses on these environmental laws, in 1992 a committee was created (*LCCM*, 1992).

Later on, the evolvement of these environmental and spatial laws is less frequent and might be due to the upcoming Environment and Planning Act (*Dutch: Omgevingswet*). Originally the Act should have come into effect in 2017, but now it is planned for 2024. This Act revises, simplifies, and restructures environmental and spatial laws to make spatial projects easier to start and plan (Rijksoverheid, n.d.-b).

Another theme of legislation that can be identified is accidents and safety. Following the EU directive 98/82/EC, the Major Accident Risks Decree (BRZO) was created in 1999. Here requirements for the prevention and resolution of accidents with large amounts of hazardous materials are described for companies that work with hazardous materials (Ministerie SZW, n.d.). In 2015, the BRZO was expended with the high-pressure transmission of natural gas (VELIN, 2018).

In addition, throughout all levels of the Dutch government (national, regional, local) the integration of safety has been set out in institutions. The state has to ensure its people and nature are safe, this task has ultimately been assigned to the provinces, security regions, and municipalities (Risicokaart, n.d.; Tonnaer, 2018). The national government will make a national spatial planning which has to be incorporated into the regional spatial plans, and local zoning plans (Ministerie van I&W, n.d.-d).

[4] The official Dutch legislation website is https://wetten.overheid.nl/.

Following the Alignment Perspective framework, when an infrastructure's main tasks are divided over a small group of actors, the infrastructure is most likely closed access (Scholten & Künneke, 2016). This is in line with technical (physically) closed access that was identified on the technical side of the framework in the previous chapter. The safety regulations for the environment and the pipelines (BRZO) and the technological complexity of the system also indicate that due to the natural gas system's highly dangerous nature, the involvement of many responsible parties could not be beneficial for the integrity of the system. This is an example of the Normal Accidents Theory which indicates that a system's complexity can cause some inevitable accidents within systems.

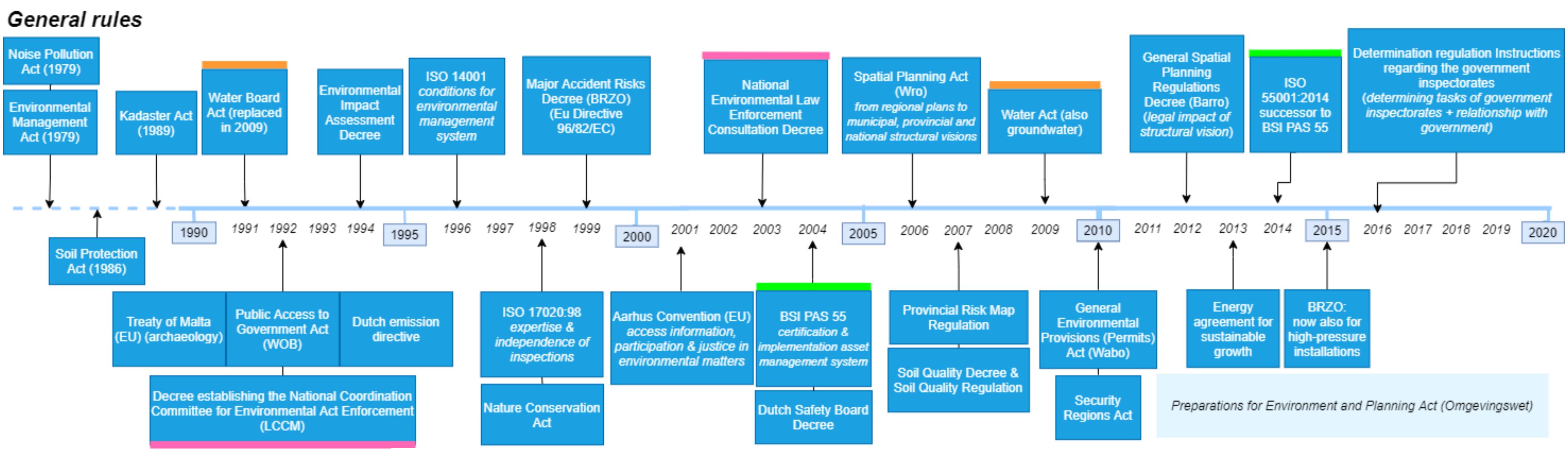

Figure 5.1: The institutional developments on Layer 1 of the Alignment Perspective framework.

5.1.2 Layer 2: Specific rules & enforcement

The system-specific institutions belong to Layer 2 of the Alignment Perspective framework (Figure 5.2). These can be elaborations of institutions from layer 1, standards from the natural gas transport sector itself, or additional institutions for the system. The institutions from layer 1 serve as a given in layer 2.

The distinction between open and closed access in the network will be more apparent on this second layer due to the sector-specific institutions. For a more open-access infrastructure, Künneke (2013) identified the existence of more industry standards, protocols, and procedures. Whereas for a closed-access infrastructure, the daily routines, and technical standards are more found in legal institutions.

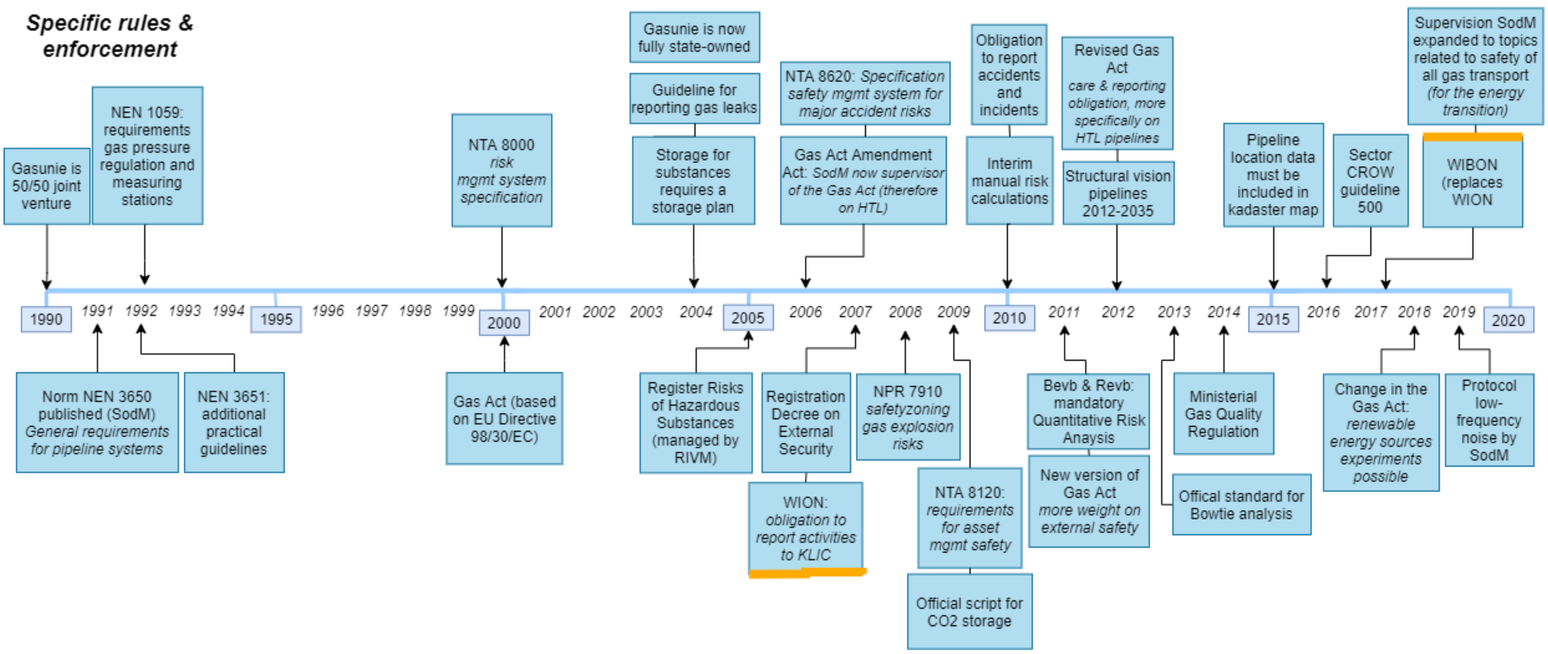

Figure 5.2: The institutional developments on Layer 2 of the Alignment Perspective.

In the Layer 2 analysis it became apparent that when technical standards and daily practices are specified in standards, procedures, and protocols, it is likely that the technical system is an open-access design. However, in Chapter 4 the technical access to the system was identified as closed-access due to its rigid physical design and access is only provided by law and the technical gas codes of the ACM. The ACM draws up the gas codes that regulate coordination and technical requirements within the network (ACM, n.d.). These are based upon the NEN standards just described. The task of the ACM is legally established in the Gas Act, were the ACM was first included as its predecessor the NMa (Netherlands Competition Authority, Dutch: Nederlandse Mededingingsautoriteit) (Gaswet, 2000). This way the standards are legally binding and therefore the institutional character of the natural gas transmission is still identified as closed access.

The specific rules within the natural gas system are mostly defined by industry standards and system-specific national laws. The creation of official standards comes from the industry and natural gas sector itself (Mr. R. Hermkens, personal communication, May 10, 2023), as a form of self-regulation. They aim for unity in safety and technical definitions for the infrastructure to communicate with and learn better from each other. This can be with RTL network managers, but also between HTL network operators from different countries (Mr. J. Aardema, personal communication, May 9, 2023).

In the early 90s, some general industry standards were created for requirements of pipeline systems (NEN 3650) and gas pressure regulation and stations (NEN 1059). Here the design, construction, operation, and termination of pipeline systems and installations are specified (NEN, 2019, 2020). Every few years they are reviewed on their content (NEN, n.d.).

In the years following, the risk analysis and safety management systems were also standardized within the gas transport industry and the standards collection grew to a more inclusive package. However, the requirements for safety zones around natural gas infrastructures and asset safety were standardized in 2008 and 2009, respectively. This is quit late in comparison to the NEN 3650 and the Bowtie method in 1992 concerning the network's safety as well.

One of the most important Acts specific to the natural gas sector and the transmission of gas is the Gas Act. Throughout the years this Act has evolved into a more justified and complete version. Originally the

Gas Act came into effect in 2000 and was based on the EU directive 98/30/EC which concerns common rules for internal (national) markets in natural gas for the European Union (European Parliament & European Council, 1998). The Act split the organization of natural gas transmission from the production and economic market activities around the natural gas supply. There was the desire to give the gas market itself more power in providing the security, affordability, and efficiency of natural gas supply (Riemersma, Correljé, et al., 2020). The Act includes regulations about the supervision of energy suppliers, network access, and the split between energy provision and economic market activities (i.e., price settings). The ACM is the technical and coordination supervisor of the Act (Gaswet, 2000). In 2006 the SodM became the safety supervisor for the HTL network based on a revised Gas Act. Hereby safety became more included in the operational routines and processes described. Before this, the supervision of the network's safety was done by Gasunie internally.

A third change in the newer version of the Gas Act is the incorporation of alternative energy injectors like biogas and green gas producers. But also, how decentral energy transition projects can be coordinated to ensure their value within the energy transition when phasing out the use of natural gas. Before 2018, renewable energy experiments were not legally supported. The SodM's task portfolio has been expanded accordingly with the task to ensure safety in all projects related to the natural gas network and its future with for example hydrogen as a replacement for natural gas (SodM, 2018).

Besides the Gas Act, the Bevb came into effect in 2011. The Bevb (*Degree on External Safety of Pipelines, Dutch: Besluit externe veiligheid Buisleidingen*) regulates the tasks and responsibilities of the network managers, operators, and municipalities to manage and mitigate external safety hazards of pipelines (VELIN, n.d., 2018). It also states the obligation for municipalities to integrate pipelines in zoning plans together with their safety barriers appropriate for the specific environment they are in. More rural areas have other safety requirements than urbanized areas with hospitals and schools close by. This is associated with individual and group risk contours (barriers) (Kenniscentrum InfoMil, n.d.). With the introduction of the Bevb a new supervisor was introduced. The ILT is responsible for inspecting the compliance of these institutions by network operators including Gasunie.

Lastly from the analysis of Layer 2 presented in Figure 5.2, there has been an increase in the number of safety guidelines and obligations to report gas leaks and incidents. Legally this is binding with the WIBON (*Information Exchange Act on Aboveground and Underground Networks*) which was first split into a law for underground (WION) and one for above ground (Beukers, 2018). Reporting excavation work in advance is required with a KLIC report to the public register of real estate, land (Kadaster), and therefore also pipelines. The accident and incident information is used by the SodM as input for their risk calculations (SodM, 2011).

5.1.3 Layer 3: Organization

In the third institutional layer of the Alignment Perspective framework, coordination and organization among stakeholders and actors are situated. When analyzing SodM and ILT year reports and conducting the interviews, changes in collaboration, coordination, and organizational structures were collected to form the overview in Figure 5.3. The arrows in Figure 5.3 represent continuous developments.

Organization

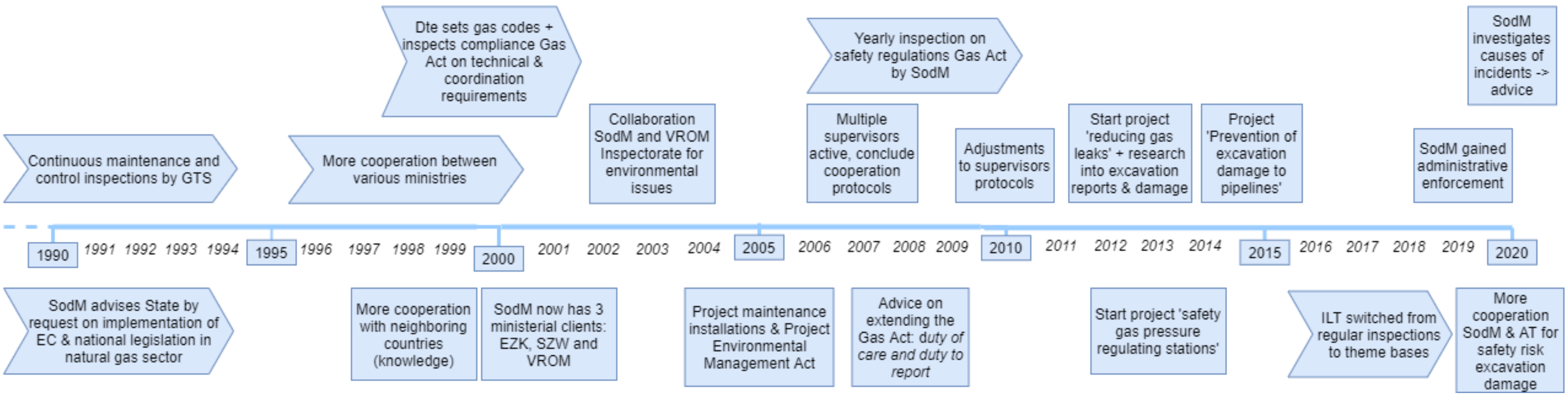

Figure 5.3: The institutional developments on Layer 3 of the Alignment Perspective.

At first, Gasunie and its subsidiary GTS were and are fully responsible for the HTL network operations, maintenance, and construction. The coordination of the network can be seen as central-orientated with little cooperation with other stakeholders to manage the network. In 1997 and 2001, this changed slightly when various ministries intensified their cooperation. Besides the technical transmission of natural gas, the economic and social sides of the network became important to the Ministry of Economic Affairs (EZK) and the Ministry of Social Affairs and Employment (SZW) respectively (SodM, 1998, 2002). This was also noticeable in the research requests the SodM would get which was first only from the Ministry of Ministry of Housing, Spatial Planning, and the Environment (VROM).

Since 2005, SodM has executed projects to build its knowledge and see how the natural gas industry was performing (SodM, 2006). The projects were designed to gain knowledge on environmental effects, maintenance work (2005), the safety of compression stations (2013), or causes and solutions for gas leaks (2012). The latter is seen to be a big problem within the natural gas industry. In Chapter 6 this will be discussed in more detail. Based on the outcomes of the project 'excavation damages to pipelines' in 2015, the sector guideline CROW 500 was created. Here the responsibilities for preventing such damage have been made explicit and are with the clients AND contractors of excavation work (De Rijksinspectie Digitale Infrastructuur, n.d.). The control therefore is enlarged to third-party excavation projects.

Simultaneously with the projects, the SodM started to collaborate more with ministries and other supervisors to establish a better understanding of which industries were influencing and affected by the natural gas transmission and distribution networks. Their collaboration with ministries was mainly to see how national laws and regulations were performing. The SodM would give them advice for alterations or additions if needed. Other supervisors like Agent Telecom were helping to better understand how cables and pipelines were located under the ground and how these two different sectors could affect each other. Positively or negatively (Deloitte, 2021; SodM, 2021).

When in 2011 ILT became the supervisor of the Bevb, their their inspections looked into all aspects of the Bevb. Later in 2016, it was decided that the inspections were going to be based on a theme, one year gas leaks were a priority, and the year after it could be about pipeline damage causes (Mr. J. Aardema, personal communication, May 9, 2023). During the interview with Mr. J. Aardema, he explained that theme-based inspections provide more specified data which would contribute to better improvement advice and knowledge-gathering projects.

Just as discussed in Layer 2, the overlap and contrasting beliefs of different supervisors do not help the network operator to address areas of concern. One of the reasons for these problems is the fact that the inspections are distributed over different ministries. Therefore in 2010, an adjustment was made to the inspection collaboration protocol (SodM, 2011).

5.2 The interaction between the different layers

Similarly to the technical side of the analysis of the natural gas system, the following aspects were looked at when evaluating the interaction between the institutional side of the framework layers: influence from other layers, consequences between layer developments, and developments supported by other layers.

Throughout the analyzes of the three layers, it has been noticed that four themes could be recognized from the institutional and regulation analysis figures, namely:

1. HTL inspection responsibilities;
2. Risk management integration in protocols and practices;
3. Incident and gas leak reporting; and
4. Environmental law.

Based on these four developments, the interactions between the layers will be discussed.

Starting with the HTL inspection responsibilities. The Gas Act has been changed multiple times throughout the years, and has increased the number of HTL supervisors. In the beginning, the NMa, the predecessor of ACM, was responsible for the technological practices and coordination between the actors involved in the system. This was besides the internal controls set up by Gasunie. Later in 2006, the SodM gained the supervisory task of looking at the safety requirements and compliance with safety regulations within this same network. This was on the advice given by the SodM itself to the ministry of VROM. Their knowledge about natural gas transport and safety in RTL networks, and the fact that the HTL and RTL are dependent on each other in terms of safety, makes the SodM the logical supervisory for the HTL (SodM, 2006).

Later, in 2011 when the Bevb was introduced, the ILT became the third big network inspector (VELIN, n.d.). Even though there was a protocol made for their coordination and task division, and the Gas Act and Bevb were explicit about the supervisors' tasks, it was found that these was uncertainty about who was inspecting what aspect of the network and its operations (SodM, 2011). The organization between the three supervisors was not coordinated as well as they thought (Layer 3), which caused a revised Gas Act in 2012 and an updated protocol in 2010 (Layer 2). The problems could have been avoided if the general ISO standard 17020 was consulted in Layer 1 which 'ensures the competence of the inspection bodies and the impartiality and consistency of their inspection activities' (Excedr, 2023).

For the integration of risk management in protocols and practices, the hierarchal characteristics of the Alignment Perspective framework are mostly prominent. The institutions in Layer 1 are supposed to be a given for Layers 2 and 3, in other words, a constraint framework or background against which more specific regulations and organizational modes are created. Throughout the analysis above of both Layers 1 and 2, it was questioned whether the institutional side of the natural gas system was characterized as open- or closed-access. While in Layer 2 many different industry standards and norms are presented, their basis is upon the broad spectrum of general environmental and risk management laws and regulations in Layer 1. This is seen for the international standard ISO 14001, here the conditions for environmental management systems are defined for organizations in general (NEN, n.d.-a). In the Netherlands, these are integrated into the industry norm NTA 8000 on the second layer which sets out the requirements for risk management systems for transmission pipeline networks (Gasunie, 2013).

Nevertheless, the development of regulations within the natural gas system can be more seen as a bottom-up process. From the interviews with Mr. R. Frinks, Mr. R. Hermkens, and Mr. J. Driessen it became apparent that Gasunie and regional distribution network managers like to keep their processes ‘old school’. What this means is, that the network operators and managers will find problems in their operational tasks (i.e., gas flow control, gas balancing, maintenance work) or during collaboration with third-parties (i.e. cable companies, private construction companies) as the safety requirements and practices are not always aligned. Within these collaboration projects, as well as during inspections by the SodM, ILT, and the ACM, certain supervisory tasks or regulations are noted to be missing. This was the case for hydrogen projects in 2017. The SodM took it upon themselves to supervise these projects on their safety procedures, while in 2018 the Gas Act was updated to allocate these tasks to the SodM legally (SodM, 2019). Now the SodM is allowed to give advice reports, warnings, and fines in case of dangerous practices in the hydrogen projects, or even other renewable and sustainable energy projects.

This was not the first time the SodM investigated the HTL on its own. When they first gained supervision of the HTL network safety, they advised the Dutch government to put more weight on the external safety of pipelines to society and its environment (SodM, 2010). Another example of a bottom-up process from Layer 3 to 2, but it helped the SodM in creating theme-based projects concerning safety and gas leak problems in the HTL network (back to layer 3). However, for external safety management the Kadaster Act (1989) was already in place, together with guidelines for reporting gas leaks from 2004 (SodM, 2005) and the WION (2007) which indicates how network operators should exchange information about their networks with excavators with the help of KLIC-reports.

In addition, general industry standards on risk analysis and major accident risks for pipelines and installations were integrated into the NEN 3650, NEN 3651, NTA 8000, and NTA 8620. These are for the whole Dutch natural gas industry, and therefore also Gasunie and construction companies who work on maintenance and construction of the HTL network (i.e., Heijmans). These were implemented between 1991 and 2009. In Layer 1, there is the Major Accident Risks Decree (BRZO) from 1999 which followed from the EU directive 96/82/EC. The BRZO contains rules preventing major accidents with pipelines of hazardous substances, including natural gas (Gasunie, 2013). In 2015, the BRZO became applicable to high-pressure stations, which are the compression stations, GOSs, measurement- & regulation stations (Chapter 3). However, the gas industry standards had already integrated major accident risks into their regulations before 2015.

The fourth and last theme that was noticed in the institutional system developments is environmental law. The theme of environmental law has been elaborated on extensively when analyzing the individual layers. Here their interactions were based on the existing environmental preservation formal laws set out by the government which apply to all industries and businesses. The importance of external safety was noticed by the SodM from their supervisory inspections and research projects, while the government regularly updated the environmental laws: Water Act (2009), Wabo (2010), and from 2011 onwards the preparations for the Environmental and Planning Act coming in 2024. Therefore the natural gas industry was influenced by top-down governmental restrictions and routine requirements (Layer 1) in order to incorporate environmental safety into their daily and project practices. But also, from the bottom-up with the SodM and later the ILT doing inspections of environmental law and safety compliance (Layer 3). This resulted in the industry standard NPR 7910 which prescribes the safety zoning for gas explosion risks, frequent revisions of existing network asset requirements, and the incorporation of renewable energy sources experiments in the Gas Act in 2018.

5.3 Processes within institutional & regulation developments

Within institutional and regulation changes, different processes are present that influence the way institutional directions and implementation strategies are formed, as well as how it is responded to. To understand the institutional developments just described even better, it is beneficial to discuss some of these processes. Firstly, the making of formal and in some cases sector-specific laws is based on the political direction of that period (Harrison, 1998). As was indicated, there has been an increase in the focus on environmental and external safety since the 2000s. The national institutions are subject to developments within European regulations where this environmental perspective started (European Commission, n.d.; OSCE, n.d.), and later continued with the Energy agreement for sustainable energy (2015) (IEA, 2020).

Secondly, the political discussion, which can be followed by the news, is also influential in the way the natural gas industry organizes its developments and strategy directions (Harrison, 1998). The industry can anticipate on institutions that are coming well before they are implemented. A result of this can be that the natural gas sector has already implemented said technology or safety-related procedures while the actual legal background is officiated later. This can give an opposite/skewed impression of which development triggered which.

Something similar also happens the other way around, the political arena has little knowledge about what is needed within the natural gas network. What are people struggling with, and how does the structure vision have to be changed in relation to new technological developments. Therefore, the institutional processes will gain knowledge from within the sector to make the right decisions regarding law and regulation adjustments (Scoones, 2016). Important to note here is the pressure of other industries and society on the government, which all want to be seen, heard, and get the political outcome they want.

Lastly, technical and procedural changes in the natural gas system cannot be implemented in one day. Therefore, most of the time there is an integration phase or an official notice in advance (Jansen Schoonhoven et al., 2008; Rijksoverheid, 2022; Vereniging van Nederlandse Gemeenten, 2020). These implementation plans can have multiple regulatory phases to make sure the whole industry (or rather the targeted group) is changing in the same structured manner. This creates more uniformity between involved parties, easier control & intervention possibilities, and opportunities to learn from each other. An example of this is the Bevb in which it is stated that Location-Specific risk contour bottlenecks have to be remediated within 3 years after diagnosis (Raad van State, 2010).

5.4 Conclusions from the institutional developments evaluation

In this chapter, the institutional side of the natural gas transmission system has been analyzed with the help of the Alignment Perspective framework. Each layer individually, but also the interconnection between these layers. It was seen that the institutional developments throughout the 30 years have been centered around evolving the existing environmental, safety, and incident reporting regulations. The first layer of the framework represents the institutional background upon which industry standards and norms are built into Layer 2. The development of institutions within the system mainly comes from Gasunie and the SodM. They either experience a problem in their safety operations and collaborations, or they find a gap in the institutional framework which is causing a lack of supervision on a certain theme within the system. This indicates a reactionary way of regulation.

The modes of organization in Layer 3 were evaluated for Gasunie and the three big supervisors of the system: ACM, SodM, and ILT. It was found that their scope and time to intervene was appropriate for their task allocation within the Gas Act or in the Bevb for the ILT. Only the ability of ILT to send warnings and fines is not coherent with the modes of organization defined by Künneke, Groenewegen, and Ménard (2010).

6

The system's alignment and effects on integrity

The last step of this research is to evaluate the alignment between the technological and institutional developments and to what extent this has affected the integrity of the natural gas system. To do this, firstly the integrity data and its sources will be shortly discussed. Hereafter, for each layer in the framework, the alignment will be evaluated including its possible effects on the integrity. Here also the interaction between these layers and their degree of alignment is discussed. Thirdly, a practical case study is done where the Alignment Perspective is applied to a new-built housing project in Zaanstad. Lastly, the results of the Alignment Perspective framework on the natural gas system will be discussed on their meaning, relevance, and limitations, as well as the consequences for the future of the system.

6.1 Integrity evaluation method, data sources, and data presentation

As seen in Chapter 3 and Chapter 5, several different organizations and companies have been responsible for the supervision and control of the system. And therefore the integrity measures, procedures, and risk analysis within the system. When doing desk research, it became apparent that finding data from one source about the integrity of the system for all 30 years was impossible. Therefore, based on the stakeholder analysis from Chapter 3 and the supervision responsibilities scheme from Chapter 5, the following resources were used for the integrity data:

SodM year reports

The SodM was the only organization that had available documents about how integrity is viewed in general in the natural gas sector for the time horizon of this study. In addition, they reported issues and knowledge gaps about integrity and institutions in the HTL network from around 2000. *(1990 – 2021)*

ILT year reports

Their involvement in the system's integrity started with the implementation of the Bevb in 2011. The ILT is responsible for the pipeline inspection on integrity. (*Besluit Externe Veiligheid Buisleidingen, English: Decree on External Safety of Pipelines*) *(2011 – 2021)*

VELIN year reports

The perspective of the pipeline owners themselves is represented by incorporating the year reports of VELIN, the association of pipeline owners which was set up in 1978 but reports about safety and incidents since 2005. *(2005 – 2021)*

Interviews

As earlier data (before 2005) could not be verified with the data of ILT and VELIN, the interviews were structured in a way where knowledge & experiences from this earlier time were still verified and elaborated on. Also, the interviews helped to recognize different perspectives & experience stories besides the mostly technical and numerical data from the year reports. *Over 35 years of experience*

With these four resources, the evaluation of the system's integrity will give a good overview of all periods within the 30 years set out for this study. In addition, for all data obtained from one of these resources, at least one other resource type was used to verify the data.

The numerical integrity data (i.e., incidents, damages, inspection numbers, etc.) was not available consistently for the time period. Therefore, integrity is 'measured' in the way of a synthesis of the dynamic evolution of problems/issues the system has faced and how the system has responded to them. These issues point out possible integrity perspective changes in the stakeholder playing field, as well as spot the changes in the surroundings of the network that might have played a role in the system's integrity.

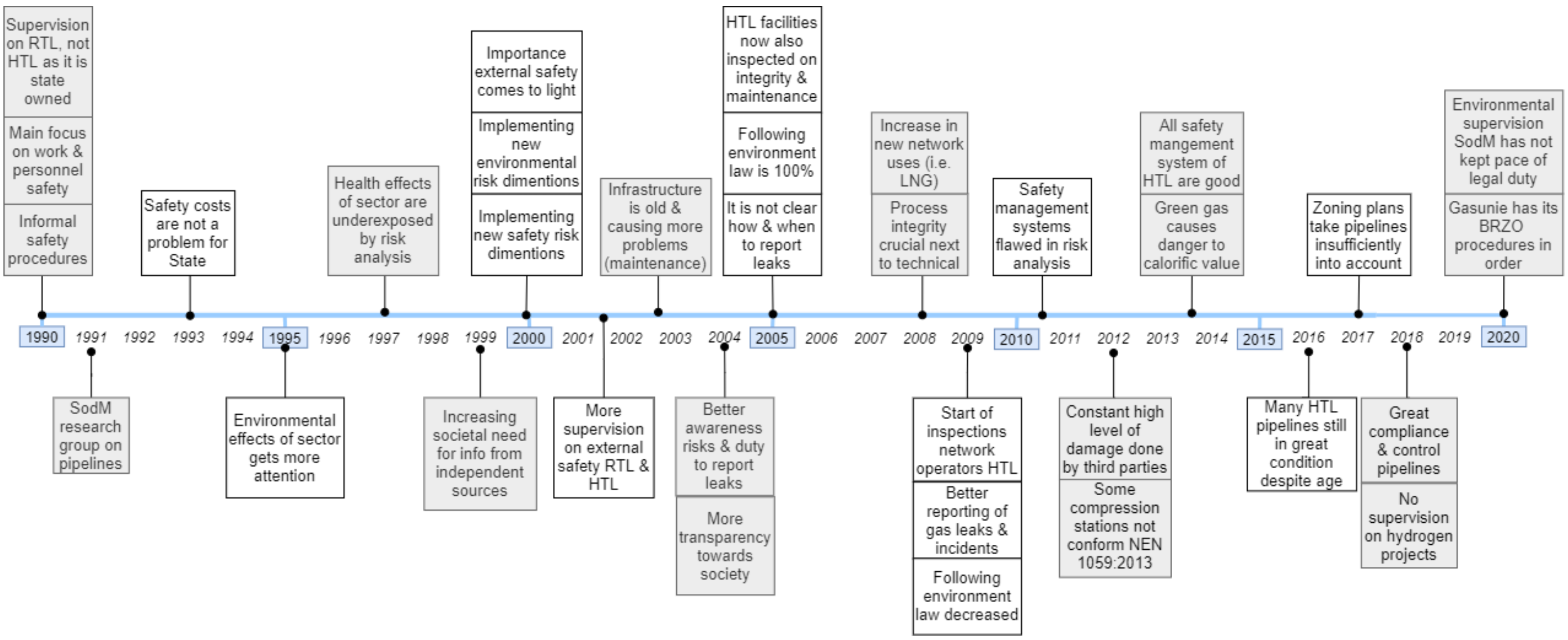

Figure 6.1: Integrity perspective and issues over the last 30 years.

In Figure 6.1 the integrity perspective changes, issues, and notable statements for the used data have been visualized. To discuss this figure generally, it can be seen that the perspective on system integrity has changed over time. In the 90s the focus was mainly on the safety of personnel and their work environment (SodM, 1992, 1993). Mr. R. Hermkens agreed with this perspective of the SodM during the interview: *"The integrity of the pipelines themselves was not a priority. The potential costs for maintenance or repair were little in comparison to the earnings for the natural gas transport."* (Mr. R. Hermkens, personal communication, May 10, 2023).

In 2000, the importance of external safety came to light for the Dutch government due to the fireworks disaster in Enschede where 23 people died in the neighborhood surrounding the explosion site (Marijnissen, 2020). Now one could argue the link between this disaster and the natural gas network. Nevertheless, the SodM took it upon themselves to look better into the procedures of external safety in the whole natural gas sector as a result of this disaster and was strongly supported by the government to do so (SodM, 2001). Even though the SodM was only responsible for the RTL network at this time. In addition, reporting gas leaks became a point of improvement to ensure the safety of the network and its surroundings (SodM, 2006; VELIN, 2009).

The last significant change in the system's integrity perspective came after 2012. VELIN had noticed that gas leaks were mainly caused by miscommunication and insufficient knowledge from third parties who were doing construction or digging work around the network (VELIN, 2013). But also, the injection of bio gas into the system was getting dangerous as the calorific value was fluctuating too much

(*Regeling Gaskwaliteit*, 2014; SodM, 2014). Later on, the SodM recognized that there was insufficient supervision over these third-party activities and the growing number of renewable energy projects near the HTL network. Therefore, the integrity perspective made another change towards integrating the activities around the energy transition as well. This was to ensure that future technical changes or use cases for the natural gas network were verified to be safe as well.

Besides the overview given in Figure 6.1, Figure 6.2 is created to visualize the incident data of the last 2 decades within the whole natural gas transportation network: RTL companies, HTL companies, and private pipeline owners. This is based on VELIN's yearly incident surveys. Even though this data is therefore not only about the HTL system, the association recognized that the trends were similar throughout all three network types.

The data was split into three categories: 1) accidents that led to major injuries and/or damages, 2) incidents that led to injuries and/or damages that take some weeks to heal from or fix, and 3) minor incidents that lead to little or no injury and/or damage at all.

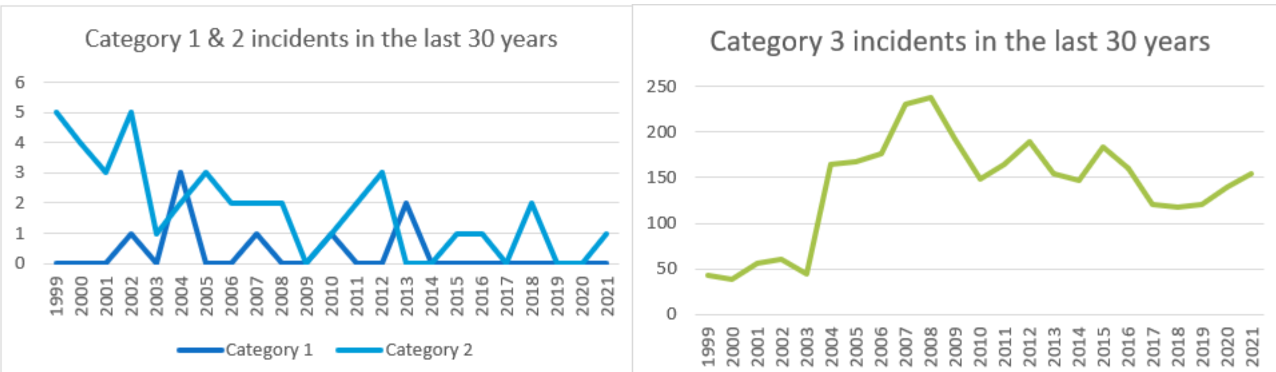

Figure 6.2: Number of incidents categorized in 3 categories from the last 30 years (based on VELIN incident records).

Within these graphs, some notable moments can be identified. Besides this might be random occurrences, these occurrences might also align with findings in the synthesis section within the alignment between the technological and institutional developments. On the right side of the table, a possible explanation is given based on Figure 6.1.

The spike in 2004 in Category 1 incidents	*An increase in awareness of reporting incidents & gas leaks*
The growing trend of category 2 incidents between 2009 and 2012	*The process of reporting incidents became more clear to parties doing the excavation work*
The flatline of category 1 incidents after 2014	*-*
The spike from 2003 to 2004 in category 3 incidents	*Many reports of difficulties with the pipeline infrastructure due to the aging of the network*
The stabilization of category 3 incidents between 2010 and 2021	*The interference of third parties (contractors, private construction companies, and cable companies) has increased*

6.2 Synthesis for the alignment between technological and institutional developments

6.2.1 Alignment Layer 1 – Embeddedness

The first layer of the Alignment Perspective framework is about the systemic and institutional environment alignment to ensure the functioning of the natural gas system on the generic design level. On the technical side, the main component is the access design of the network. On the institutional side, it focuses on whether the network is more set up as a market with open competition, or like a vertically integrated monopoly that is regulated or owned by the government. The high-level natural gas system is in alignment on Layer 1 when the technical access design and institutional competition setup are complementary: open access with market institutional set up, or closed access together with a vertically integrated monopoly.

In the technological analysis, it was found that access to the system was defined as closed access. Gasunie is the only owner of the high-pressure transmission network, and the physical design of the network is planned. This is in line with the vertically integrated monopoly of Gasunie and therefore GTS. They are responsible for the gas balance, gas flow, maintenance, construction, and controlling the network, in other words, the whole transmission operation which is the focus of this research. If a new producer of big consumer wants to connect to the network, this has to be organized via the Gas Act (Article 10, paragraph 6b) (Layer 2). The management of this contact is specified in the ACM gas codes, and specifically in the LNB Connection Code (GTS, 2021) (Layer 3). All are organized and controlled by the government for GTS, no party will gain access to the network without the permission of the Dutch government and the GTS.

Another way this vertical integration can be seen is the slower innovation process from Gasunie in comparison to private companies. Gasunie is further away from the market setup where competition is located, where being the first to implement new technologies or incremental development is crucial for a company's existence. It is known that innovation efforts in (vertically integrated) monopolies are defeated by rigidity, hierarchy, and routinization (Belloc, 2014; Teofilovic, 2002). The slower initiative to change and innovate was also discussed during the interviews with Mr. M.T. Dröge and Mr. R. Frinks. They both recognized that innovation coming from Gasunie itself was not happening a lot. Gasunie rather invests and joins private initiatives to grow their knowledge and to be at the forefront of new technologies that may be used within the high-pressure network. An example of this is the CO_2 capture, transport, and storage project Amaris between private companies Shell and TotalEnergies, and public companies Energy Management Netherlands and Gasunie (Aramis, n.d.).

For Layer 1 of the Alignment Perspective framework, the technical closed-access and the vertically integrated monopoly do align. Even though the institutional ownership specifications for the natural gas transmission system are specified in sector-specific laws on Layer 2 as seen in Chapter 5.

Despite the alignment between the technological and institutional set up of the system on Layer 1, there were two integrity issues found related to this layer. In Layer 1 of the institutions, many formal institutions were created, revised, and updated for the preservation and protection of the physical environment. However, in 1997 and 2000, the health impacts of hazardous materials and the importance of external safety were underexposed. As a reaction, the natural gas industry implemented new environmental risk dimensions to their risk analysis (SodM, 2001), incorporating more risk events and possible scenarios.

Even though in 2005 it was reported that there was 100% environmental law compliance in the HTL, in 2009 this was already decreasing (SodM, 2006, 2010). It appears that the compliance practices were not updated to the national legal background while these were updated and revised regularly to ensure most environmental risks were covered and regulated. Later in 2020, SodM even recognized that their environmental law supervision was not on par with their legal duties (SodM, 2021). This can be an indication that due to negligence in environmental law supervision, the compliance started to be subordinated by other obligations and security risks that needed to be monitored. For example, when the Bevb was added to the list of safety regulations in 2011. Or that due to this supervision negligence, newer versions of environmental institutions did not get implemented into the routines of HTL stakeholders the way they should have been implemented (Mr. R. Frinks, personal communication, June 26, 2023).

Secondly, the Kadaster Act (of 1989) as discussed before states that network operators and managers have to locate their pipelines very neatly and report this to the Kadaster (land register) (Kadaster, n.d.). However, in 2015 the SodM stated that the registration and maintenance of these locations was not up to par. During the interview with Mr. R. Frinks, he stated that due to time constraints and the negligence of regional network operators during excavation projects, these locations are not requested (on time) at Gasunie. This leads to the use of old location data within current excavation project plans.

6.2.2 Alignment Layer 2 – Governance

In the second Alignment Perspective layer the more specific technical and regulatory arrangements are situated. This could be arrangements that focus on control mechanisms in the technical part of the network, but it could also be about task division contracts. This second layer is aligned when the scope of control & responsibility of an actor in reality, is coherent with its officially assigned role in the natural gas system. This is different from the modes of organization discussed in Subsection 5.1.3. Examples of misalignment could be if GTS would be intervening in the routines of regional distribution network managers, or if the Ministry department would micromanage compression station personnel on a daily basis.

During the 90s, all responsibilities were with the Gasunie when it came to the transmission of natural gas on a national level (Riemersma, Correljé, et al., 2020). Including the integrity topics of asset management, network conditions, and risk management systems. Up till 1998, there was only supervision by Gasunie itself on its daily practices and protocols. The technical knowledge and the control of activities were with the same party.

The institutional and technological developments were minimal during this period. Some general requirements for gas pressure and measuring stations (NEN 1059) and for pipeline systems (NEN 3650 & NEN 3651) were established from within the total natural gas transport sector itself. Technically, the M.E.R. became a standard national practice for pipeline network-altering projects that involve construction into the ground on a bigger scale (Raad van State, 1994). This is an Environmental impact report that analyzes which environmental consequences a project will have and how these effects will be mitigated to maintain the natural state of the environment as much as possible (Ortolano & Shepherd, 1995). As the M.E.R. is a requirement in the preliminary stage of a construction project by law (Besluit Milieueffectrapportage, 1994), and the national government has the final decision on the project, the analysis is still focused on the national scale (and is in line with the government being the owner of the network).

From the integrity perspective in the system, the state supervision and minimal developments resulted in safety procedures that were generally informal and with the main focus on personnel & work environmental safety (Mr. R. Hermkens, personal communication, May 10, 2023). The costs for maintenance and repair work did not outweigh the earnings from the natural gas transmission which did not give an incentive to improve the integrity performance of the system.

With the introduction of the Gas Act, the control responsibilities changed. First, in 2000, the Dte (later ACM) gained the supervisory task to look at the compliance of the Gas Act with in particular the technological requirements of the natural gas transmission network, and the coordination between the actors involved (A. F. Correljé, 2005). Their expertise in the energy market and collaborative relations, fits with the change the Act initiated. The Gas Act states that trading and transmission of natural gas had to be separated and therefore these companies are not able to have collaborative relations to work around competition for advantages. This left the safety and environmental responsibilities still in the hands of Gasunie as the owner of the network.

When the Gas Act was updated in 2006, the SodM gained the supervision tasks to look at the compliance of the Gas Act safety and risk regulations within the HTL network (SodM, 2008; Tweede Kamer der Staten-Generaal, 2018). The responsibility matches with the ability of the SodM to fulfill this task as it was already the safety supervisor of the RTL networks. Now Gasunie is still performing internal safety & performance audits besides the external ACM and SodM inspections (Mr. J. Aardema, personal communication, May 9, 2023).

During these control responsibility changes, the integrity perspective and insights have also changed. When the SodM gained its new supervisory tasks, it soon became clear that gas leaks and the reporting of these gas leaks were big integrity issues within the HTL network. The problem with gas leaks and the reporting process emerged in 2002 when SodM did a project on the aging of the HTL network. It was found that the network was getting older and was going to need more maintenance work than expected (SodM, 2003, 2004). One of the side effects was gas leaks, for which in 2004 a guideline was created to ensure the reporting process could be as effective as possible. In the VELIN incident reports data a spike can also be seen in this year which makes it highly possible that this spike in reports and the guidelines are related. Even though this seemed to help for some time, in 2005 when SodM voluntarily was analyzing the reporting process of gas leaks in the HTL, it was found that the reporting process was perceived as difficult (SodM, 2006; VELIN, 2009).

Before 2007, there was the (non-binding) self-regulation from the Cables and Pipelines Information Center (KLIC) to report incidents and gas leaks (Boog et al., 2007). This changed with the introduction of the WION (Information Exchange Underground Networks Act) which made this an obligation by law (SodM, 2008; VELIN, 2009, 2018). The effects were seen by the SodM in 2009, in the better reporting of leaks and incidents as well as the uniformity in the definition of risks, gas leaks, and incidents between Gasunie, RTL network managers, and private contractors. VELIN incident data shows this with a stabilization in the number of smaller incidents reported. During this period the number of injectors and producers of biogas, green gas, and LNG increased, this technical development seems to not have effects the gas leak integrity negatively.

Following on the topic of the WION, KLIC reports are now obligated before excavation work nearby cables and pipelines. Mr. R. Frinks argued during the interview that this KLIC report is a bottleneck in the preliminary procedures (June 26, 2023). Heijmans N.V. is the construction company that works for Gasunie to maintain, control, and construct the HTL network. Many times they experience problems with requesting specific locations from the RTL network managers or cable companies to effectively submit a KLIC-report. Some of the reasons for this he mentioned were time constraints, not up-to-date data on the locations, or miscommunication about safety risk consequences.

However, the integrity issue of not sufficiently being able to submit a KLIC report seems unnecessary when looking at the institutional structure in Layer 1. To prevent gas leaks or damages to the network, the Kadaster Act (1989), the WION, and regional zoning plans are made to ensure the location information is available and the coordination of sharing is designed. Also, VELIN has provided information on this several times and reported in their annual overviews that this is an important mandatory step to complete in time and correctly (VELIN, 2014). The SodM repeated this once more in 2015 as a response to the ongoing problems.

The last topic to discuss in the analysis of Layer 2 on the system's integrity is the influence of risk analysis and safety management systems within the natural gas system. This topic started in Layer 1 from the academic literature (Ale, 1991), Shell's Bowtie method, and complex ICT calculation systems. The SodM further developed the Bowtie method specified for the natural gas transport (transmission and distribution) sector. But it took a long time for the sector to actually use it themselves. Firstly, the risk contours and calculations were adapted unofficially in 2006, whereas in 2008 & 2009 safety zoning risks and requirements for asset safety were included in national standards (NPR 7910 and NTA 8120). This technology-to-institutional development has influenced the perspective of risks and integrity from looking at the work environment and later also environmental effects within the perspective, and now also processes and assets were included to ensure the integrity of the network.

Despite the broader integrity perspective change, in 2010 the safety management systems were not flawless in there risk analysis and inclusion of these processes and asset safety aspects (ILT, 2012; SodM, 2011). As a result, the Bevb was introduced, together with the inspections of the ILT (Mr. J. Aardema, personal communication, May 9, 2023). This is in line with their inspection role for the Ministry of Infrastructure and Water management, as they are also the supervisor of the Soil Quality Decree. The Bevb presents more specific and additional requirements to the external risks pipelines than what the Gas Act and industry norms do. The introduction of the Bevb seemed to have worked, as the safety management systems all pasted the inspection from ILT and the SodM (ILT, 2014; SodM, 2014).

6.2.3 Alignment Layer 3 – Transactions

The third alignment layer represents the interactions and coordination between different actors in the high-pressure natural gas system. Ideally, there is a coherence between the technical coordination between stakeholders and actors in the network, and which institutional structure that was chosen to structure this coordination and regulation. Signs of misalignment could be miscommunication, delays in technical implementations or even normal standard procedures, or intervention strategies when a problem occurs (R. Künneke et al., 2010; Scholten & Künneke, 2016).

Technical coordination could be categorized as central management, decentralized management, and of course every form in between. Whereas the institutional structures focus more on contractual business relationships, i.e., the use of third-party contractors, vertical monopolies, etc.

Within the technical developments of the third Alignment Perspective layer, the developments are centered around system activities like investments, asset management decisions, and disturbance response. During the first 10 years, ICT is a big technical aspect under development within the system (SodM, 1993, 1998). As the transmission network is under fully owned Gasunie, decision-making had mainly to do with building better information structures and incorporating integrity data into the calculation and administrative systems (Mr. R. Hermens, personal communication, May 10, 2023). Economic or market decisions were not necessary due to the lack of competition. Technical coordination can be categorized as central management by the state. This is seen in the supervision of the system. The SodM and the ILT are inspections from respectively the ministries of EZK and I&W (ILT, n.d.; SodM, 2016). The ACM is indirectly connected to the ministry of EZK as the board is appointed by EZK, and they are legally bound in Layer 2, i.e., the Gas Act and Ministerial Regulation of Gas Quality (ACM, n.d.-b).

The last 15 years have mostly been characterized by the energy transition and the investments in the Bowtie method. Collaboration and operations centered around informing new players like for gas storage and the electrification of gas about the standard practices in the natural gas system as well as designing business models to in the future implement the technologies on a national scale. The new players in the field of energy are closely watched by the SodM and Gasunie itself. This is to ensure the integrity of the current natural gas system is not affected by a new project or experiment nearby that might not be aware of certain safety protocols and standards like the safety barrier or with the right implementation design to role out the technique nationally. They also educate these parties about the safety risks and aspects of a national network that is surrounded by nature, people, and buildings in all different types of compositions (Mr. R. Frinks, personal communication, June 26, 2023). These projects are regional, and their informal supervision by SodM and Gasunie is central.

As the modes of organization of Gasunie and the three biggest supervisors already have been discussed in Chapter 5 in relation to their technical operation or scope, here two integrity issues will be discussed in light of these organization modes and the central/decentral coordination.

Firstly, since 1995 Gasunie started to outsource more and more daily activities via contracts with private companies. The SodM and VELIN later in 2005 recognized that most of the gas leaks and incidents were caused by these private companies or others who do not have anything to do with the transmission of natural gas at all (SodM, 2006; VELIN, 2009). In 2012 these damages were even more frequently happening, and the problem maintained (VELIN, 2013, 2021; Mr. J. Driessen, personal communication, June 30, 2023). VELIN identified that miscommunication in risk definitions and safety strategies could also be a cause of these issues (VELIN, 2014). Around the same time, more projects with gas storage and electrifying gas started, which are connected to the HTL. SodM identified this as one other cause of this integrity problem. Therefore they advised a revision of the Gas Act (2012), and the excavation industry created the CROW 500 (2015) guideline aiming to prevent excavation damage with clear protocols and guidelines. However, the numbers on damages and incidents have not come down. The SodM legally does not supervise the contracted private companies and excavation workers, but is looking into how to ensure this group is up to date with their knowledge on how to work nearby the HTL network (SodM, 2020).

Secondly, this was already lightly touched upon, but throughout the researched period the supervisory tasks have not always been specified clearly enough. The SodM reported that due to the increasing number of supervisors (they also were looking here at the supervisors of the RTL network), the tasks were sometimes overlapping (SodM, 2008). Therefore they created a cooperation protocol besides the legal registration of their tasks. This is the case for the responsibilities of the SodM (Gas Act). the ILT (Bevb), and ACM (Gas Act, Ministerial Gas Quality Regulation). In 2010, an adjustment had to be made to this protocol as the Gas Act was going to be extended on the advice of the SodM for the duty of reporting and care.

When speaking with Mr. M.T. Dröge of GTS it became clear that despite this protocol the supervision on GTS is still extensive. Different reports with sometimes only slight changes have to be made for different supervisors. This can be about the same issue found in a previous inspection, technical aspects of the network, or physical network section (Mr. M.T. Dröge, personal communication, May 15, 2023). This problem plays on both Layers 2 and 3, with a misalignment between the official supervisory tasks specified in the Gas Act and the Bevb and the actual supervision scope the inspections take on within their inspections. The created cooperation protocol located on Layer 3 is a tool to combat this but has proven to not be as effective as hoped.

6.2.4 The effects of layers' interactions on the integrity of the system

While discussing the alignment between the technological and institutional design in previous subsections, some links between the layers have been made occasionally to explain a development or effect on the system's integrity a bit better. Here, the effects of the layers' interactions will be discussed in more of a general sense and will be based on the interactions seen in Chapters 4 and 5. In Figure 6.3 an overview is created with the development trends on each of the layers. Two of the interaction effects will be discussed.

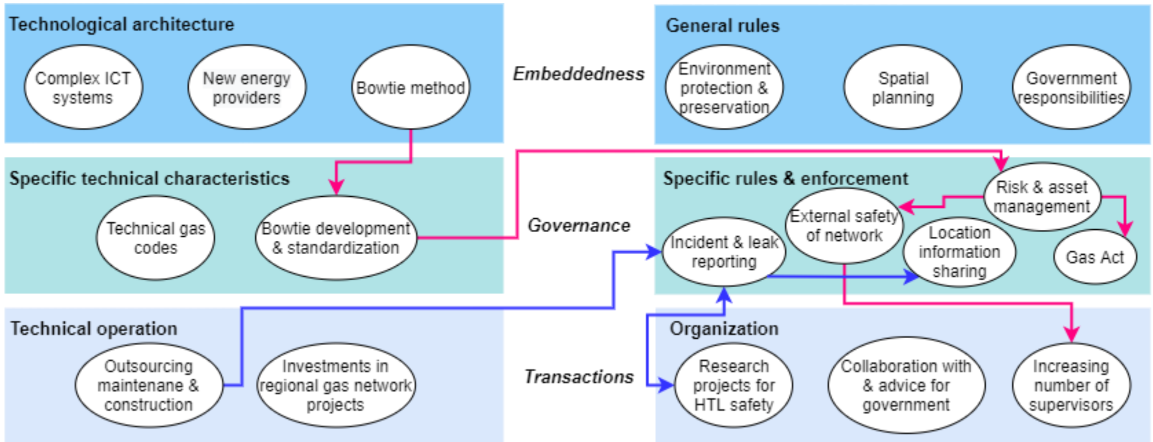

Figure 6.3: Development trends presented in the Alignment Perspective framework.

The first interaction effect that will be discussed is about the Bowtie method which is presented by the pink arrows in Figure 6.3. It was first adopted by Shell Group (1992) into its standard risk analysis toolbox (Wolters Kluwer, n.d.-b), which was presented on the technical side of Layer 1. After a decade, the SodM created its own version which was applied to natural gas pipeline infrastructure (SodM, 2004). Here the technology moved to the second layer of the framework as it became a system-specific routine. Because of this, the SodM started to think more about which risk dimensions or aspects needed to be analyzed and managed to ensure pipeline integrity, mainly environment and external risks.

In addition, the findings of new risk aspects were also picked up by the industry which included them in norms like the NPR 7910 and NTA 8120. Eventually, the Bowtie method gained more traction in the industry itself after SodM started to use it as its standard tool in 2011 (SodM, 2012). The method went from being on the first technical layer to being on the second, but in the meantime also influenced the industry's perspective on integrity (more in-depth and including surroundings) and influenced the safety regulations imposed on the system as well. In 2013 it was seen that the safety management systems had improved due to the Bowtie method and to the SodM and ILT supervision.

A second effect of layer interactions is found in the problems with gas leaks and reporting these gas leaks, and is represented with blue arrows. It started with Gasunie outsourcing more activities regarding construction and maintenance work. The network is a closed-access network where Gasunie has the most knowledge about the technical and operational aspects to ensure the integrity of the network and the supply of natural gas. When outsourcing such asset-vulnerable activities, the knowledge was recognized as not sufficient in the private companies contracted to do such tasks. The ownership and end-responsibility were still with Gasunie, but the technical knowledge entering the network was not sufficient. The integrity results being an ongoing problem with gas leaks due to miscommunication and third-party access to the network, and an insufficient understanding of the risks and protocols to report these gas leaks. This was first recognized by the SodM through their research projects and later confirmed by VELIN's yearly incident surveys. Sharing correct information about pipeline locations is one of the most crucial elements to perfect in order to lower the incident and gas leaks (Mr. R. Frinks, personal communication, June 26, 2023).

Here the importance of the external environment of the natural gas network is emphasized again. Even though the SodM is indeed the safety supervisor of the Gas Act, and the ILT of the Bevb, their supervisory scopes do not reach these third-party companies, only Gasunie and GTS.

During the analysis of the technical developments, the institutional developments, and the synthesis of the alignment between the two sides of the framework, it was noticed that due to inspections and

Gasunie's own evaluations, new integrity perspective changes were made. The SodM and the state (ministry of EZK or I&W) mostly noticed these findings like environmental risk inclusion or gas leak procedures. The integrity issues therefore mostly were found on the second and third layers of the Alignment Perspective. The SodM would advice the state and the industry to make changes to their regulations and standards based on their theme projects around network safety. This is seen in the many revisions of the Gas Act that were stimulated by the advice of the SodM. The inclusion of the external safety of pipelines themselves even led to a new inspector (ILT) of the system.

The issues of environmental law compliance and gas leaks were already felt in the processes and operations of the natural gas system but were passively taken into consideration. The issue and its cause were found in the SodM research projects, VELIN incident surveys, or from conclusions drawn after a year of GTS inspections. The improvements and compliance with new or updated regulations were then later seen in the system inspections or integrity data, either directly or with an improving trend.

Before going into the discussion of this synthesis, and the relations between technical/institutional developments and the system's integrity, a small practical case study will be presented. Here it will be seen whether the relations and alignment issues found above are also present on a much smaller scale of a system. Also, the utility of the Alignment Perspective will be evaluated from a more practice side.

6.3 Case study: New-build project in Zaanstad

6.3.1 Context and location

In the municipality of Zaanstad, from 1860 to 1952 there was a gas factory located on the terrain between de Westzijde and the Zaan (see white lined area in Figure 6.5) (Gemeente Zaanstad, 2018). On this terrain, a gas receiving station (GOS) is located which is connected to a high-pressure natural gas pipeline. In Figure 6.4, the high-pressure pipeline and the GOS are highlighted in blue within the Westzijde terrain. The rest of the area was cleaned up in the 90s and only a bit of greenery was left.

In 2015, the municipality sold the old gas factory location to a project developer called Verwelius (De Orkaan, 2015; Hekking & Vonk, 2018). The buyer's plans for this area were not made clear at this point in time, but a couple of years later they finalized their development plans: 124 homes divided over two large apartment buildings with underground garages and a field of grass for kids to play (Gemeente Zaanstad, 2018; Rodi.nl, 2017; Zaanij, 2017).

Figure 6.4: The location of the high-pressure pipeline & GOS (modified from (Hekking & Vonk, 2018)).

Figure 6.5: Location of project site (Source: Gemeente Zaanstad, 2018).

The start of the project was in 2017 when Verwellius and the municipality signed an anterior agreement. This meant that the project was allowed to start and the municipality would handle the applications for permits and the procedure to change the zoning plans for the region (Rodi.nl, 2017; Zaanstad, 2017). These zoning plans were still based on the functionality of the terrain being for industry instead of housing. The municipality changed the zoning plans in a year (Rodi.nl, 2017) and the sale of the apartments already started in May of 2018 (Zaanstad, 2019a). However, the plans for the project were still subject to inspection and objections. In September of the same year, one objection was filed by Gasunie Transport Services concerning the construction near the high-pressure pipeline and the GOS in the middle of the project plans (De Orkaan, 2018; Zaanstad, 2018). GTS argued that in the first project plans the integration of the natural gas infrastructure was not mentioned, and in the detailed official second version, the integration of the infrastructure was not done sufficiently. In their objection, they mention three main problems that they had with the project (Zaanstad, 2018):

1. The apartment buildings were less than 15 meters away from the GOS, as the GOS was incorrectly implemented into the zoning & project plans;
2. The noise pollution from the GOS was not taken into consideration when measuring the noise levels in the area while the municipality already allowed for a higher noise level than set by the Noise Pollution Act (1979);
3. The pipeline operator is not consulted in case of construction or excavation work near the pipelines. Through an environmental permit, these activities can be done without the operator's consent.

After the objection by GTS, the municipality made adjustments according to their recommendations and comments. However, GTS did not agree with these changes and therefore decided to go to the Council of State and take it to court. Unfortunately, the letter by the Council of State was not made public by Zaanstad and therefore it is not possible to gain information about which objections the municipality did not honor (De Orkaan, 2019; Zaanstad, 2019b).

In 2020, all problems seemed to be resolved as construction work had begun on the terrain and the zoning plans of the municipality have been labeled as final since (De Orkaan, 2020; Planviewer, 2019). In a Council proposal and decision note from the end of the year 2019, it seems that the objections made by Gasunie were acknowledged by the municipality as it was clearly stated that have been an objection to the previous plans: "*The opinion has been submitted by Gasunie*", and "*This reaction has led to a minor adjustment to the zoning plan to prevent Gasunie from being restricted in the operation of the gas receiving station by the new construction*." (Gemeente Zaanstad, 2019). Specifically, additional research was done in collaboration with and guidance of Gasunie for the noise pollution levels near the area.

6.3.2 Alignment Perspective framework application

In the same way as before, the Alignment Perspective framework will be used to analyze the Zaanstad case to see whether a misalignment is a possible cause of the problem in communication just described. First, the three layers will be discussed separately whereafter the interactions. To help this analysis, in Figure 6.6 the framework was filled in with the technical and institutional context of the case.

From the context above, the Zaanstad case is located mainly in the third layer of the Alignment Perspective framework. The coordination between the different parties involved did not go as planned which is seen through multiple signs of misalignment from Künneke and Scholten (2013): miscommunication and delays in technical implementation or standard procedures. The coherence between the technical coordination requirements and institutional structure for the coordination & regulation of the system might not be aligned. Since the case can be situated in Layer 3, the analysis will be started from here.

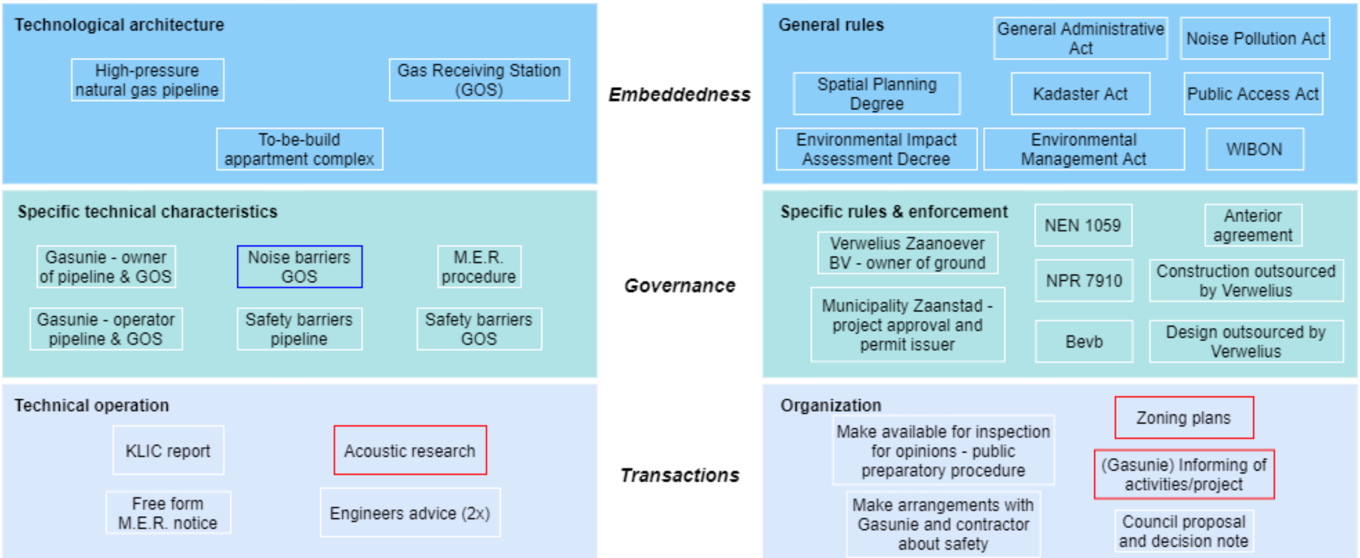

Figure 6.6: The Zaanstad case presented in the Alignment Perspective framework.

The institutional coordination in Layer 3 of the framework focuses mainly on the project planning and the coordination between the different parties involved: the municipality of Zaanstad, Gasunie representing GTS, and the project developer Verwelius. The municipality has the responsibility to consider involved and affected stakeholders, coordinate decisions, and provide permit agreements. Due to the municipality's public duty, the project has to be open to objections from society and interested companies who might request changes in the project plans. This public preparatory procedure is different from informing affected parties about the project in advance, as Gasunie would have wanted from either the municipality or Verwelius. Therefore this box is colored red on the bottom right of Figure 6.6. Gasunie's technical expertise on pipeline and GOS safety barriers could have been helpful when the municipality was changing these from the old industry terrain.

The zoning plans were not sufficiently updated to prepare for the new function of the terrain. The '*industry*' label was changed to '*housing*', but the space where the GOS is located stayed categorized as '*industry*', while this does not cover the activity that is performed (Zaanstreek -Waterland, 2019). In addition, the project developer performed acoustic research to determine the noise levels around the new apartments from close-by industry facilities. However, they did not include the GOS that is actually on the terrain itself while these have a noise barrier themselves to avoid housing being to close to the installation that they would be affected by the noise it makes (Zaanstad, 2018).

The alignment of Layer 3 is not right when looking at the three imperfections just described. While the acoustic research is part of the technical requirements for housing projects (Kenniscentrum InfoMil, n.d.), the execution was not sufficient according to Gasunie (Zaanstreek -Waterland, 2019). This is a standard task for the project developer and the municipality following the Noise Pollution Act and the quality requirements stated in the zoning plans of the municipality (Kenniscentrum InfoMil, n.d.). The performed acoustic test was not in line with the zoning plans. Not when the zoning plans were not changed, nor when they were changed the first time around. Because Gasunie was not previously involved in the project, they were unable to protect the municipalities and the project developer from making this mistake. This is one of the reasons why in Gasunie's objection they request to be involved earlier in projects.

The governance in Layer 2 seems to be well organized. Technically, the noise and safety barriers for the infrastructure are in place and coordinated by their owner Gasunie with the objection to the project. Institutional, these barriers are integrated into the industry norms and laws (NEN 1059, NPR 7910, Bevb).

But not rightfully integrated into the zoning plans in Layer 3. The technical coordination and the institutional organization are divided over on one side Gasunie and on the other the municipality and Verwelius Zaanoever. Their scope of control within the system is in coherence with their responsibilities by the Gas Act and the General Administrative Law (Algemene Wet Bestuursrecht, 1992). Gasunie is not allowed to make any national laws, while the municipality cannot intervene in the network operation.

Even though the municipality is responsible for valuing all involved and affected parties in the project, with Gasunie objecting to the plans for the project, their values and requirements were not taken into account sufficiently. Therefore, the municipality did not execute the project decision-making routines well enough to avoid this objection. The results of this can also be seen in the news articles regarding the project. There were multiple signs of delay (Rodi.nl, 2017; Zaanstad, 2019a), and the project had already been put up for sale without being made available for inspection (De Orkaan, 2019). Essentially, there seems to be a need for a formal arrangement between municipalities and national utility companies to guide their collaboration on the regional level better. More including the expertise of the utility company in projects when their assets or network is subject to regional project developments.

The monitoring and control of the system in Layer 1 appears to be aligned. Where the technical background of this case is not very extensive, the main features are the GOS, the high-pressure natural gas pipeline, and the housing project. As discovered in the general analysis of the natural gas system, and because the government is the owner of Gasunie, the Noise Pollution Act and Environmental Management Act also apply to the natural gas system. And therefore these types of formal institutions are integrated in Layer 1 of this case analysis as well. The vertically integrated monopoly is a result of this ownership and legislation structure. The responsibilities of the municipality are specified in the General Administrative Act (Algemene Wet Bestuursrecht, 1992). Here it states how government bodies should prepare for and announce their decisions and decision-making process.

For the housing project, the private project manager is subject to the municipal government with its restrictions in design through the zoning plans. These zoning plans are a result of the Spatial planning Degree which indicates that the national spatial plans form the basis for municipal zoning plans (Ministerie van IenM & Ministerie van ELenI, 2012)

It is seen that the integrity problem regarding the safety barriers and involvement of Gasunie is located in Layer 3, where the management of the project was not sufficient to avoid misalignment issues like miscommunication and time delays. It seems that the involvement of Gasunie in the process earlier on could have helped to avoid the problems regarding the safety barriers, acoustic tests, and the zoning plan changes. Based on this synthesis of the Zaanstad case, the following learning points can be identified:

- Gain technical knowledge from the expert/source or check with the expert when a study has been conducted to see if nothing is forgotten or misinterpreted; In the future, this can be done via the Digital System Environment Act which will support the Environmental Act in 2024. Here, information can be found about what is allowed in the physical living environment, i.e., construction projects and permit requests (Ontwikkelaarsportaal, n.d.).
- Carefully consider an objection to a project proposal, the risk of publicly announced delays or pointing fingers is not worth the extra time to check the made plans for mistakes;
- The inclusion of national utility companies in the regional decision-making process can benefit the execution of technical research, making design plans, and changing zoning plans accordingly. This can avoid possible project objections, delays, and miscommunication;
- The application of the Alignment Perspective framework in this practical case study shows that the framework is not only useful when analyzing the operation of a big technical system, but also when focusing on a small component, asset, or region of this system. The interpretation of the framework does slightly change, i.e., institutions are more focused on a particular situation.

6.4 Discussion of results

This research aimed to gain more insight into the relationship between technical and institutional developments in the Dutch natural gas transmission system and their impacts on the system's integrity. The results can be used to find patterns and/or relationships to help future technical and policy changes for the system to be established in a safe and organized manner.

6.4.1 Interpretation of results

Despite the alignments found on the layers of the Alignment Perspective framework, certain integrity perspective changes, issues, and trends were able to be matched with developments in the technical and/or institutional side of the system. It was seen that the integration of environmental risks within risk analysis was one of the integrity perspective changes in the last 30 years. This came from environmental law revisions and the realization of the environmental effects the system has. As the environmental laws and regulations started to incorporate sustainability goals and the way technical assets can be managed in the physical environment, the compliance of these laws started to decline.

With this, the technical innovation changed from risk analysis developments to focusing on renewable energy transport projects and alternatives for natural gas. This seemed to have overshadowed environmental law compliance and safety management when it came to gas leaks. The new projects, however, also help to gain knowledge about how the future of the natural gas system can be developed when natural gas is not the preferred energy source anymore due to its negative environmental effects. In addition, the effects of these projects on nearby natural gas transmission networks are being controlled by Gasunie to ensure the current system will not be negatively affected as it was recognized these projects have different ideas around safety measures.

The governance of the network has gone through the biggest transformation with the introduction of the Gas Act, the Bevb, and technical gas codes of the ACM to ensure the technical system functions properly. These were regularly updated to ensure newly found essential integrity aspects like environmental effects, external safety, and gas leak reporting duties were included in the latest versions. Their revisions were based on integrity issues found in inspections, surveys, and incident data. This can be characterized as a reactive approach to maintaining an integer system. Here the communication between actors involved in the transmission of the gas and third-party companies performing activities near the network is found difficult and becoming more complex. It was argued that reasons like time constraints, an increase of interest parties, the use of different risk definitions, and not up-to-date network location data were influencing these collaborations and therefore the safety of the network.

The outsourcing of construction and control activities to third parties in the 90s, and the rise of regional renewable energy transport projects after 2010 both created a new set of players within the natural gas system. And both caused the same reaction, an increase in public-private partnerships which were centered around knowledge sharing. For third-party involvement, this is important to ensure these companies are aware of the risks that come with working in the natural gas system. However, this is difficult due to the difference in risk definitions, mitigation strategies, and integration of technical sector-specific knowledge that is less in private companies than in Gasunie itself.

These main findings show that the integrity perspective within the system is not a fixed understanding. Integrity problems, events, or external influences (i.e., private energy provision projects, societal perspective) cause triggers to think about what integrity entails for the transmission system. Based upon these perspective changes, the industry itself responds with revised or new industry standards that include this integrity change in its requirements, or the advice of the SodM to the Dutch government to influence the formal institutional background that affects the system's organization and regulation.

The use of the Alignment Perspective framework also showed that developments are reactive. First, there are integrity issues found like gas leak increases, compliance with environmental law, or a new technology arising from research that is not yet subject to safety and technical supervision. After this, the regulations are revised on their accuracy, scope of control, applicability on new development, or clarity in communication structures to avoid reporting and information management problems.

However, based on the reactive nature, and the 'we've always done it that way' mentality (Mr. J. Driessen, personal communication, June 30, 2023), knowledge and information collaboration is difficult to achieve. With Gasunie being a vertical monopoly there is a lack of competition which normally is an incentive for proactive and innovation behavior due to profit and market position goals (Romero-Martínez et al., 2010). On the other hand, society is not giving Gasunie this push to be more proactive. People in the Netherlands are more focused on the effects of natural gas production than the transmission, as many people in Slochteren experience major negative effects of the production in their environment (Stroebe et al., 2018).

Within the system itself, the skewed knowledge distribution does not help to be more reactive. From risk analysis and policy makers with expertise on the integrity definitions and technical requirements for the system, to the people working on site who are time-limited in their decision-making in case of an incident or unpredictable situation that is not studied for in their education (Mr. R. Frinks, personal communication, June 26, 2023).

6.4.2 Generalization of results

Within the preliminary literature study of this research, it was found that within the gathered articles no research was done that integrated technical and institutional developments when assessing the integrity of a natural gas network. This either was how technology could help in managing the integrity of the network, or which institutional consequences a technology had when it would be implemented in real life. Therefore, this research adds to the body of literature researching the safety of a natural gas system, but then in light of both its technical and institutional changes. With a span of 30 years of gathered data, a better understanding of the system's evolution is created with a focus on its integrity perspective.

Looking at the results, and especially the case study, the importance of the involvement of Gasunie in regional project decision-making came to light. This relation has also been seen in previous research. The Public space management Services (PSMS) which is a service provider for the Dutch government, argues that municipalities are not yet managing national underground networks whether this is natural gas, water, or electricity (Boonstra, 2014). However, collaboration between these national utilities and local municipalities influences the operations of these networks. PSMS states that without better collaboration, underground utility services are going to fail (Boonstra, 2014). Even though this is of course not their main task within their scope of control, their construction projects do affect these national networks. Trying to make agreements with network operators is difficult for municipalities (Boonstra, 2014; Takken, 2017). The importance of utility networks is not high on the agenda for local governments like municipalities, as they do not see the benefits directly for their local society or their portfolio already contains many complex issues that have been handed over by the national government (Hansen et al., 2020; TNO, 2022).

This suggests that local governments do not take the national utility services into account in their investment decision-making and spatial planning as much. The collaboration between Gasunie and Zaanstad was difficult and Gasunie felt it was not sufficiently involved in the decision-making process even though their expertise and interest were highly valuable in the creation of a correct project plan.

6.4.3 Limitations of this research

This research mainly looked at the integrity perspective, the attitude, and the idea of integrity within the system itself. The numerical data on integrity infringements in the high-pressure transmission system was not available for this research. Therefore, identifying trends and developments in quantitative data was not possible. To minimize this limitation, the incident data from VELIN and the case study helped to see the practical and quantitative side of integrity besides the qualitative perspective developments.

However, the case study that was chosen appeared to be more located on the institutional side of the Alignment Perspective framework with the integrity issue found within the collaboration and coordination of the housing project. The results of this research could have been enhanced with a practical case study which would be leaning more toward the technical side of the studied system. This could give a more in-depth understanding of how both institutional and technical-focused cases are analyzed with the chosen framework and how the results would relate to the general national system analysis.

Another research limitation is the chosen Alignment Perspective framework. This limitation concerns the restrictions within the framework itself. During the analysis of the SodM and ILT year reports, multiple times it was difficult to locate a development either in the technical or institutional side of the framework. An example of this is the economic perspective on the natural gas system. This is not a technical coordination aspect, nor is this an institutional structure for the maintenance of the network. However, economic incentives also influence decision-making processes and policies on which institutions can be built (Ruser & Butler, 2009). An example of this is the longer production of gas in Slochteren for the government budget, even though this is not beneficial for society and the climate.

The two-sided structure of the framework does not allow to incorporate societal or economic developments within the analyzes unless this eventually influences a technical or institutional development. The underlying reasoning of developments is therefore underexposed when using the framework strictly with technical and institutional perspectives.

6.4.4 The contribution of this research

Besides the societal and scientific contribution of this research described in the introduction, the outcomes of this research are relevant for the upcoming energy transition where natural gas will be used less, and alternative use cases for the network are becoming more realistic. The identified integrity issues and their relation to technical and/or institutional developments can be used to learn from the previous struggles and system characteristics that could cause them. It is now known that the natural gas system is reactive, struggles with the interference of third parties, and focuses a lot on renewable energy transmission projects which obscures the responsibilities of the current system. Also, it is known that integrity encapsulates more than only work environment safety and that the integrity perspective changes and is subject to external events.

If the natural gas system evolves as before, its reactive nature could cause safety issues when the natural gas system is switched out, for example for a hydrogen system. Hydrogen has different chemical characteristics as seen in Chapter 3, and therefore requires different safety measures and protocols. Mainly as it is more flammable with a larger area of damage. With the reactive nature of the system, these differences and their consequences could be encountered after the switch in a negative way of major safety incidents that could harm society and nature.

The results of this research therefore can help in making strategic and tactic plans in exploring safety differences and integrity issues that come with transitioning into another energy provision network. As well as for the development of an implementation plan, where safety measures and risk mitigation routines are identified to ensure involved actors are aware and equipped to deal with the changing network's characteristics and regulations.

7 Conclusion & recommendations

This thesis research has explored the technical and institutional developments within the Dutch natural gas system, while also linking integrity data and integrity perspective changes to these developments. With the help of the Alignment Perspective framework, the two development histories have been compared on how aligned / coordinated they were over the last 30 years in terms of scope, responsibilities, formal rules, and organizational structures. In the following Section 7.1, the research sub-questions will be answered, whereas in 7.2 the main research question of this thesis will be answered. Subsection 7.3 will provide recommendations for the natural gas system and its stakeholders, as well as a research agenda based on the findings of this research.

7.1 Research sub-questions

This research aimed to gain more insights into the relationship between technical and institutional developments in the Dutch natural gas pipeline infrastructure, and their impact on the integrity of the system. The following five sub-questions will be answered in order to help to answer the main research question in Section 7.2.

What physical & technical system aspects and stakeholders are of importance when analyzing the integrity of the Dutch natural gas transmission system?

The Dutch natural gas pipeline system consists of four technical elements that are essential for the system's integrity:

1. The physical underground transportation pipelines with a pressure between 66 and 80 bar. An important characteristic of these pipelines is the 5-meter safety barrier on both sides.
2. Compression stations every 100 km throughout the network, and gas receiving stations between the HTL and the RTL networks.
3. Large consuming industries which are directly connected to the HLT network via delivery stations.
4. Connection locations to neighboring countries, production facilities, and biogas injection stations.

Besides the technical aspects, also some stakeholders are of importance when analyzing the integrity of the Dutch natural gas system. The GTS is responsible for the operation, maintenance & development of the high-pressure natural gas network. As this company is owned by the Dutch government, at the time of writing this the ministry of Economic Affairs & Climate and the Ministry of Infrastructure and Water Management are responsible for regulations & legislation involving the natural gas sector. These ministries are also the ones who are involved in making the national structural vision which represents the spatial planning plans of the government. These plans are then implemented by provinces and municipalities into their own spatial plans which represent the physical surroundings of the natural gas system.

The last important group of actors in the natural gas system is the group of inspections. The ACM is the technical and coordination supervisor based on the Gas Act (2000), the SodM has been the supervisor on safety regulations and environmental law compliance since 2006, ant the ILT inspects the compliance of the Bevb & Revb legislation since 2011.

How have the institutions that manage the Dutch natural gas transmission system changed over the last 30 years?

The Dutch regulation and institutional background of the natural gas transmission system has gone through three phases. First, the main concern was about environmental protection and preservation. This actually remained for the whole 30 years the focus of the high-level institutional background of the system. The acts and decrees have been revised and updated according to the changing idea of what environment protection entails and what aspects were still undervalued like the societal safety and risks of environmental changes. It was later argued that the environmental and spatial legislation had become too complex. This resulted in the preparation of the Environment and Planning Act (Omgevingswet), which will come into effect in 2024, to better regulate and organize spatial planning, projects, and the requirements regarding societal risks in a more concise way.

While the specific rules and organization of the natural gas network were first focused on technical standards of assets and the management of these assets, the inclusion of environmental effects and risks started around 2000. This introduced the Gas Act, where the transmission became separated from economic market activities in the natural gas sector. And also changed the ownership of the HTL network, which was first a 50/50 public-private joined venture between the Dutch government and two oil companies. With the Gas Act, the Dutch government became the full owner of the transmission network. Gasunie was and still is the network operator, but since 2000 fully state-owned.

A second phase in the institutional developments was seen after, where reporting and preventing gas leaks were the main priorities in changing and revising institutions to minimize their effects on the integrity and functioning of the system. Different industry standards and laws were created to better organize the information sharing between parties involved in construction work around and of the high-pressure network (WION, Register Risks of Hazardous Substances, guidelines for reporting leaks), and the external safety became more integrated into the technical standards and management procedures (NPR 7910, NTA 860, NTA 9120, Bevb). During this phase, the three main supervisors (ACM, SodM, and ILT) were appointed.

The development of these institutional revisions and industry standards came from these inspections and research projects of the SodM. They either experienced a problem in their safety operations and collaborations, or they found a gap in the institutional framework which was causing a lack of supervision on new energy projects or the registration of incidents.

The third phase of the institutional developments that is identified is the inclusion of renewable energy sources and transportation projects within the scope of environmental and safety regulations. The SodM and state started to see that these types of projects could be beneficial for the future of the natural gas system as with the Energy Agreement of 2013 for sustainable industrial growth. In 2018, the SodM expanded its supervisory task to all topics related to the safety of gas to be ready for / help guide the energy transition. This was included in a new version of the Gas Act the same year, which made these types of renewable energy projects legally possible.

How have technological developments in the Dutch natural gas transmission system changed in the last 30 years?

From the academic literature and year reports of the GTS and SodM, it was recognized that the reasoning behind technical development in the Dutch pipeline system has changed. Starting during the 90s, technical developments were focused on expanding and improving the ICT systems that control and monitor the technical network. Data became more important for gas flow and communication purposes, but also for risk analysis of the network. Risk analysis became more uniform in risk definitions and mitigation strategies with the help of the Bowtie method and VELIN's incident data surveys. During this time Gasunie started to invest more in outsourcing their maintenance and control activities to third-party private companies. The SodM further developed the Bowtie method to make a standard that eventually gained interest from Gasunie and RTL network managers to use the methodology themselves as well.

There was also a shift in the academic world which started to develop ideas about more sustainable and future-proof uses of the classic natural gas transport network, with for example: biogas, CO_2 capture & storage techniques, and hydrogen capabilities. Before researchers were mainly interested in risk analysis and the integration of ICT in natural gas networks.

Around 2018, some of these ideas became a reality in the form of experiments and small regional project networks. This created a new wave of new parties involved in the natural gas system and led to an increase in interest by the government to research these new use cases. Currently, the government-owned Gasunie is investing in renewable energy projects and network preparations to support these projects when transitioning to the national scale.

The technical requirements for these new projects were not set out in the system very clearly, as it was noticed that the injection of green gas in the network was making the calorific value fluctuate too much within the safety boundaries. The injection of green gas was minimized after. Also, no specific technical requirements for these projects were found in the consultant year reports of Gasunie and SodM.

Which insights do we gain from looking at the level of alignment between technical and institutional developments in the Dutch natural gas transmission system from the last 30 years?

The first layer of the Alignment Perspective framework is about the systemic and institutional environment alignment to ensure the functioning of the network on the generic design level. If the technical closed-access design of the network is combined with a vertically integrated monopoly, following the framework, there is alignment on Layer 1. It was found that Gasunie has always been the only network operator for the high-pressure natural gas transmission network, despite not fully state-owned during the 1990s. They are responsible for the gas balance, gas glow, maintenance, construction, and controlling of the network. As well as the access to the network is organized in such a way that the access has to be granted by the government and Gasunie. The technical design of the network was found to be closed-access due to the pre-determined and rigid physical design with only a few production facilities and injectors connected at the input side. On the output side of the network, the regional distribution networks and the big consumers that are pre-accepted by Gasunie are situated. There is no possibility to connect to the network without an acceptance process or unannounced.

This alignment between the technical closed-access characteristics and the vertical monopoly of Gasunie has been throughout the whole 30 years, and indicates that technical expertise and one network operator are essential to perform the transmission task.

For the second layer of the framework, alignment is seen when the scope of control and responsibility of an actor, in reality, is coherent with the officially assigned role of this actor. It was found that due to the creation of the Gas Act, the assigned scope and responsibilities of supervisory tasks were not aligned within the real-world desired or obvious way. ACM became the supervisor of the technical and task coordination side of the Gas Act, while the SodM was only the safety and environmental law supervisor of the RTL and not the HTL. Gasunie was assigned to continue with their internal audits on these two themes, despite the expertise of the SodM on these themes because of their many years of experience in the RTL.

With a revision of the Gas Act in 2006, the SodM gained the supervisory tasks for safety and environmental law for the HTL network as well, which became more in line with their skill set making this a better and more efficient choice. Also, with the experience from the years before in the RTL networks, the SodM was able to pinpoint integrity issues in the HTL soon after their assignment as supervisor.

When the Bevb was introduced in 2011, the responsibility for the compliance of this external safety regulation for pipelines was assigned to ILT. This is in line with their inspection role for the Ministry of Infrastructure and Water management, as they are also the supervisor of the Soil Quality Decree. However, its scope of control sometimes overlaps with the SodM regarding environmental risks and the compliance of the reporting obligation as the SodM tends to look into this as well in their research projects.

The alignment on the third and last layer of the framework is when there is coherence between the technical coordination between stakeholders and actors in the network, and which institutional structure was chosen to guide these coordination and regulations. The technical coordination is done by Gasunie which is on a central level due to its vertically integrated monopoly characteristic. However, during the 90s, Gasunie started to outsource more and more of its daily maintenance and control activities via third-party private contractors. The specific natural gas technical knowledge was found to be less within these companies and regular information about risks and safety routines were shared by Gasunie.

This same pattern happened when regionally, or more so locally, new renewable energy transportation projects were emerging after 2017. Gasunie as the central manager of the natural gas network and the supervisor SodM had foreseen that the risk definitions and safety procedures were not as established as those in the natural gas sector. Which is most likely due to a lack of experience. Therefore, the SodM took it upon themselves to supervise such projects despite it not being their official responsibility. Gasunie created a similar connection to these projects by investing money and time to ensure the natural gas system nearby would be protected, as well as to learn for the future.

What insights can be obtained from the alignment framework applied to a specific Dutch natural gas pipeline case study?

With the application of the alignment framework on a specific case in the natural gas transport system, the applicability was tested. As well as some interesting results that coincide with data found in the analysis of SodM and ILT year reports for the integrity history of the system. It was discovered that due to the institutional change from national to regional spatial planning when it comes to pipeline integration and coordination of construction, the municipalities have yet another theme in their portfolio to manage. Municipalities experience pressure from the higher government to manage and fulfill strategies set out that might indeed clash or take longer in practice to integrate. This pressure was also indicated by the SodM in 2017 and 2020 in the integrity data timeline.

Also, the involvement of national utility companies in spatial planning was seen to be underestimated. Therefore the construction of new spatial projects can take longer and face multiple rounds of changes which could have been avoided it the technical expertise of these utility companies was consulted early on in the project design.

The case that was looked into, did not represent a big technical system like the whole national natural gas transport system in this research. The application of the alignment framework actually demonstrated that also for small practical cases, the framework be applied to determine where detected issues are situated. For this particular case, one layer of the framework was central in the analysis of the problem while the others worked as a backstory. A benefit of using the framework is the organized way a socio-technical issue can be broken up into the technical characteristics and requirements side, as well as the necessary institutional background. This establishes the playing field of stakeholders & actors, which rules apply to the particular case, and what technical design knobs can be changed in order to direct the situation to its desirable state. It creates an overview of what possible interventions, risks, and potential relationships are possible when an issue arises. Whether this is on a small scale or nationally.

7.2 Main research question

Following the answers of the sub-questions and the alignment analysis done in this research, the main research question can be answered. To quickly look back, this is the main question of this research:

What insights do we take when reflecting on the influence of technical and institutional developments on the integrity of the natural gas system in the Netherlands?

This research showed that before the year 2000, there was little technological development to improve the physical network itself as was focused on the further development of data collection and network monitoring ICT systems. The legislation was mainly focused on general pipeline and station requirements with collaboration between different ministries. The system's integrity was not top of the priority list as their costs were generously compensated by the earnings of the system. When speaking about integrity issues, the conversation would be about the workspace and personnel safety.

After the arrival of the Gas Act and some unfortunate external safety events in the Netherlands, the perspective of integrity itself changed. From the data on institutional developments, it was seen that from within the industry itself more safety procedures and environmental effects of the network were taken into account. The government and the SodM joined later in this development with organized national projects to look further into integrity issues to do with asset safety and its effects on the system's environment. Here, Gasunie of the HTL learned a lot from safety practices in the RTL network, supervised by the SodM. Their knowledge of data sharing, standardizing safety practices, and regional environment differences, helped Gasunie to evolve their own practices and risk management systems. During this time, many industry standards were created to ensure unity in integrity definitions, intervention, and prevention procedures. It can therefore be concluded that developments, either technical or institutional, on integrity issue interventions mainly come from the industry itself or the advice by the SodM to the government.

Another development had to do with the integration of natural gas infrastructure into the spatial planning of the country. As this was normally done on a national level, the spatial & environmental protection legislation slowly started to become more regional. Municipalities and provinces gained more responsibility to ensure the national infrastructure was safely looked after in times of construction and spatial changes. Years later it came to light that this was not done as smoothly as it was intended with the hierarchal integration of national planning into regional planning. Regional authorities were insufficiently taking into account the safety regulations around natural gas pipelines and processing stations.

Within the evolution of the integrity perspective from a more narrow workplace perspective to a broader overall system (technical & societal) perspective, the SodM played an important and sometimes leading role. As the supervisor of the regional distribution network at first, they recognized that the integrity procedures and interventions were not as clear and formally formulated in the HTL system. What started with research projects on risk awareness and gas leak reporting, the SodM found ways to improve the regulatory sector-specific processes that would be beneficial for the HTL.

After the SodM gained supervision of the technical and safety side of the HTL network due to their involvement and suggested improvements, they also took the lead in analyzing the effects of the natural gas system on its surroundings. A couple of years later, the advice to look into the environmental effects of the network as well in light of integrity, the government incorporated this in sector-specific laws and a special inspection for the compliance of this legislation. It also tried to add more collaboration and coordination between the different natural gas system inspections to unify perspectives on integrity and to learn from each other's expertise. Later on, the same pattern however occurred when there was little to no supervision on projects with renewable energy transportation projects. Despite the recognized risks of these projects on the natural gas system as they were close to the natural gas infrastructure.

Based on the development of the integrity perspective and how actors have managed the integrity risks found, it can be recognized that the sector-specific institutional developments are a reaction to the integrity developments found. This reactive instead of proactive behavior has resulted in miscommunication between actors and delays in construction projects, an occasional overlap in supervisory tasks (mainly the SodM and ILT), and ambiguities about which aspects and projects are controlled by whom. This has led to an ongoing gas leak and gas leak reporting problem, and the SodM expanding its supervision portfolio despite it not being their responsibility or scope of control.

7.3 Recommendations & research agenda

Based on the analyses performed in this research and additional insights obtained while studying this topic, there are a couple of recommendations that can be made. Both for the natural gas sector and for the academic research agenda.

7.3.1 Recommendations for the natural gas sector

In line with the insights gained from this research, and the specific learning points from the case study in Chapter 6, some recommendations can be given to Gasunie as the network operator and the Dutch government authorities for the natural gas system. These two actors respectively influence the technical and institutional side of the network on the implementation level. Therefore, their ability to change regulations, routines, and coordination is most impactful.

The Dutch national and regional government authorities:

- Evaluate the current translation processes from national spatial planning to regional zoning planning in order to avoid insufficient integrations of natural gas pipelines and their safety barriers in these regional plans and construction work agendas. The help of the Ministry of Public housing and spatial planning could be beneficial in this case as their knowledge of housing construction agendas and the spatial integration of our new energy transition (Rijksoverheid, n.d.-c). Possibly, an additional supervisory or consultancy commission can be created to ensure the translation from national to regional planning is made correctly within procedures that are set to guide this process.
- For the regional government authorities, it was shown from SodM annual reports and the practical case study in Chapter 6, that the collaboration between national utility companies and municipalities is not always going well in terms of communication and involvement in construction projects. Therefore it would be recommended that early on in construction projects or other spatial impact projects, the feedback and expertise of the GTS about safety measures and potential risks are included in their project designs. This can of course still be beside the potential involvement of private contractors and engineering companies who initially draw up the plans. The Digital System Environmental Act (DSO), which will come into effect in 2024, will also be beneficial to ensure all technical requirements of utility networks and what is allowed in the physical environment are in one place when construction plans are being developed.
- In this study, it was recognized that most of the institutional background of the natural gas system is not always up to date and fully specified when a new technical development or ownership change occurs. And as in the technical development history was seen, the next system change is evolving in the direction of new sustainable material technologies which can eventually substitute the use of natural gas in the country. Therefore, it is recommended that an analysis is done about what kind of regulations these new technologies need in order to be supported in their integrity responsibilities and accompanying technical operations to ensure a safe transition in the future.

Gasunie (Transportation Services):

- An intervention for the insufficient integration of natural gas infrastructure into regional spatial planning could be to communicate in advance of a project (so in general) what kind of changes in zoning plans or construction project regulations are needed to avoid integrity infringements. This would also be beneficial for upcoming technical developments that are being researched right now and might need alterations in incident reporting procedures or supervision requirements. It will be required to actively involve Gasunie itself is such spatial planning and technical development projects, as this is not early on a legal requirement.
- As the activities of third parties like electricity cable managers & internet providers are still one of the major causes of incidents and accidents with natural gas pipelines, a recommendation could be to share more information about safety and risk analysis with these parties from the perspective of Gasunie. This can be advice on activity reporting protocols or how to manage integrity issues in a more efficient way to limit the damages from these incidents. The idea behind this recommendation is based on the fact that the more these other parties know about the natural gas network and the importance of effective risk analysis, the better they can understand what aspects they have to consider for their next activities in the ground.
- Following VELIN's incident data surveys and the interview with Mr. R. Frinks, keeping information about pipeline locations up to date is crucial for construction and maintenance projects. Not only for Gasunie itself but also for contractors and RTL network managers. However, it was seen that this information is not up to date even though KLIC reports are mandatory and the WIBON act states that information sharing about these locations has to be performed before every project near a pipeline or cable network. Therefore it is recommended that as the owner of the HTL network, Gasunie provides these contractors and HTL network managers with information on the importance of up-to-date location data and KLIC-reports within the project's planning.

7.3.2 Research agenda suggestions

Based on the insights and limitations of this research, there following recommendations can be made in light of a future research agenda.

- As described in the introduction of this research, the security of assets and technical ICT systems have also been under attention recently due to the explosions of the North Stream 1 and 2 in Europe. Due to the focus of this research on safety and not security which has more to do with data, a great follow-up study could be on how data security in the natural gas system has evolved over time and how this is related to a system's integrity (and its integrity perspective). Looking into the elements of integrity considered here, security would probably go hand in hand with asset management and risk analysis systems.
- The analysis of the Alignment Perspective framework showed that in Layer 1 the institutional background was also highly influenced by the regulations and directives. Each European Union member state has its own way of implementing these institutions into its national law. This raises the question of how the found relationship between technological and institutional developments in terms of integrity compares to other EU member states. A benefit from this suggested research could be the ability to learn from other EU directive institutional implementations which might have had more efficient/sufficient impacts on the integrity of their natural gas systems or the coordination of the system.

- During the analysis of the integrity timeline, it became apparent that the institutional side of the system was reactive to findings from inspections or integrity perspective shifts. A recommendation for a follow-up study therefore could be to look into how technological interventions can help institutions in their effectiveness and adaptation to the energy transition to maintain the necessary level of integrity. Examples here can be the automation of KLIC report procedures, or the use of digital twins in order to pinpoint critical network segments.
- In the interpretation of the results of this research, it was stated that the Alignment Perspective framework might be limited to which influences are taken into account when talking about integrity. During the study economic and social developments were also recognized like technical personnel shortages and the economic cycle with periods of innovation booms and periods of regression. Therefore it can be recommended that further research is done in which other ‘pillars’ can be identified that can have an influence on the natural gas system’s integrity and the perspective of this integrity.

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A. Knowledge gap literature review

Before this research, the domain of interest was investigated on an academic level utilizing a literature review. Here the state-of-the-art on a literature basis was analyzed. The goal was to identify potential gaps or opportunities within the existing literature. Appendix A is referenced in Chapter 1.

A.1. Search strategy

For the analysis, the scientific database Scopus was used to gather the literature. The search process is visualized in Figure A.1 and was performed on December 4th, 2022. In the identification stage in the figure, the search query is presented as well. These keywords had to be in the title, abstract, or keywords of the articles to come up in the search.

Some terms can have multiple definitions, therefore a couple of terms were made explicit to gain a better understanding of the focus of this literature review.

Pipeline infrastructure:
Within different pipeline infrastructures, different types of materials are transported through a network of pipelines. Here the focus is on underground pipelines inland that transport hazardous materials (Gasunie, 2022b). The infrastructure includes overground stations where measurements and maintenance can be performed as well.

Hazardous materials:
For the definition of hazardous material, the definition by the United States Department of Transportation was used: "*a substance or material that is capable of posing an unreasonable risk to health, safety, and property when transported in commerce*" (Ziavras, 2022).

Trends and developments:
For trends and developments, an example can be the privatization of the pipeline infrastructure, but also the aging of the network (Baird, 2002; Ministerie van IenM & Ministerie van ELenI, 2012). But developments in the use of the infrastructure with the introduction of hydrogen and LNG, and the decrease of technical schooled employees in the field are included as well (CEDEFOP, 2016). To keep it short, technical, political, and systematic changes and innovations encapsulate the trends and developments in the research theme.

The integrity of the system:
The integrity of the system can be also called the safety of the system, which is on a continuum scale (Redmill, 2000). The integrity says something about 'how well' the infrastructure is operating now and how it will operate in the future. Here the consequences of future unexpected events happening in the environment of the system or to the system itself are considered (Peculis & Shirvani, 2017).

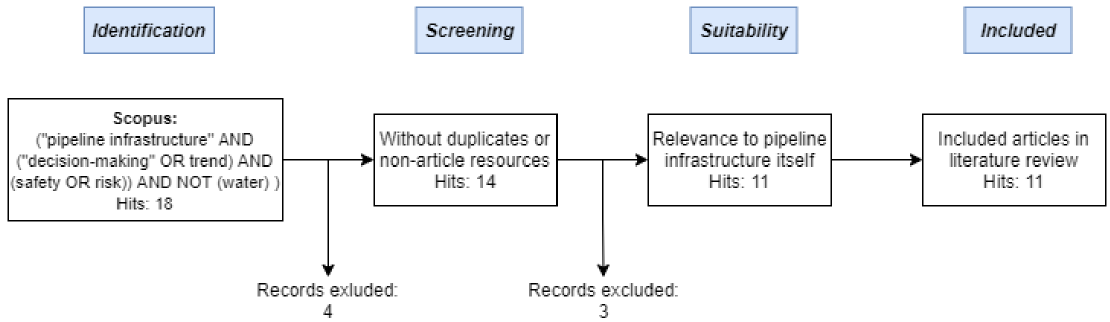

Figure A.1: Search process for the preliminary literature review.

In the screening phase, the acquired literature was screened to remove duplicates and grey literature types of articles (document notes and interviews). Within the third stage, the articles were analyzed to see if they were suitable for the focus of the research theme: the pipeline infrastructure itself of hazardous materials. In the end, 11 articles were suitable for the literature review.

A.2. Overview of selected literature

In Table A.1 the final selection of literature is presented. In the colored columns, the three main aspects (technical developments, policy developments, safety/integrity issues) of the literature review was about are located. In addition, the geographical area and the pipeline infrastructure type were recorded for all articles. This was done to see if there was a variety in results, a dominant location or type of pipeline, or if no major pipeline infrastructure groups were missing from the acquired literature. The green color represented that the topic was one of the main aspects of this research, and the orange color means that this topic was not covered.

Table A.1: Analysis of acquired literature based on three criteria.

Author(s)	*Year*	*Focus area*	***Innovation or trend***	***Governance/policy developments****	***Safety or risk issues***	*Sort pipeline infrastructure*
Hayes, Sandri & Holdsworth	2021	Australia	No	Yes	Yes	Natural gas
Suarez Suarez et al.	2020	Canada	Yes, mathematical computer model	No	Yes	Oil
Feijoo et al.	2018	USA	Yes, globalization of the natural gas market	No, based on an economic view on the safety issues and differences between locations with a shared pipeline infrastructure	No	Natural gas
Gong, Essa & Asari	2018	USA	Yes, technical model to ensure safety when doing construction around pipeline infrastructure	No	Yes	Oil and gas
Brogan	2017	USA	No	No	Yes	Natural gas
Meiring, et al.	2015	Wordwide	Yes, small scale LNG producing supply chains	Yes	No	LNG
Burton	2014	USA	Yes, Carbon Capture, Utilisation and Storage	No	No	CCUS
Parfomak & Folger	2008	USA	Yes, Carbon Capture, Utilisation and Storage	No, focus on what is needed (nothing happend yet)	Yes	CCUS
Schoots et al.	2011	Not specified	No	No	No	Natural gas, carbon dioxide and hygrogen
van der Zwaan et al.	2011	Not specified	No	No	No	Natural gas, carbon dioxide and hygrogen
von Bassenheim et al.	2000	Canada	Yes, private investments in pipeline infrastructure	Yes	No	Natural gas

** = only specified when a different approach was taken other than governance/policy developments, otherwise no other persepctive chosen.*

Following Table A.1, one thing can be noticed right away. The geographical area of focus is truly centered in Northern America. While specific European countries have not been analyzed before within this area of study. On the other hand, however, for the pipeline infrastructure types, there is a lot of variety. There are the classics like natural gas and oil, but also innovations in hydrogen transportation and Carbon Capture, Utilization, and Storage technology (Schoots et al., 2011; van der Zwaan et al., 2011).

Looking at the three criteria set out for this literature review, none of the articles has covered all three themes at the forefront of their research. Either the safety of the network was connected with a certain innovation or technical trend, for example in the articles of Suarez Suarez et al. (2020) and Parfomak & Folger (2008). Or the innovation was linked to the governmental changes that needed to happen to realize the innovative technology (Meiring et al., 2015; von Bassenheim et al., 2000).

Besides, many focus on the technical trends and innovation side of the research domain of pipeline infrastructure. The governmental or policy developments that have happened over the last 4 decades are not mentioned by most authors when it comes to the integrity of the system. Only Hayes et al. (2021) look at the relationship between the perceived safety of engineering professionals and the governance of residential development planning around pipeline infrastructures.

A last thing to note is that even though safety and integrity issues were incorporated into the search query, there was little focus on risk issues and safety itself in the acquired pipeline infrastructure literature. There were only 5 out of 11 authors whose focus was on the safety of the pipeline infrastructure itself. Whether this is for its environment if something happens with the network or the other way around: if the environment can cause damage to the network itself.

B. Modes of Organizations article summary

The article by Künneke, Groenewegen, and Ménard from 2010 has been discussed when analyzing the third layer of the Alignment Perspective framework, as well as in the stakeholder analysis in Chapter 3. In this appendix, a short summary of this article will be given with the necessary visuals to understand the background of technical scope, interference speed, and modes of organization.

In the article, it is argued that infrastructures are complex technical systems with many different subsystems and components involved. All technical elements of an infrastructure system interact with each other to perform its designed services. There is need for a coordination between functions like capacity management, system management, interconnection, and interoperability. A failure of one of these aspects can lead to a technical integrity failure of the system.

When viewing these infrastructure systems as socio-technical systems, the interaction between technical components and governance structures becomes important. These governance transactional structures are built from the New Institutional Economics literature. This literature emphasizes the alignment of modes of organization with the coordination needed in a system.

The control of an infrastructure revolves around the critical function of this infrastructure. In this research, the critical function is the supply of natural gas, which needs an integer infrastructure system to be able to provide this supply. The mode of organization suitable for this critical function depends on the transactions impacting this function. Transactions are about the transfer of the 'rights to use' a certain good or service (Ménard, 2008; Williamson, 1985). Critical transactions are the transactions that are essential to perform the critical function of the infrastructure. These critical transactions in the technical control of the system depend on two mechanisms:

1) The technical scope of control within the system that is looked at from a certain perspective;
2) The time constraint in which intervention is needed to avoid catastrophic effects in the system.

The perspective mentioned in point 1 is that from a certain stakeholder within or affecting the system. Following these two points, in Figure B.1 the appropriate mode of organization is presented to secure the critical transactions and therefore the critical function of infrastructures.

(Organizational requirements in parenthesis)

Scope of control / **Speed of adjustment**	**System** *(requires directive intervention)*	**Subsystem** *(requires coordination)*	**Component** *(requires corroboration)*
T_0 Operational balancing *(requires supervision)*	Authoritative supervision ['system operator']	Collaborative supervision ['system regulator']	General framework conditions ['system norms and standards']
T_5 Capacity utilization *(requires monitoring)*	Compulsory monitoring and enforced adjustment	Mutual monitoring and stimulated adjustment	Self monitoring and voluntary adjustment
T_{15} Capacity allocation *(requires facilitation)*	Controlled allocation mechanism	Guided allocation mechanism	Competitive allocation mechanism
T_{50} System transformation and innovation *(requires planning)*	Directive planning	Indicative planning	Decentralized planning

Figure B.1: The modes of organization identified by Künneke, Groenewegen, and Ménard (2010).

C. Technological progress literature review

To obtain a balanced and as complete as possible picture of the technological developments in the natural gas transport sector, a literature study has been carried out. The goal was to analyze which new technologies were implemented into the Dutch natural gas transport system. As European Union directives have to be implemented by all member states, as well as the international collaboration between neighboring countries due to the connectedness of the natural gas system, other natural gas systems in Europe can be representative of the Dutch technological degree of implementation.

Appendix C is an addition to Chapter 4.

C.1. Search strategy

For the analysis, the scientific databases ScienceDirect and Web of Science were consulted to gather academic literature. The full search process is visualized in Figure C.1 and was performed on May 12th, 2023. In the identification stage in the figure, the search queries are presented. Here also some filters were used to obtain literature for European research or to keep the period within the 30-year horizon of this study. These keywords had to be in the title, abstract, or keywords of the articles to come up in the search.

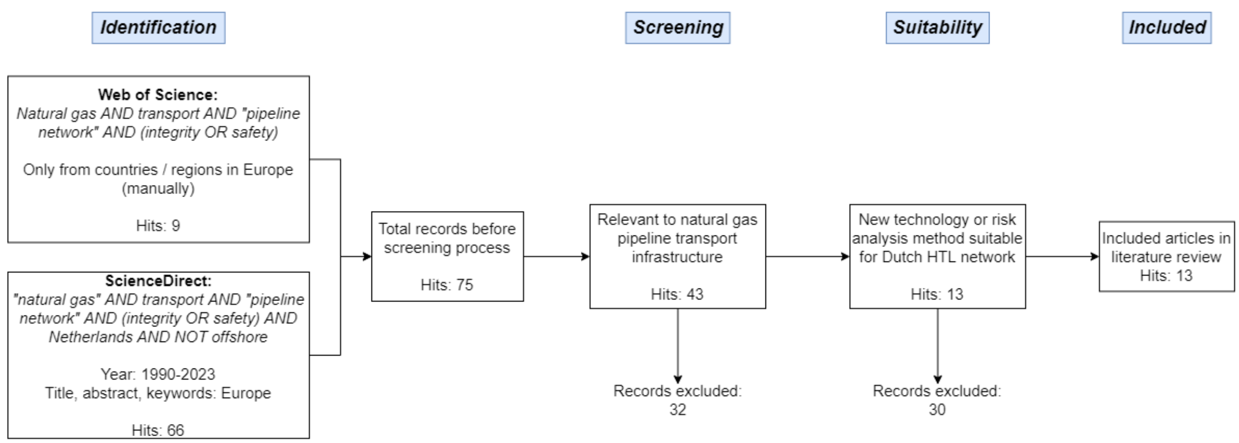

Figure C.1: Search process for the literature review of technological developments.

In the screening phase, the acquired literature was screened to remove any articles not related to the natural gas pipeline transport infrastructure at all. Here the energy transition in which the network can be used in other ways in the future is included in the literature review as this also might affect how network operators create current strategic plans.

Within the third stage, the articles were analyzed to see if they were presenting a new technology or risk analysis method which is suitable for how the Dutch HTL network operates. In the end, 13 articles were suitable for the literature review itself.

C.2. Overview of selected literature

In Table C.1 the final selection of literature is presented. The articles were analyzed on the technological purpose and which part of the HTL network they can be applied to. In addition, the implementation level of this technology was documented to understand its state of development and whether it can be seen in practice or not. Lastly, their application to the Dutch HTL network is analyzed.

For the implementation level, there were three different color codes used. Green represents a technological development that is already implemented within a pipeline system within the focus area of that study. This can be a full implementation or a real-world pilot project. Yellow represents technological developments that are more simulation/calculation based, but that are ready to use within risk assessments or network topology evaluations. Lastly, the orange represents technologies that are still in development. This can be computer models/simulations which do not yet have real-world versions.

Table C.1: Analysis of the acquired academic literature on technological developments.

#	Authors	Year	Main purpose of article	Part of targeted infrastructure	Implementation level	Application to Dutch HTL system
1	*Ale*	*1991*	To identify the limits, techniques & application of quantitative risk analysis in the Dutch hazardous material policies.	Risk analysis procedures	Fully established in practice	It is a reflective study of past decisions within the Dutch HTL.
2	*Faaij, Koornneef, Molag, Spruijt & Turgenburg*	*2009*	To identify knowledge gaps & uncertainties in Quantitative Risk Assessments (QRA) for CO2 pipelines and to assess to what extent those gaps & uncertainties affect the QRA outcomes.	Future uses for the HTL pipelines + QRA procedures	Literature review / study	The results can be used to improve current QRA procedures in the HTL industry.
3	*Andrews & Pearce*	*2011*	To provide a technical and economic methodology to determine the viability of establishing waste heat greenhouses using waste heat from industry.	Industrial clients from the natural gas HTL	Multiple real-world implementations	Possibly in the future for energy transition, already multiple projects started, i.e. Rotterdam, Hengelo & Eindhoven.
4	*Benson, Brandt & Farhat*	*2011*	To provide a general analysis of the technical aspects associated with varying CO2 injection rates of the CO2 Interim Storage technique.	Future use + connecting facilities to HTL	Simulation	Possibly in the future for energy transition.
5	*deGuillebon, Gaultier & Ha-Duong*	*2011*	To describe the social aspects of CO2 capture, transport & storage.	Future use + connecting facilities to HTL	Pilot project	Construction of 2 project most likely start this year (2023).
6	*Fimbres Weihs, Ho & Wiley*	*2011*	To determine which characteristics of a CO2 Capture & Storage transport network are most important when wanting to reduce the total CO2 cost of the network in tons.	Future uses of the current HTL network	Computer model / simulation	Can be used to calculate network topology (changes) to future Dutch Co2 Capture & Storage projects which might use old natural gas transportation pipelines.
7	*Hashim, Hoo & Ho*	*2018*	To identify an appropriate biogas supply chain to different demand using economic models, spatial analysis & scenario analysis.	Future uses of the current HTL network	Computer model / simulation	Possibly in the future for energy transition to biogas.
8	*Abhari, Chokani & Eser*	*2019*	To propose a novel gas system model to capture both the market behavior of gas traders and gas system operators.	Network topology + future uses	Simulation	This model can help to determine how renewable energy sources affect the natural gas demand share and which topology is beneficial to use in the future when more renewable sources are available.
9	*Hoo, Hashim, Ho & Yunus*	*2019*	To investigate biomethane injection into the natural gas grid through a virtual pipeline.	Future uses of the current HTL network	Computer model / simulation	Possibly in the future for energy transition to biogas.
10	*van Gelder, Liang, Zhang & Zhou*	*2020*	To propose an integrated methodology of 4 analytical models to the supply reliability analysis of multi-product pipeline systems under pumps failure.	Pipelines + pump stations for flow maintenance	Real-world pilot	Possibly in the future for energy transition.
11	*Gong, Huang, Li, Liu, Lu, Wen, Wen & Yu*	*2021*	To propose an integrated method for gas supply reliability evaluation based on demand-side analysis in order to identify the weakest nodes and key links of the natural gas pipeline network.	The natural gas transportation infrastructure (pipelines)	Simulation	Can be used to evaluate the condition of the pipeline infrastructure and to see where weak nodes and key links are located based on demand.
12	*Chen, Yang, Yang, Zhang & Zhou*	*2022*	To study the diffusion process and explosion characteristics of hydrogen-blended natural gas.	Network uses + current material pipeline performance	Simulation	Possibly in the future for energy transition.
13	*Jia, Li, Ren, Wu, Yang & Zhang*	*2023*	To propose a model to calculate the diffusing coefficient of natural gas/hydrogen mixtures.	Compressor stations	Simulation	Possibly in the future for energy transition.

Looking at Table C.1, one of the first things that can be noticed is that many technological developments that are talked about in the selected articles are focused on renewable energy sources. The idea can be to transport them through the existing natural gas transport infrastructure (Hoo et al., 2018) or to create a new pipeline network besides the already existing one (Farhat et al., 2011; Hoo et al., 2019).

In the early 2010s, most research was done to analyze the technique of CO_2 capturing, transport & storage (CCS). As the technology was still very new, the characteristics of such a network needed to be analyzed to gain knowledge about the costs, which was done by Fimbres Weihs, Ho & Wiley (2011). On the other hand, the social aspects when implementing CCS in a region were still unknown. With a pilot project in France, deGuillebon, Gaultier & Ha-Duong (2011) found that transparent risk control and a direct positive economic effect for the people nearby the CCS network were key to gaining acceptance by society. However, their called '*modern governance*' (big corporate meetings with little interaction with the people affected, and no long-term plans) negatively affects the perceived value of the CCS technology within society. With the solid establishment of the biggest HTL operator Gasunie's position in society, their focus is no longer on societal acceptance. Nevertheless, Gasunie's current projects into renewable energy and also CCS (Gasunie, 2023), will be subject to this societal perspective.

Later the focus seemed to have switched to the transport of renewable energy sources, like biogas & hydrogen (Hoo et al., 2019; Jia et al., 2023; C. Zhou et al., 2022). This can be because the CCS technologies are indeed worked on in practice already.

When looking at the implementation level of the discussed technologies there is a diverse mixture. One could think that some of the technologies of earlier research would be implemented by now. However, this is not the case. It can be seen that throughout the period of 30 years, there are technologies that are still in the simulation phase marked in orange (Eser et al., 2019; Koornneef et al., 2009; Yu et al., 2021), while others are fully implemented in the real world which is marked by the green (Ale, 1991; Andrews & Pearce, 2011; X. Zhou et al., 2020). Nevertheless, some of the simulation/computer models may not be implemented yet, but are waiting on the shelf to be worked with in the pipeline & materials transport industry, like a reliability evaluation method to determine weak nodes and key links. These ready-to-use technologies indicate that the knowledge is available to take the natural gas sector to a new stage and to prepare itself for the future.

The targeted infrastructure component that is most discussed is the pipeline themselves, and in particular, how they can be used for future uses or be mimicked as mentioned before. Having said that, within the earlier period (before 2010) risk assessment and risk analysis were also a topic of discussion. This is good to see as the natural gas network and its surroundings are changing, and that the evaluation methods are critically looked at. It could be in looking at the limitations of risk Dutch procedures in hazardous material transport (Ale, 1991), or identifying which knowledge gaps there are in evaluating risks of potential future uses of the network like transporting CO_2 (Koornneef et al., 2009).

One noteworthy thing, is that the majority of the technologies are simulation/computer models regardless of whether the technology has already been implemented. This might be in contrast with the more physical character of the pipeline network and its somewhat 'old-fashioned' reputation.

D. Short descriptions of laws & regulations

In Chapter 5 the laws & regulations associated with the Dutch natural gas system have been explored. Here for each of these, a brief description of their purpose will be given. Only the contents related to the natural gas industry will be discussed. To establish this overview, the following sources were consulted:

- Infomil.nl – *The central information point for legislation and regulations within the environmental domain by Rijkswaterstaat*. (Rijkwaterstaat, 2023)
- Bsigroup.com - *An international certification agency that also consults companies about the implementation of norms & industry standards.* (The British Standards Institution, 2023)
- Nen.nl – *The Royal Netherlands Standardization Institute Foundation which establishes national industry standards*. (NEN, 2023)
- Iso.org – *The International Organization for Standardization, an independent, non-governmental international organization with a membership of 168 national standards bodies*. (International Organization for Standardization, 2023)
- Rijksoverheid.nl – *The website where the government informs the public on legislation, strategy, and policy activities*. (Rijksoverheid, 2023a)
- Wetten.overheid.nl – *Via this site, citizens and professionals can search for regulations, announcements, and other government data collections*. (Rijksoverheid, 2023c)
- The document '*Guidance on how to prepare for combating pipeline incidents*' by IPV (Tonnaer, 2018)

Table D.1: Description of laws & regulations associated with the Dutch natural gas system.

Law/regulation/norm	**Description**
Besluit Algemene Regeling Ruimtelijke Ordening (Barro) *Decree General Spatial Planning Regulations*	*This Decree is part of the legal safeguard of national spatial policy. It is the legal effect of the national Structural Vision. This includes the obligation to keep strips free for pipelines when drafting or amending zoning plans or integration plans.*
Besluit bodemkwaliteit & Regeling bodemkwaliteit *Soil Quality Decree & Soil Quality Regulation*	*The Decree and Regulation lay down rules for quality assurance in soil management, the allocation of quality standards, and the environmental soil quality statements. The rules relate to environmentally harmful activities concerning the soil.*
Besluit milieueffectrapportage *Environmental Impact Assessment Decree*	*This is an Order in Council and is essential for determining whether an EIA (assessment) procedure must be followed when preparing a plan or a decision. In this way, environmental interest is given a full place in the decision-making of construction, building, and environmental projects.*
Besluit Onderzoeksraad voor Veiligheid Dutch Safety Board Decree	*A Decree establishing the Dutch Safety Board and describing its duties. The work of the Dutch Safety Board is mainly aimed at improving safety and preventing accidents in the future.*

Besluit Risico's Zware Ongevallen (BRZO) *Decree Risks Major Accidents* (based on EU-richtlijn 96/82/EG)	*The objective is to prevent and control major accidents involving hazardous substances. This also includes the transport of hazardous materials like natural gas. Since 2015, the BRZO also applies to high-pressure installations (for example, compression stations).*
Besluit externe veiligheid buisleidingen & Regeling externe veiligheid buisleidingen *Decree on external safety of pipelines & Regulation of external safety pipelines*	*This contains rules on external safety around pipelines with hazardous substances. This concerns risk contours, the integration of pipelines in zoning plans, and which information must be included in spatial decisions.*
BSI PAS 55 (before) / ISO 55001 (2014)	*An international norm for the certification & implementation of management systems for asset management. This contains the way incident risks and procedures need to be described & implemented in everyday practice.*
CROW-500	*Guidelines on how to avoid damage to cables & pipelines during excavation.*
Energieakkoord (voor duurzame groei) Energy agreement (for sustainable growth)	*The energy agreement contains agreements about energy saving, more sustainable energy, and extra employment opportunities within the energy sector. The contract is signed by the State, employers, trade unions, and environmental organizations.*
Gaswet *Gas Act*	*The Gas Act contains rules about the transport and supply of natural gas within the Netherlands. It also states that network managers and operators cannot have any relation with energy suppliers. The network managers and operators are responsible for the safety of the network. Implements European Directive No. 98/30/EC of June 22, 1998.*
Wijzigingswet Gaswet *Gas Act Amendment Act*	*The inclusion and prioritization of sustainable energy, restriction of low calorific natural gas by big consumers, and the closing of the natural gas field Groningen (Slochteren).*
Instelling Landelijke Coördinatiecommissie Handhaving Milieuwet (LLMC) *Establishment of the National Coordination Committee for Environmental Act Enforcement*	*A law for the establishment of a national commission whose task is to coordinate various environmental enforcement policies. The intended result is to make enforcement more transparent and to improve the implementation of this environmental policy.*
ISO 14001	*Specifies the requirements of an environmental management system that an organization can use to improve its environmental performance. Network operators need to have such an environmental management system since 2007 when the SodM became the supervisor of the HTL.*
ISO 17020:98	*General international criteria for the operation of several types of bodies performing an inspection.*

Kadasterwet *Kadaster Act*	*The legal foundation of the basic registration cadaster contains administrative data about real estate and the national cadastral map. Here the location of pipelines is also required to improve the processes of civil construction work.*
Landelijk Overlegbesluit handhaving milieurecht *National Environmental Law Enforcement Consultation Decree*	*Within this Decreet the tasks and responsibilities of a ministerial discussion group that focus on the enforcement of environmental law. They are responsible for making proposals about law enforcement developments, advising other government bodies on their law enforcement methods, and making a policy plan with strategic plans two times a year.*
Ministeriële Regeling Gaskwaliteit *Ministerial Gas Quality Regulation*	*The regulation lays down quality requirements for the gas composition for injection into and delivery from the public gas networks*
Natuurbeschermingswet *Nature Conservation Act* (replaced)	*Rules were drawn up for specific areas in the Netherlands regarding the protection of this nature.*
Nederlandse emissierichtlijn *Dutch emission directive*	*The NeR was a directive about requirements for emissions into the air and therefore only had legal effect once it had been legally established, i.e. if the legislator has included this directive in a decree. This guideline is applicable in case of gas leakages.*
NEN 1059	*This norm contains functional requirements for gas pressure regulating and/or measuring installations that are part of a gas transport system and of connection pipes. This norm applies to the design, materials, construction, testing, operation, and maintenance of these installations.*
NEN 3650	*This norm specifies safety requirements for the design, construction, operation, and termination of pipeline systems, concerning people, environment, and goods.*
NEN 3651	*An addition to NEN 3650. This norm specifies the safety requirements for pipelines on land and located nearby major water management structures.*
NTA 8000	*Specification for a risk management system for risks of pipeline systems for the transport of hazardous substances in the management phase.*
NTA 8120	*Requirements for a safety, quality, and capacity management system for electricity and gas network management.*
NTA 8620	*Specification of a safety management system for major accident risks.*
Provinciale Verordening Risicokaarten *Provincial Risk Map Regulation*	*This ministerial regulation describes which vulnerable objects and high-risk situations must be shown on the provincial risk map. Also, rules for the*

	production, management, and design of the Risk Map are included. The risks of pipeline transport are also included.
Registratiebesluit Externe Beveiliging *Registration Decree External Security*	*It is mandatory to register risk situations involving hazardous substances and these are stored in the Risk Register. This concerns situations of production, storage, and transport.*
Vaststellingsregeling Aanwijzingen Rijksinspecties *Determination Regulation Instructions for National Inspectorates*	*The Instructions lay down government-wide rules on the position and functioning of the government inspectorates within the ministries. The Instructions strengthen and anchor the independence of government inspectorates. The SodM and ILT are part of these inspectorates.*
Verdrag van Aarhus (EU) *Aarhus Convention* (EU)	*Convention on access to information, public participation in decision-making, and access to justice in environmental matters.*
Verdrag van Malta (EU) *Treaty of Malta (EU)*	*European Convention for the Protection of the Archaeological Heritage. This is applicable when doing maintenance & excavation work in the ground when working on the pipeline network.*
Waterschapswet *Water Boards Act*	*The Water Boards Act regulates the cancellation and establishment of water boards and lays down rules regarding the duties and structure of the water boards and the composition of their boards. For the natural gas transport system, the Water Boards are involved in how the quality of groundwater is maintained during construction work.*
Water wet *Water act*	*The Water Act mainly regulates the management of water systems, including flood defenses, surface water bodies, and groundwater bodies. The quality of groundwater and nearby surface water of pipelines has to be maintained. This includes avoiding any pollution.*
Wet algemene milieubepalingen (vergunningen) *General Environmental Provisions Act (Permits)*	*The Wabo is responsible for the environmental permit, which entails an integrated permit for buildings, living, monuments, space, nature, and the environment.*
Wet bodembescherming *Soil Protection Act*	*Article 13 of the Soil Protection Act (Wbb) lays down the duty of care. This provision obliges in the event of soil contamination (including groundwater) to take all measures that can reasonably be required. The Wbb focuses on preserving the quality of the soil.*
Wet Milieubeheer *Environmental Management Act*	*This law determines which legal tools can be used to protect the environment. The Environmental Impact Assessment requirements are included, as well as how environmental policy plans have to be made.*
Wet openbaarheid van bestuur (WOB) *Government Information Act*	*This Act organizes the way the government informs the public and guarantees that everyone was able to obtain information about an administrative matter of an administrative body.*

Wet ruimtelijke ordening (Wro) *Spatial Planning Act*	*Determination of procedures for establishing spatial plans and which administrative layer is responsible for these plans. In addition, the Wro regulates the relations in the spatial domain between the various governments and administrative bodies in the Netherlands. Pipelines are included in these spatial plans.*
Wet veiligheidsregio's *Security Regions Act*	*The Security Regions Act regulates (among other things) the organization of firefighting, disasters, and accidents in the Netherlands. In case of incidents with natural gas pipelines, these organizational structures are used to help in these situations.*
Wet informatie-uitwisseling bovengrondse en ondergrondse netten en netwerken (WIBON) *Information Exchange Act aboveground and underground nets and networks* (replaces WION)	*Rules on the exchange of information regarding above-ground and underground infrastructure of nets and networks to prevent excavation damage. It is the next version of the WION where now above-ground and underground are combined in one law.*
Wet informatie-uitwisseling ondergrondse netten (WION) *Information Exchange Underground Networks Act*	*The WION law obliges diggers to report any 'mechanical earth disturbance', such as digging, piling, vibrating, dredging, and laying pipelines. Cable and pipeline managers must have all their cables and pipelines digitally available within a specified accuracy & report them to the KLIC service.*