Nitrogen Emission Models in the Netherlands

The identification of practical problems in the input variables for road traffic by local governments

Master thesis

T. Rietema

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by

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Preface

In front of you lies the master's thesis titled "The identification of practical problems in the input variables of the emission model for road traffic." This research aims to uncover the practical challenges local governments face in input variables and assessing their impact on nitrogen emission model outcomes. The thesis has been undertaken as part of the graduation program in Transport, Infrastructure, and Logistics at the Technical University of Delft, the Netherlands.

Before starting this research, I recognized the politically sensitive nature of nitrogen emissions in the Netherlands. But I had not yet fully understood the distinction between nitrogen affecting nature and human health. By conducting multiple interviews and conducting surveys during the conference of the Schone Lucht Akkoord, I incorporated different perspectives from different policymakers regarding the emissions model in the research.

Throughout the research process, I encountered the challenge of working independently on my research and lacking the opportunity to brainstorm with fellow students about the topic, especially in the initial stages when I was shaping the research direction. To address this, I engaged in joint study sessions with other students. This collaborative approach proved advantageous when I encountered obstacles related to specific topics. This thesis has equipped me with valuable experience in qualitative research and formulating effective interview questions. Furthermore, I have gained substantial insights into the emission models employed in the Netherlands, which significantly contributes to my new role as an air quality and nitrogen deposition consultant at Witteveen and Bos.

First and foremost, I express my gratitude to all the respondents and interviewees who contributed to this research. I also extend my appreciation to Fileradar, particularly Dr. C. van Hinsbergen, for their invaluable guidance in steering my research. Special thanks go to Dr. J.A. Annema from the Faculty of Technology, Policy, and Management, and Dr. H. Taale from the Faculty of Civil Engineering, for their feedback and guidance. I acknowledge Dr. A. Pel for chairing my thesis committee. Lastly, I wish to acknowledge the unwavering support of my family and friends throughout the thesis period.

I hope you find this thesis an enjoyable read.

T. Rietema
Scheveningen, October 2023

Summary

Currently, the Netherlands is facing a nitrogen crisis. Consequently, several measures have been taken to reduce nitrogen emissions. In this context, emission models play a crucial role in calculating both nitrogen concentration levels for air quality and nitrogen deposition on Natura2000 areas. Specifically, two distinct emission models are mandated for these calculations. The AERIUS Calculator is employed for nitrogen deposition calculations, while the Standard Calculation Method (SRM) is utilized to assess air quality. These emission models are instrumental in computing pollutant levels originating from both traffic and agriculture sectors. Since road traffic is the largest contributor to NO_2 emissions, this research focuses exclusively on this sector [14].

In current literature, studies are focused on the epistemic uncertainty of emission models. Studies from Kühlwein and Friedrich (2000) and Dey, Caulfield, and Ghosh (2019) are focused on determining the uncertainty of input variables and parameters, such as emission factors, by means of uncertainty and sensitivity analyses [9, 27]. What is still missing in literature are the practical problems decision-makers of local governments deal with when using emission models. Emission models in the Netherlands have a variety of users, where one has more experience with the model than the other. This leads to potential practical problems with the corresponding input variables.

This research aims to identify the practical problems decision-makers encounter when using emission models for nitrogen deposition and air quality. Hereafter, it is assessed how practical problems related to the input variables affect the model's outcome. The main research question answered in this research is: ***"What are the practical problems associated with input variables in the Dutch emission models, and how do these problems impact the decision-making process of local governments?"***

Methodology

In this research, interviews, surveys, and a sensitivity analysis are used to identify and quantify the practical problems of the input variables of the emission model in the Netherlands. In total 9 interviews and 22 surveys are conducted with municipalities and environmental agencies. The results of the interviews and the surveys are used as the problem analysis of this research.

First, interviews are conducted with various municipalities and environmental agencies to gather information about the process, limitations, and possible uncertainties for nitrogen deposition emission modeling and air quality monitoring. Thereafter, this research focuses strictly on air quality monitoring. Deposition calculations are conducted exclusively for projects or activities that possess the potential for deposition to occur within Natura2000 areas. Additionally, the deposition calculations consider assumptions about future scenarios. Air quality monitoring is annually performed and is a reconstruction of the previous year. For air quality, this makes it more accurate to investigate the practical problems regarding the input variables. Additionally, a survey is conducted specifically for air quality to gather more information on the practical problems in the emission model of air quality.

The problem analysis stage involves identifying practical problems of input variables and data usage. The second phase assesses how these problems may impact the model's outcome. This analysis focuses on two distinct municipalities: Utrecht and Almere. Both municipalities participated in the research with an interview or a survey. Each municipality has different urban characteristics in the form of total road length and traffic volume. The default data used in the sensitivity analysis are obtained from the CIMLK monitoring tool for the year of 2021.

Results

The results of the problem analysis reveal that there are practical problems with the input variables *selection of roads*, *stagnation factor*, and *traffic volume* for both air quality and nitrogen deposition. Furthermore, specifically for the air quality, additional practical problems are found with the input variables *building type* and *tree factor*. These input variables involve linguistic, epistemic, and ambiguity uncertainties.

For the input variable *selection of roads*, there are no clear rules or guidelines on which roads to include for both models. This indicates the presence of linguistic uncertainty. Municipalities have set internal guidelines for implementing specific approaches within their respective organizations. Nevertheless, there is notable variation in applying these guidelines from one municipality to another, particularly concerning the inclusion of 30 km/h and 50 km/h roads in the monitoring tool. For instance, when Utrecht and Almere exclude 30 km/h roads from the air quality monitoring tool, it led to an average reduction of 10 percent in the model's output for NO_2 concentration attributed to traffic.

For the variables *traffic volume* and *stagnation factor* forms of epistemic uncertainty are involved. The results of the interviews and the survey indicate that there is generally a lack of knowledge about how *traffic volumes* were established. In the emission models, the *traffic volume* is based on the weight distribution of the vehicle class. However, the results of the problem analysis show that some municipalities use length distribution (L123) and other use weight distribution (LMZ). The two distributions are not equal to each other. Fileradar created a conversion matrix to convert length distribution to weight distribution. According to the matrix, the middle heavy and heavy vehicle classes are overestimated when the length distribution is used instead of the weight distribution. Similar results are observed in the sensitivity analysis for the *traffic volume*; the analysis shows an overestimation of the NO_2 concentration from traffic between 10-12%. This outcome aligns with the sensitivity analysis results of the individual vehicle classes. The results of the individual vehicle class indicate that light and stagnant traffic are not sensitive to changes in the input values, but middle heavy and heavy traffic are.

The impact of adding stagnant vehicles in the monitoring tool is relatively low compared to the other analysis; for both Almere and Utrecht, there is a maximum increase of 2% of the NO_2 concentration from traffic.

Ambiguity uncertainty is introduced by input variables *building type* and *tree factor*. For both input variables, default values are used in the air quality monitoring tool. The report of RIVM describes the different factors for the *building type* and *tree factor* [44]. However, the choice of factors depends on how the user of the model interprets the local situation. The impact of inserting the "incorrect" *building type* and *tree factor* depends on the factor used in the monitoring tool. The biggest impact on the NO_2 concentration from traffic is when *building type* 4 is entered instead of *building type* 2. This results in a concentration increase of the model of 23%. When *building type* 3 is chosen instead of *building type* 2, the NO_2 concentration from traffic shows the least impact. This resulted in an increase of 6%. For the *tree factor*, the largest concentration increase is when factor 1.0 is used instead of 1.5. This leads to a concentration increase of 13%.

Discussion

In this research, the decision is chosen to conduct a sensitivity analysis instead of an uncertainty analysis on the input variables of the emission model of air quality. Studies of Kouridis et al. (2010) and Kioutsioukis et al. (2004) use the sensitivity analysis as a screening tool to identify the most sensitive input variables of the emission model [26, 23]. In this study, the sensitivity analysis is not used as a screening tool but is used as a method to asses the robustness of the model's outcome. A robust emission model output indicates that minor input value variations lead to negligible fluctuations in the output, implying relatively low uncertainty in the output. Conversely, substantial changes in model output indicate greater sensitivity to input variations. From the results of the sensitivity analysis, it can be concluded that the input variables of the emission model for air quality are not robust. Variations in the input variables lead to significant differences in the model's outcome. The only robust input variable is *stagnation factor*. Varying the *stagnation factor* in the sensitivity analysis has little effect on the model outcome. Prior to the analysis, it was expected *stagnation factor* would have significant effect on NO_2

concentration. But the definition of *stagnation factor*is not a factor of stationary vehicles due to congestion but is a factor of traffic volume with a speed lower than 15 km/h. Since the *stagnation factor* only has a certain fraction of influence on traffic volume, changes contribute little to the outcome of NO_2 concentration of the model. However, the limitation of this research is that the uncertainty of the input variables is not established, whereas Kouridis et al. (2010) and Kioutsioukis et al. (2004) studies did account for and quantify these uncertainties [23, 26].

The results of this study only consider the individual sensitivity of the emission models input variables and do not look at the joint effect. Fileradar used this research to develop a case study of a street in Capelle to determine the input variables' joint sensitivity. The case looks at the main street in Capelle in a southwesterly direction. Here, the values entered from the monitoring tool were compared with real-time data from Fileradar. The inserted input values of the *traffic volume* are too low, the *stagnation factor* too high, and the wrong *building type* is inserted in the monitoring tool. The new calculations with the data of Fileradar increased the outcome of total NO_2 concentration with 11% and NO_2 concentration from road traffic with 151%. This indicates the simultaneous effect of inserting the ”incorrect” input values has a large effect on the outcome of NO_2 concentration from the emission model.

Conclusion

The problem analysis addresses the first part of the main research question, which explores the practical problems associated with input variables in the Dutch emission model. These issues manifest in both emission models for deposition and air quality, primarily concerning the input variables of *selection of roads*, *stagnation factor*, and *traffic volume*. Challenges arise with input variables of *building type* and *tree factor* specifically for air quality modeling. The sensitivity analysis shows that the most sensitive input variable is the *building type*, and the least sensitive input variable is *stagnation factor*.

The second part of the main research question is related to how these practical problems impact the decision-making process of local governments. Generally, municipalities are unaware of the significant impact of ”incorrect” input variables on the outcome of the emission model. Prior to this study, it was assumed by decision-makers that inaccuracies in input variables did not significantly affect model outcomes because models are an abstraction from real-life. However, this research shows that variation in input values has a significant impact on the outcome of the emission model.

The quality of input values plays a pivotal role in determining the outcomes of emission models. For air quality monitoring, decision-makers are responsible for providing traffic data. The quality of this data varies among municipalities based on the knowledge and experience of decision-makers with the emission model. The results from the sensitivity analysis underline that the model's outcomes are highly sensitive to changes in input values, leading to potential overestimation or underestimation of NO_2 concentration from the model's outcome. This, in turn, can have further consequences for policies and measures taken by decision-makers within a municipality.

Recommendations

In order to address the practical issues associated with input variables in the Dutch emission model, it is crucial to raise awareness among a wider group of users of the model. Municipalities should share their experiences and challenges with one another to establish clear and comprehensive guidelines. The Schone Lucht Akkoord (SLA)[1] organizes annual conferences about critical air quality issues. By actively sharing findings with the SLA, a greater number of municipalities can be informed and engaged within a short time frame.

Furthermore, to adress the different types of uncertainties related to these practical issues, the following recommendations are proposed:

[1]The SLA is a voluntary agreement between several municipalities, provinces, and the state aimed at permanently improving air quality in the Netherlands

- **Epistemic uncertainty**: To mitigate uncertainty stemming from insufficient knowledge and data, it is advisable to incorporate more empirical data. For estimating *traffic volume* and *stagnation factors*, the use of loop measurements and floating car data is recommended to enhance accuracy. When employing length distribution for *traffic volume*, it is advisable to utilize the conversion matrix of Fileradar, as demonstrated in this study.
- **Linguistic uncertainty**: To address uncertainty arising from vaguely defined input variables in the emission model, it is crucial to establish more explicit regulations and guidelines concerning the *selection of roads*. Developing consistent guidelines to assist municipalities in determining which lower-order roads should be included in monitoring is of utmost importance. Additionally, it is essential to institute a standardized approach for delineating nitrogen deposition projects to minimize ambiguity and ensure consistent application of guidelines in calculations.
- **Ambiguity uncertainty**: Managing uncertainties related to input variables such as *building type* and *tree factor* is challenging since there are already clear guidelines and examples illustrating which default values are applicable in specific situations [44]. An alternative approach to determining correct default values involves the development of a mathematical model with the guidelines of RIVM (2014) as constraints. This approach ensures that the choice of default values is not reliant on individual interpretations but is standardized instead.

For further research, the following recommendations are given:

- Performing an uncertainty analysis on the same set of input variables
- Performing a joint sensitivity analysis on the practical problems of input variables.
- Investigate the effect of including roads in monitoring tool instead of excluding them
- Investigate the effect of correct use of the SRM method on the calculation points and their location
- Re-evaluate the input values in the air quality monitoring tool with empirical data

Abstract

The Netherlands is currently facing a nitrogen crisis, which requires measures to reduce nitrogen use. Two essential emission models, AERIUS Calculator for nitrogen deposition and Standard Calculation Method (SRM) for air quality concentration, are mandatory. While existing literature investigates uncertainties in input variables and emission factors, practical challenges faced by decision-makers in local governments when applying these models are less explored. This research aims to identify these practical problems and their impact on decision-making. The main research question addressed is: "What are the practical problems associated with input variables in Dutch emission models, and how do they affect the decision-making process of local governments?" The methodology involves semi-structured interviews, a survey, and a sensitivity analysis. Practical problems are identified in the input variables for both nitrogen deposition and air quality, including "selection of roads", "stagnation factor", and "traffic volume". In addition, air quality also includes "building type" and "tree factor". These problems impact nitrogen concentration from road traffic by under- or overestimating it. The most sensitive input variable of the air quality emission model is "building type", and the least sensitive input variable is "stagnation factor". The sensitivity of the input variables has not only an effect on the outcome of the emission model but also has further consequences. Local governments use the emission models to determine if a project or activity may continue. In addition, it is used to determine whether the limit values of NO_2 are not exceeded. When, for example, the limit values are exceeded, measures need to be taken by local governments. In this study, recommendations are given regarding practical problems and for further research in this area.

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Nomenclature

Abbreviations

Abbreviation	Definition
CIMLK	Centraal Instrument Monitoring Lucht Kwaliteit
DCMR	Dienst Centraal Milieubeheer Rijnmond
EF	Emission factor
EU	European Union
MRDH	Metropoolregio Rotterdam Den Haag
NIBM	Niet In Betekende Mate
OAT analysis	One At a Time analysis
OPS	Operational Priority Substances
RIVM	Rijksinstituut voor Volksgezondheid en Milieu
SLA	Schone Lucht Akkoord
SRM	Standard Calculation Method
WHO	World Health Organization

Symbols

Symbol	Definition	Unit
NO_2	Nitrogen dioxide	$[\mu g/m^3]$
PM_{10}	Particular Matter	$[\mu g/m^3]$

1 Introduction

The Netherlands is currently facing a nitrogen crisis. The cause of the crisis is an accumulation of problems and decisions that have occurred in Dutch politics, which mainly relates to the agricultural sector. In the 1970s and 1980s, the problem occurred first because of the large excess of fertilizer use in the agriculture sector and increased emissions from industry and traffic. From the 1990s through 2015, the sector's nitrogen emissions decreased by three-quarters. This has to do with stricter guidelines of the European Union (EU) regarding using fertilizers and introducing the catalyst for industry and traffic. However, the agricultural sector's decline in nitrogen emissions has stagnated over the last decade, while the traffic sector is becoming cleaner [10]. As a result, politics are primarily focused on nitrogen emissions from the agriculture sector .

Nitrogen emissions are a pressing concern and a significant challenge across multiple sectors, including agriculture, transportation, and industry. Nitrogen oxides (NO_x) and ammonia (NH_3) are harmful to nature if too much is deposited in water or at the surface. Plants like grass and nettles will grow faster from these substances, leaving no room for other plants to grow. This, in turn, influences the variety of insects and animals that live in the area, ultimately changing the diversity of nature. Ammonia is mainly released from animal manure and urine, and nitrogen oxides are mainly released into the air by road traffic and industry [30].

NO_x is the sum of nitrogen monoxides (NO) and nitrogen dioxide (NO_2) [37]. Combustion reactions of, for example, traffic release NO and NO_2 simultaneously but NO is quickly converted to NO_2 in the air [30]. In figure 1.1, an overview of the top 10 sectors contributing to NO_2 concentration in the Netherlands are stated. Over the years, the traffic and transport sector has made the most significant contribution. Of that, much comes from shipping in the North Sea, followed by road traffic [49]. NO_2 is mainly in the air at locations with heavy road traffic. In the Netherlands, this is primarily on the highways and in the Randstad near large cities with a lot of road traffic. From the year 2000 - 2021, the NO_2 contribution of the sectors in Figure 1.1 decreased. This has to do with the measures taken [3]. For example, road traffic measures are taken by reducing the maximum speed on highways and by prohibiting diesel vehicles from city centers. Still, the traffic and transport sector has the largest NO_2 contribution in the Netherlands.

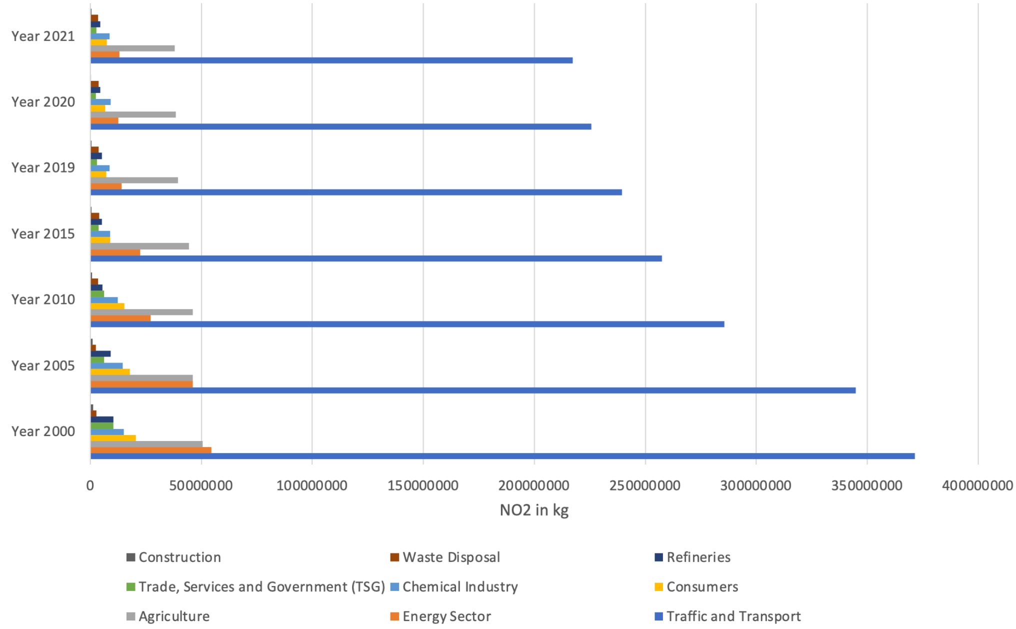

Figure 1.1: NO_2 contribution of the sectors [14]

There is a distinction in nitrogen related to nature and human health. Nitrogen deposition concerns nature reserves, while air quality concerns human health. Too much NO_2 is harmful to human health, it can worsen lung disease and cardiovascular disease. In addition, people with respiratory diseases such as asthma are especially sensitive to NO_2 [3].

For calculating the concentration and deposition, emission models are used. Several emission models are available to determine road traffic emissions. However, it is mandatory in the Netherlands to use the AERIUS emission model for nitrogen deposition and the Centraal Instrument Monitoring Luchtkwaliteit (CIMLK) calculation tool for air quality. In Section 2.3, the current literature on the emission models are discussed in more detail. This literature encompasses a range of focuses, from the uncertainty in input variables to emission factors used in the model. Sensitivity analysis determines which input variables cause the most significant variation in the model's outcome. This method is a theoretical approach that focuses on the imperfect knowledge of an input variable or model. The studies mentioned in Section 2.3 have a limitation in that they did not address practical problems associated with these emission models.

In this research, practical problems are defined as the challenges and unclear guidelines when using emission models, which cause variation in the model's outcome. Local governments in the Netherlands are responsible for data management of input variables for the emission models. Emission models are becoming more specialized as municipalities encounter problems with filling in data into the air quality monitoring tool and checking deposition calculations. This research examines the practical challenges associated with input variables within the emission models in the Netherlands. The aim is to identify practical problems that municipalities struggle with and how they affect the model's outcome. Based on this, recommendations are made on how municipalities can best deal with these problems.

In the literature, much can be found of the uncertainties from emission models and their input variables. This research will focus on practical problems local decision-makers encounter using the emission models for nitrogen deposition and air quality. In this chapter, first, the delineation of the study is described in Section 1.1. Next, the reason for the study is made clear in Section 1.2 and the aim with the research questions in Section 1.3. Finally, the study's relevance is described in Section 1.4 along with the outline of the study in Section 1.5.

1.1. Scope

Nitrogen is currently a significant concern in the Netherlands. As shown in Figure 1.1, different sectors play a role in NO_2 contribution. In this study, a deliberate decision has been made to limit the focus to the road traffic domain, as the traffic and transport sector has the largest NO_2 contribution [14]. This choice is underscored by the involvement of Fileradar, a company specializing in road traffic analysis. Together with their expertise, the proper use of traffic data to determine nitrogen concentrations from road traffic is being considered.

The initial phase of the research encompasses a broad perspective, including air quality and nitrogen deposition. This approach of starting with a broad scope facilitates the identification of various practical problems about both topics.

Subsequently, in the study's second phase, the focus is on air quality. This is because the variability of nitrogen deposition is influenced by several external factors, with weather being a prominent contributor to the uncertainty in the outcomes. Also, it is challenging to specifically perform research on the deposition since it is project and activity dependent and includes calculations of future scenarios for the year 2030. Air quality monitoring must be performed yearly and is a reconstruction of previous year. As a result, much data is already available from the municipalities from previous years. Because of this, it is possible to perform a sensitivity or uncertainty analysis with their data. The lessons learned from air quality can also be applied to deposition. The input variables used in air quality correspond also to deposition. In Chapter 2, the differences between air quality and deposition are discussed in more detail.

1.2. Problem definition

Nitrogen plays a crucial role in affecting various sectors and local governments in the Netherlands. The nitrogen crisis not only affects the traffic and transport sector by the measures being taken but also impacts the continuation of land use plans and projects. The associated project or plan faces termination if substantial nitrogen deposition occurs within a Natura2000 area. This leads to wide-ranging consequences for the specific project and broader crises, like the country's housing crisis.

There has been a political shift in the Netherlands regarding nitrogen from air quality to deposition. Previously, between 2014 and 2016, the focus on nitrogen was mainly on air quality along roads. During those years, air quality standards were exceeded in several municipalities, including Utrecht. Nowadays, this is no longer the case in most municipalities. This is due to the measures taken, such as introducing environmental zones and lowering the maximum road speed [40]. Nevertheless, the role of nitrogen as a limiting factor may be reintroduced when Brussels adopts the World Health Organization (WHO)[1] air quality guidelines. Therefore, again a political shift may take place from the focus of deposition at Natura2000 areas to the monitoring of air quality.

For nitrogen deposition and air quality, users of the models are responsible for collecting data on input variables of the emission models. No research has yet been conducted on practical problems of emission models in the literature. There is a case study conducted by Kioutsioukis et al. (2004), which determined the effect of input values on the output from the COPERT emission model [23]. However, a theoretical approach is used in conducting a sensitivity analysis in combination with an uncertainty analysis. With this method, the practical problems of users of the model and their effect on the outcome of the emission model is not determined.

Emission models are complex and contain various input variables and parameters. Because municipalities must provide their input data for the models, there may be errors in the data due to possibly incorrect assumptions or lack of knowledge. Therefore, it is important to quantify the practical problems' effect on the model's outcome.

[1] The World Health Organization is a specialized agency of the United Nations responsible for international public health

1.3. Research objective and questions

The primary objective of this research is to identify the practical problems related to input variables faced by local governments in the context of nitrogen deposition and air quality modeling. These challenges have the potential to significantly impact the outcomes of the models, leading to potential underestimation or overestimation of nitrogen concentrations. By shedding light on these practical problems, the research seeks to provide valuable insights that can contribute to the enhancement of nitrogen emission models in the Netherlands. To achieve this objective, the following research question is formulated:

What are the practical problems associated with input variables in the Dutch emission models, and how do these problems impact the decision-making process of local governments?

To answer the main research question, multiple sub-research questions are formulated. The sub-research questions divide the main research question into sub-topics to answer them. The following sub-research questions are:

- What are the regulations in the Netherlands regarding emission models for road traffic?
- What type of input variables are used in the Dutch emission model?
- What practical problems are associated with input variables within emission models in the Netherlands?
- What is the effect of the identified practical problems on the outcome of the Dutch emission model?
- How can these problems be addressed to develop more accurate estimations for nitrogen calculations of road traffic?

1.4. Relevance

The study is relevant to the scientific literature because it provides practical problems faced by local government when using emissions models. Herein, the main focus is on the practical problems of the input variables rather than the theoretical problems of the model. Empirical insights are obtained by interviewing and conducting surveys with different experts from local governments. It creates awareness and understanding of the practical problems and their effects on the model's outcome. By knowing the problems local governments deal with, it is possible to create better policies and guidelines for the input variables of the emission models. The improved guidelines could lead to more accurate nitrogen concentration calculations and a general approach for local governments to implement.

Notably, within such a delicate context as nitrogen, with implications for both human health and the environment, the quality of policy decisions should not depend on whether parties have properly managed their data. Improved guidelines also help ensure accurate outcomes from models.

1.5. Thesis Outline

The study consists of two parts. The first part investigates the practical problems and type of uncertainties present in the input variables of the emission models for deposition and air quality in the Netherlands. In chapter 2, the sub-question *"What are the regulations in the Netherlands regarding emission models for road traffic?"* and *"What type of input variables are used in the Dutch emission model?"* are addressed. Subsequently, in chapter 4 the sub-question *"What practical problems are associated with input variables within emission models in the Netherlands? "* is addressed. Interviews and surveys are conducted with local governments combined with a literature review to identify practical problems that may contribute to model uncertainty.

The second part of the study is to quantify the qualitative results. The fourth sub questions *"What is the effect of the identified practical problems on the outcome of the Dutch emission model?"* is addressed in Chapter 5 by means of a sensitivity analysis. Chapter 6 interprets and discusses the results of this study. Finally, chapter 7 answers the main research question and provides a recommendation for developing a more effective process for estimating road traffic emissions.

2

Exploring the knowledge gap

This chapter discusses the Dutch emission models for road traffic. Section 2.1 gives an explanation of the methods and input variables used in nitrogen emission models. Subsequently, in Section 2.2, the definition of uncertainty and different types of uncertainties are given. Section 2.3 consists of an exploration of previous research on road traffic emission modeling conducted both internationally and within the Netherlands. Finally, Section 2.4 describes the knowledge gap of the current literature.

2.1. Dutch nitrogen emission models

In the Netherlands, there exist two distinct categories of nitrogen emission models: one designed for deposition in nature reserves, particularly Natura2000 areas, and another tailored for assessing air quality. The deposition of pollutants is related to nature and air quality to human health. The reason for the two different models is because of the law and regulation in the Netherlands which make a distinction between human health and nature reserves. In this section, the emission models for nitrogen deposition (Section 2.1.1) and air quality (Section 2.1.2) are explained.

2.1.1. Deposition

For deposition the online application AERIUS Calculator, developed by RIVM[1], is used. The application is applied for multiple sectors (energy, livestock, traffic, mobile machinery, industry, etc.) to determine its effects. It computes deposition of the pollutants sulfur dioxide (SO_2), NO_x, and NH_3 on nitrogen-sensitive areas (Natura2000 areas) resulting from an activity or porject. The Omgevingsregeling[2] states that the use of AERIUS Calculator is compulsory for determining whether a project or activity has significant effects on Natura2000-areas. If there are significant effects, a permit is required. There is no significant effect when nitrogen deposition is less than $0.005 \quad mol/ha/year$. The outcome of the deposition calculation is evaluated per hexagon of Natura2000 areas [20]. In the Wet Natuurbescherming[3], environmental standards are established to monitor nitrogen deposition. The sensitivity of nature to nitrogen varies across Natura2000 areas. To determine the maximum nitrogen deposition without harming nature, critical deposition values are set for each Natura2000 area. Additionally, reduction targets have been established for the years 2025, 2030, and 2035, aiming to maintain nitrogen deposition levels below established thresholds in Natura2000 areas. Specifically, the target for 2025 is to ensure that a minimum of 40% of the area including nitrogen-sensitive habitats maintains a nitrogen deposition level that does not surpass the specific threshold of a Natura2000 area, measured in moles per hectare per year. This implies that in at least 40% of these areas, nitrogen deposition must remain below the predetermined value to prevent degradation of habitat quality. The targets for 2025, 2030, and 2035 are presented below [32].

[1] RIVM: National Institute for Public Health and the Environment of the Netherlands
[2] Omgevingsregeling: ministerial regulation to the Environment Act in the Netherlands
[3] Wet Natuurbescherming: rules for the protection of animals and plants in the Netherlands

- In 2025: at least 40%
- In 2030: at least 50%
- In 2035: at least 74%

In figure 2.1, a schematic overview is given of the AERIUS model. The model consists of two methods, the Operational Priority Substances Model (OPS) and Standard Calculation Method 2 (SRM 2). The OPS model is used to estimate the distribution and deposition of substances, **except for road traffic up to a 5 km distance**. The concentration of air pollution from road traffic **within 5 km of the road** is calculated by SRM 2, which is subsequently converted to deposition using OPS. For distances greater than 5 km, OPS is used for both concentration and deposition calculations. The computational range of AERIUS is 25 km from the pollution source [17]. For the calculation a fixed set of calculation points are used to determine deposition. The resulting value is assigned to a hexagonal area of 1 hectare.

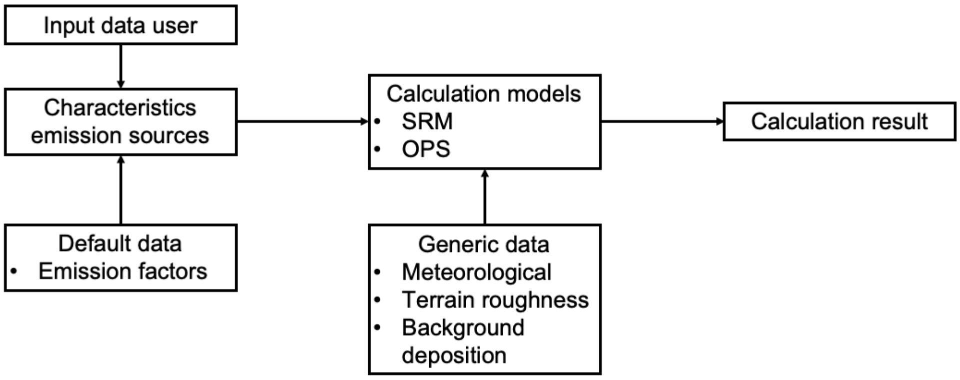

Figure 2.1: AERIUS model - Schematic review [17]

Local governments and project developers are responsible for the input data of the model. The following input data need to be inserted by the user of the application:

- Selection of roads
- Stagnation factor
- Traffic volume
- Shielding structures
- Tunnel factor

In the laws and regulation are guidelines about the required data. For *selection of roads* all roads that receive traffic from an activity or project should be considered in the deposition calculation, except when traffic merges into the prevailing traffic pattern [15]. For the input variable *traffic volume* the classification is based on the weight distribution of vehicles. Herein, the vehicles classes are light vehicles, middle heavy vehicles, heavy vehicles and buses [38]. These vehicle classes are further subdivided into vehicle types (Table 2.1). The *stagnation factor* is derived from the proportion of traffic volume with a speed lower than 15 km/h and is entered as a factor in the monitoring tool. For *shielding structure* and *tunnel factor* there is in the online application a box you can check which will automatically include factors in the calculation when there is a sound barrier or a tunnel.

Table 2.1: Vehicle classes & types [38]

Vehicle classes	**Vehicle type**
buses	Line buses for public transport (not for the highway)
Light duty vehicles	Passenger vehicles
	Delivery vans
	Motorcycles
Middle duty vehicles	Trucks < 20 ton GVW
	Touringcars
Heavy duty vehicles	Trucks > 20 ton GVW
	Tractor

In addition to the input data there are generic data and default data of emission sources in the application. The generic data consists of meteorological data, background deposition, and terrain roughness. The most important inputs in the default data are the emission factors (EF). The EF used in the calculation are derived from the VERSIT+ model of TNO [18]. The EF are derived annually from measurements under test conditions and from real-world driving. EF are determined for both urban roads and highways in combination with the vehicle class, vehicle type, road type and pollutant. The vehicle classes with its vehicle types are stated above in Table 2.1 [38]. The road types considered are country road, urban road (flowing, stagnating, normal), and highway (80 km/h, 100 km/h, 120 km/h, 130 km/h, congestion). Per vehicle type and per road type there are different type of EF's for NO_x, PM_{10}, $PM_{2.5}$, VOC, NH_3 and CO. The EF per vehicle class and road type are determined with formula 2.1. In the formula $BASw$ is the emission per vehicle kilometer travelled with a hot engine, $AGEw$ is the effect of aging of the motor on a hot engine, $BASc$ is the extra emission caused by driving with a cold engine, $PERCc$ is the average number of cold starts per kilometer travelled, and $AGEc$ is the effect of ageing of the engine on a cold engine [18].

$$Emission \quad Factor = BAS_w + BAS_w * (AGE_w - 1) + PERC_c * BAS_c * AGE_c \tag{2.1}$$

2.1.2. Air Quality

The monitoring of air quality of NO_2 and Particular Matter (PM_{10}) levels in the air are mandatory for agglomerations[4] which lay in or are close to a focus area. Focus areas are locations with high concentrations of NO_2 and PM_{10}. There are two types of focus areas for air quality: those for NO_2 and PM_{10}, and those for PM_{10} alone. Given the focus of this study on nitrogen, only agglomerations related to nitrogen are considered. These are the following agglomerations (Figure 2.2) [42]:

- Amsterdam/Haarlem,
- Arnhem,
- Eindhoven,
- Etten-Leur,
- ’s-Gravenhage/Leiden,
- Rotterdam/Dordrecht, and
- Utrecht.

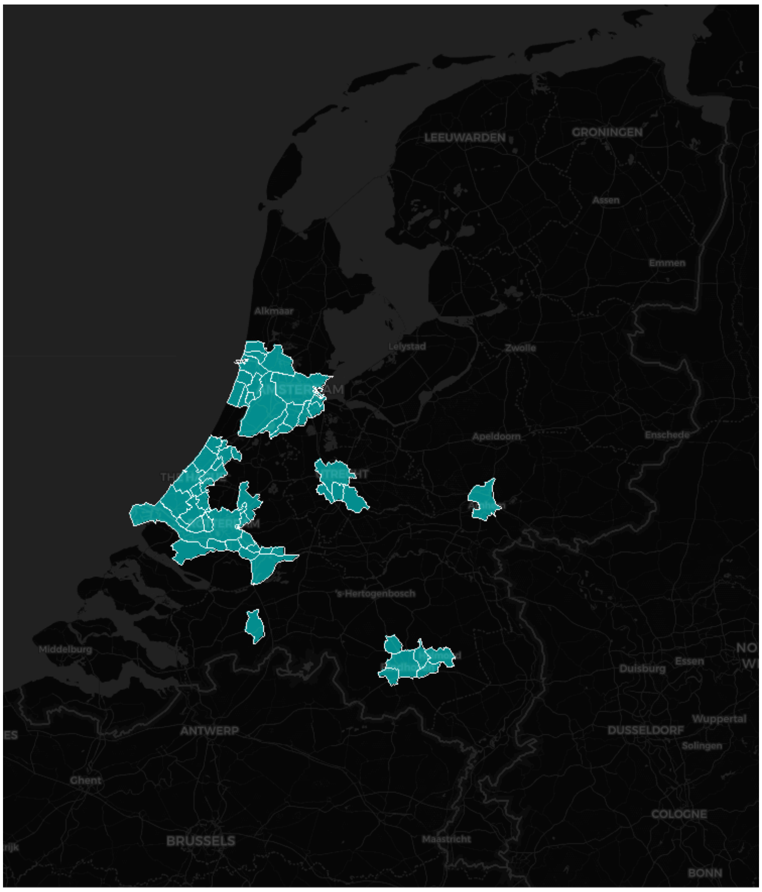

Figure 2.2: Agglomerations NO_2 [42]

Municipalities located in or near focus areas are required to comply with environmental standards when assessing a project or activity. Also, the Omgevingswet mandates that the aforementioned agglomerations provide annual data on traffic and livestock farming for air quality monitoring. Participants of the Schone Lucht Akkoord (SLA) are required to provide data every two years. The SLA is a voluntary agreement between several municipalities, provinces, and the state aimed at permanently improving air quality in the Netherlands. The monitoring data must be updated and uploaded to the web application of the Centraal Instrument Monitoring Lucktkwaliteit (CIMLK). The environmental air quality standards are intended to protect human health, rather than to address deposition of emissions on nature reserves.

[4]Agglomerations: Urban area with at least 250,000 inhabitants

As a result, it is not necessary to monitor environmental standards in areas where there is no public access or permanent residency. Also, environmental values for air quality need not be evaluated when the activity does not significantly contribute to air pollution [21]. An activity or project is considered to contribute insignificantly if it contributes a maximum of 3% to the annual average concentration of NO_2, which is $1.2 \mu g/m^3$ [39].

In addition to national standards, the WHO also provides guidelines on air quality. In 2021, the WHO published updated standards that are considerably more stricter than those issued in 2005. At the moment of writing this report, a political discussion is ongoing whether or not to adopt the WHO standards in the European regulation. The Dutch environmental standards are derived from the European regulation which means when the WHO standards are adopted it also applies to the Netherlands. Table 2.2 states the environmental standards of the Netherlands and the WHO standards.

Table 2.2: Environmental standards air quality - NO_2 [42, 48]

	Type of standard	**Max. concentration**
Netherlands	Annual average	$40 \quad \mu g/m^3$
WHO	Annual average	$10 \quad \mu g/m^3$

The SRM is fundamental in air quality assessment, having been originally developed by TNO and subsequently incorporated into the CIMLK online application within the Netherlands. The SRM 1 method calculates the concentration of pollutants near urban roads. One of the characteristics of an SRM 1 calculation is the presence of buildings within tens of meters of the road. Buildings affect the concentration of pollutants by restricting airflow between them. This is in contrast to the SRM 2 calculation. The SRM 2 calculation is applied to highways and country roads where air pollutants do not ”linger” between buildings but are carried off by the wind [44].

Municipalities within focus areas are mandatory to upload input data yearly in CIMLK. This input data is the same as input data for the AERIUS Calculator, except for the extra input parameter of *tree factor*. The density of tree leaves provides local retention of emissions from traffic. Consequently, the ambient concentration of these pollutants remains high, unlike areas with no or fewer trees along roads. The absence of trees leads to lower concentrations of such emissions. There are three *tree factors*: 1.0, 1.25, and 1.5. The lowest factor is 1.0 where there are some trees, but overall it has no effect, and the highest is 1.5 in which the leaves of trees touch and span at least one-third of the street width [44].

The definitions of some input variables differ between the emission models of nitrogen deposition and air quality. For *selection of roads*, the regulation for air quality monitoring does not specify which roads require monitoring. Staat (2023) states that *”The municipal executive board of a municipality [...] in a focus area [...] collects data on traffic volumes on roads managed by the municipality”* [42]. In addition, the definition of *building types* is used for air quality instead of *shielding structures*. For the SRM 1 calculation, nearby buildings on the road affect the concentration of pollutants. The buildings cause air eddies, which affect the height of the concentration of air pollutants. Therefore, the SRM 1 method has four categories of street layouts [44]. These are:

- Building type 1: Wide street canyon - buildings on both sides of the road and more or less connected facades
- Building type 2: Small street canyon - same situations as building type 1 only with higher facades
- Building type 3: Built on one side - buildings at one side of the road
- Building type 4: Basic type - buildings spread in the area

After the municipalities of focus areas have uploaded the input data in CIMLK, RIVM will compute the yearly concentration of air quality. This is an annual reconstruction of air quality of previous year. As in the AERIUS model, the same EF (formula 2.1) and background concentration of pollutants are used to calculate the air quality.

2.1.3. Similarities & Differences

There are similarities between the emission models for air quality and deposition. Both models utilize the same EF derived from the VERSIT+ model, which are based on vehicle types and road types. Moreover, the NO_2 concentration of road traffic from sub-urban roads are determined using the SRM 2 method. In the AERIUS Calculator, this method is applied within 5 kilometer of sub-urban roads for deposition calculations and is used as one of the methods for the concentration calculations of air quality. Figure 2.3 provides an overview of the input variables for both air quality and deposition. However, there are differences in terms of input variables, such as *tree factor* and *building type*. The deposition calculations do not consider *tree factor* and *building type* but takes into account *shielding structures*. It is important to note that *building type* describes the street layout, while *shielding structures* only indicates the presence of a barrier alongside the road.

Air quality models only calculates the concentration of pollutants, while the nitrogen deposition model calculates the deposition of pollutants at Natura2000 areas. Herein, NO_2 concentration refers to the amount of NO_2 gas in the air at a specific location and time. Too much NO_2 concentration leads to negative effects on human health. Conversely, NO_2 deposition includes the process by which NO_2 gas precipitates on the earth's surface. This deposition phenomenon has adverse environmental effects, particular on natural areas [36].

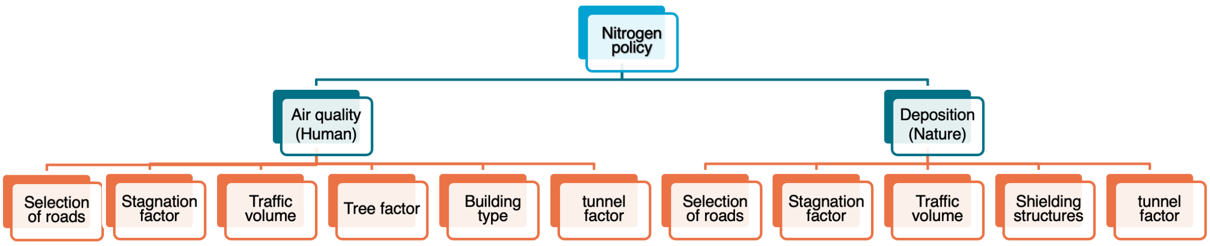

Figure 2.3: Input variables

2.2. Uncertainty

It is necessary to clarify what exactly is meant by *uncertainty*, as this term is usually used in literature when studying emission models. Within the broader literature context, uncertainty is commonly understood as a lack of knowledge and the deviation between the real world and its simplified representation in models [31]. The paper of Walker et al. (2003) defined uncertainty in models as: *"Any deviation from the unachievable ideal of completely deterministic knowledge of the relevant system"* [46]. Kühlwein and Friedrich (2000) study is related to emission models and describe uncertainty as: *"The general expression of unknown possible deviations of true emissions from calculated emission data"* [27]. There is a clear overlap between these definitions, which cover global uncertainty, model uncertainty, and uncertainty specific to emissions models. What all these interpretations have in common is that uncertainty is the result of deviations arising from the scarcity of knowledge, leading to differences between reality and model outcomes. In different disciplines and institutes the definition of uncertainty can vary. Therefore, it is important to clearly state the definition of uncertainty. In this research, the definition of uncertainty is stated below and is used because it is a combination of the current state of knowledge from using models based on the real world.

> ***Uncertainty refers to the divergence between deterministic knowledge of the real world and its representation within models***

Uncertainty can be categorized into different dimensions, as shown in Table 2.3. The literature commonly distinguishes uncertainty in three dimensions, with further subdivisions in some cases [35, 46]. The identified forms of uncertainty have overlapping types among the studies. The most common types are epistemic uncertainty, ambiguity uncertainty, and linguistic uncertainty. Epistemic uncertainty arises from imperfect knowledge of a process, model, or phenomenon. It is also referred to as knowledge uncertainty in the work of Ascough et al. (2008). Ambiguity uncertainty is associated with input data that allows for interpretation and linguistic uncertainty occurs when definitions are vague and context-dependent. Vagueness, a sub type of linguistic uncertainty, arises when there is no precise description available in scientific and natural language [2].

While the uncertainties listed in Table 2.3 are relevant and applicable to this research, the focus is specifically on the input variables of the Dutch nitrogen emission model, as discussed in Section 2.1. Consequently, this research considers uncertainties related to inputs and outcome of the model, with particular attention to the three types of uncertainties; epistemic, ambiguity, and linguistic uncertainty.

Table 2.3: Types of uncertainties in the literature

Papers	**Types of uncertainties**		
Regan et al. (2002)	**Epistemic uncertainty** - inherent randomness - measurement error - systematic error - natural variation - model uncertainty - subjective judgement	**Linguistic uncertainty** - Vagueness - Context dependence - Under specificity - Ambiguity - Indeterminacy of theoretical terms	
Walker et al. (2003)	**Location** - Context - Model - Inputs - Parameter - Model outcome	**Level** - Statistical - Scenario - Recognised ignorance - Total ignorance	**Nature** - Epistemic - Variability
Koppenjan and Klijn (2004)	Substantive uncertainty	Strategic uncertainty	Institutional uncertainty
Ascough et al. (2008)	Knowledge uncertainty	Decision-making uncertainty	Linguistic uncertainty
Uusitalo et al. (2015)	Epistemic uncertainty	Aleatory uncertainty	Linguistic uncertainty
Dewulf and Biesbroek (2018)	Epistemic uncertainty	Ambiguity uncertainty	Ontological uncertainty
Pelissari et al. (2021)	Randomness	Ambiguity uncertainty	Partial information

2.3. Previous research

In this section previous research of emission models in the Netherlands and abroad are discussed. First, the studies related to the Dutch emission model are reviewed, followed by a review of additional studies featuring international case studies.

2.3.1. Dutch emission model

As stated before, TNO is responsible for the EF of the Dutch emission model which is a major part of uncertainty in all transport emission models [26]. TNO conducted research of the uncertainties in activity data and EF using Monte Carlo simulation and expert judgement to estimate the total uncertainty for road transport. In the research a distinction is made in vehicle types of passenger cars, light duty vehicles, heavy duty vehicles, and buses. However, TNO did not make a distinction in road types in their research of the uncertainties of pollutants for traffic in 2017 but did in their previous research of 2004 [5, 7]. As a result, no good comparison can be made between the two studies of the uncertainty in activity data and EF. The results of the research of TNO in 2017 showed that the uncertainty of activity data is for every vehicle type 5%, with the exception of heavy duty vehicles which as an uncertainty of 10%. The uncertainty of EF are the same for every vehicle type which is 20% [7]. The complete results of uncertainties in activity data and EF are stated in Appendix A.

TNO have also performed efficiency studies of the AERIUS Calculator model in 2011 and 2013 by order of the ministry [45, 12]. The report states that input data (data management) is of great importance for the accuracy of the model. However, it's noteworthy that these studies did not encompass a comprehensive evaluation of the delivery, processing, and verification procedures of third-party data [13]. This is a limitation of the research which leads to epistemic uncertainty. Local governments are responsible for their own input data for the emission model. Therefore, it is important to research the data delivery of third-parties. The outcome of the TNO studies presented also uncertainties of deposition calculations of the AERIUS model. This research only focuses on the concentration calculation of emissions and not the deposition.

2.3.2. Other studies

Several studies are conducted on the effects of uncertainties in input parameters on the outcomes of various emission models used abroad. Researchers usually use a sensitivity analysis to determine these effects. The sensitivity analysis helps discriminate between uncertainty of parameters that contribute to the outcome and that do not. The paper by Kioutsioukis et al. (2004) discusses multiple studies on how to perform a sensitivity analysis to determine uncertainties in an emission model. The methods differ from one-at-a-time analysis, a Monte Carlo Simulation, and global sensitivity analysis methods to a combination of these methods [23].

The one-at-a-time analysis is a common method by varying single input variables within realistic limits. Most of the time, this method is chosen in combination with another method. The study of Dey, Caulfield, and Ghosh (2019) uses an one-at-a-time analysis in combination with simultaneous varying 2 or 3 input parameters to determine the impact of factors on the emission outcome [9]. Kühlwein and Friedrich (2000) uses a similar approach only in the form of a statistical method for error estimation. According to the paper, the emission of a pollutant can be expressed as a function of input parameters. In the used emission model IER, the input parameters are EF, traffic parameters (traffic volume, vehicle fleet composition, driving pattern mix), and road-specific parameters (speed limit, number of traffic lanes, course of road, gradient). By varying a single input parameter in the calculation model, the sensitivity can be determined with respect to the input parameter. Then, based on the sensitivity of the parameter, the absolute error of emission related to the error of the input parameter can be calculated [27].

Another widely-used method is the Monte Carlo Simulation. The study by Holnicki and Nahorski (2015) utilizes this method to evaluate the uncertainty of pollutant concentration forecasts in relation to input emission data uncertainty [19]. Pollutant concentration forecasts are made using the emission model CALPUFF. In the research the aim is to represent how the emission uncertainty relates to the emission measured at receptor points. Kioutsioukis et al. (2004) combines the Monte Carlo simulation with global sensitivity analysis. The global sensitivity analysis methods employed are variance-based and screening methods. The screening method identifies the most influential input parameters, followed by quantitative sensitivity analysis [23].

The studies by Dey, Caulfield, and Ghosh (2019), Kioutsioukis et al. (2004), and Kühlwein and Friedrich (2000) included input parameters from emission models in their analysis. The traffic parameters (traffic volume, vehicle fleet composition) used in the emission models are often derived from traffic models. In a traffic model, uncertainties also play a role, causing the outcome of the emission model to be uncertainties on uncertainties. This adds complexity to determining uncertainty of an emission model. In addition, the uncertainty of EF is a major part of the uncertainty in all transport emission models [26]. Therefore, most studies in the literature focus on uncertainties originating from EF. The study of Frey (2007) stated typical sources of uncertainty are in EF and in emission inventories; these include random sampling error, measurements error, non-representatives of the real world, and sources related to the lack of knowledge and missing data in the emission inventory [16]. These sources of uncertainty represents the epistemic uncertainty mentioned in Section 2.2.

2.4. Knowledge gap

As discussed in Section 2.3, the existing literature encompasses a range of studies that explore methods for evaluating uncertainty in emissions models. Within the Dutch context, TNO has quantified uncertainties associated with EF and activity data [7]. However, a noteworthy limitation of TNO's research is that it did not delve into the research of obtaining, processing, and validating data from third parties. TNO's analysis specifically addresses epistemic uncertainty. Similarly, the studies by Dey, Caulfield, and Ghosh (2019), Kioutsioukis et al. (2004), and Kühlwein and Friedrich (2000) also center on epistemic uncertainty. These studies highlight that uncertainties in input parameters lead to corresponding uncertainties in model outcomes [9, 23, 27].

Emission models for air quality and deposition in the Netherlands need multiple input variables to compute NO_2 concentrations. Certain input variables, such as *selection of roads*, have vague guidelines or regulations. As indicated in Section 2.2, this is a form of linguistic uncertainty.

Numerous studies have addressed uncertainties related to input variables and EFs within emission models such as COPERT and IVE, which are used abroad. However, an examination of how input variables impact Dutch emission models, specifically focusing on linguistic and ambiguity uncertainty, remains absent in current literature. The literature focuses on the potential influence of the lack of knowledge or data (epistemic uncertainty). What remains to be explored are the practical problems users of the emission model deal with and determine its effect on the model's outcome.

3 Methodology

The core objective of this research is to understand the practical problems faced by decision-makers within local governments in dealing with emissions modeling. Acknowledging the necessity of capturing the practical problems faced by decision-makers, the study employs a pragmatic methodology that encompasses interviews, surveys, and sensitivity analyses. In the first phase of the research, a problem analysis is conducted addressing both the topics of nitrogen deposition and air quality. The second phase of the study applies a sensitivity analysis to the practical problems found with input variables. First, the method of the problem analysis is explained in Section 3.1, followed by the sensitivity analysis in Section 3.2.

3.1. Problem analysis

In the problem analysis, interviews and surveys are conducted. The interviews provide more knowledge on the broadness of the topic, looking for both practical problems in the emission model of deposition and air quality. Subsequently, additional surveys are carried out to acquire more detailed information related to air quality monitoring. First, the methodology of the interviews is explained, and afterwards, the survey.

3.1.1. Interview methodology

In the research, nine interviews are conducted with municipalities, environmental agencies, and the province of South Holland. There are two disciplines regarding nitrogen; air quality and nitrogen deposition. For the interviews, the focus groups are the environmental agencies and municipalities that are part of the nitrogen agglomeration stated in section 2.1.2. Environmental agencies perform and advise municipalities about environmental monitoring of noise, air quality, and safety. They have a mandate, which means they may act for a governing body but the governing body remains the responsible party. Municipalities hire environmental agencies to perform specific tasks. Some environmental agencies are more specialized in nitrogen deposition calculations and others in the monitoring of air quality. For example, DCMR is more specialized in monitoring the air quality, and the environmental agency of Haaglanden in checking nitrogen deposition calculations for permits. Not every interviewee is an expert in both disciplines of deposition and air quality.

The quantity of interviews conducted adheres to the principle of data saturation, which signifies that no further interviews are carried out once no new value-added information is obtained from them [34]. In Table 3.1 an overview is given of the interviews conducted and in which topic the interviewee is an expert. For the interviewee's privacy, the names have been omitted and will be referred to a label in the text.

Table 3.1: Participants interviews

Label	Organisation	Expertise	Topic
I	Municipality of Delft	Policy advisor	Deposition
II	Municipality of Westland	Supervisor nature legislation	Deposition
III	Environment agency Haaglanden	Environmental licensing authority	Deposition
IV	IPLO (phone call 15 minutes)	Advisor air quality	Air quality
V	Environment agency West-Holland	Advisor environment quality	Both
VI	Municipality of Utrecht	Advisor air quality & nitrogen	Both
VII	Municipality of Rotterdam	Advisor air quality & nitrogen	Both
VIII	Environmental agency DCMR	Senior advisor air quality	Both
IX	Province of Zuid-Holland	Strategic advisor for policy analysis	Both

For the interviews, the methodology proposed by Adeoye-Olatunde and Oleniks (2021) is used as a guideline [1]. The order of the method is adjusted in this research. Initially, the first step is to determine the appropriateness of the method which is based on the purpose of conducting interviews. In this research the first step is to determine the objective of the interview. Based on the objective good research questions can be established, which helps in the second step. The following seven steps are taken to retrieve data from the interviews:

1. Objective of interview
2. Preparing semi-structured interview
3. Sampling and participant recruitment
4. Conducting the interview, transcription, and data transmission and storage
5. Data analysis
6. Drawing conclusions
7. Reporting results

All the interviews are semi-structured. This method is chosen because it has more flexibility to deviate from the standard interview questions since the goal is to analyse the potential problems in input data of emission models. Semi-structured interviews are used when the goal is to better understand the person's perspective instead of a generalized understanding of a phenomenon [1]. The semi-structured interview format used during the interviews can be found in appendix B. In order to prepare interview questions, three themes are considered that are derived from the sub-questions of Chapter 1.

- Input data of the emission model
- Uncertainties in model input
- Grey areas in the method

The next step is to sample the participants. As stated before, the focus groups are environmental agencies and municipalities. The selection of municipalities is based on one of the following three criteria; how far the municipality is from Natura2000 area, if the municipality lies in a focus area, or if it is part of the SLA. Municipalities closer to Natura2000 areas are expected to have more problems with nitrogen emissions as more pollutants will deposit in the Natura2000 area. Additionally, a mix is chosen between smaller and larger municipalities. The organisations are contacted via email, phone, or personal message via LinkedIn to schedule an appointment for an interview. The interviews took place at location or online via Teams, depending on the interviewee's preference. Every interview is recorded with the consent of the participant. Using the recording, the interview transcript is written immediately the day after. All transcripted interviews are inserted in the software MAXQDA to perform a content analysis. Based on the analysis, conclusions are drawn about the practical problems of input variables.

3.1.2. Content Analysis

For the content analysis of the interviews, the software MAXQDA is used to code data. A hybrid method of deductive and inductive coding is used for determining the coding. Some codes are predetermined based on the literature study of Chapter 2, and some codes are included during coding. A disadvantage of deductive coding is that you may miss out on key insights because of the narrow focus approach of predetermined codes [11]. By combining the two methods, specific topics raised in interviews can be coded. The danger of the hybrid method is that too many codes are created, making the analysis unclear. Therefore, an iterative approach is used to determine the codes. This mitigates the limitation of the hybrid approach.

The two main codes are derived from the theoretical framework, Chapter 2, which are air quality and nitrogen deposition. Sub codes are created for these two codes which are linked to the emission model's input variables in Figure 2.3. The table below gives an overview of the codes used in the content analysis.

Table 3.2: Codes content analysis related to uncertainty

Main codes	sub codes
Air quality	
	Selection of roads
	Intensities
	Stagnation factor
	Traffic model
	Emission factors
	Tree factor & building type
Nitrogen Deposition	
	Selection of roads (fineness & radius)
	Intensities
	Traffic model
	Shielding structure
	Emission factors

3.1.3. Survey

As part of the study, a survey are conducted during the annual SLA conference in Amsterdam. The SLA is involved in assessing air quality in various sectors in the Netherlands, including mobility. The survey is specifically related to monitoring of the air quality and included questions on the:

- Use of data (traffic model, measurements, otherwise),
- Vehicle class (weight, length, otherwise),
- Road selection,
- Uncertainty in the model according to respondent, and
- Positive and negative points of SLA & CIMLK.

The complete survey questions can be found in Appendix C. In the survey, a combination of open and multiple-choice questions are used. Fileradar's Traffic Effects platform was used to conduct the survey. In addition to surveying at the SLA conference, it was also sent to the general email address of municipalities. The selection process involved considering the size of the municipalities, followed by using a random sampling approach for distributing the survey. In total, 20 municipalities filled in the survey.

Table 3.3: Respondents survey air quality

Label	Municipalities	Label	Municipalities
A	Oss	K	Lansingerland
B	Houten	L	Almere
C	Huizen	M	Zoetermeer
D	Barendrecht	N	Schagen
E	Maastricht	O	Breda
F	Nijkerk	P	Westerwolde
G	Ridderkerk	Q	Ridderkerk
H	Bloemendaal	R	Goes
I	Middelburg	S	Pijnacker-Nootdorp
J	The Hague	T	Waadhoeke

3.2. Sensitivity analysis

In the problem analysis the practical problems for the input variables of the emission models are identified. The subsequent step assesses how these problems may impact the model's outcome. This impact can be evaluated through either sensitivity analysis or uncertainty analysis. Sensitivity analysis aims to identify input variables with the most significant influence on model's outcome. It quantifies how changes in an individual parameter affect the result while keeping all other parameters constant. On the other hand, uncertainty analysis generates a broad range of possible outcomes and focuses on the uncertainties associated with input variables [29]. A commonly used method for uncertainty analysis is the Monte Carlo simulation. Before running this simulation, it is essential to derive probability functions for the input parameters based on sample data. However, Monte Carlo simulations have some limitations. Setting up the simulation can be complex, particularly when dealing with models with numerous variables. Additionally, running the simulation can be computationally intensive. Moreover, assumptions must be made about the probability distributions of the input parameters, which can introduce subjectivity and potentially impact the analysis results[29, 22].

The emissions model is a complex model that depends on multiple parameters. The probability distributions of the parameters require multiple assumptions to be taken for the Monte Carlo simulation. In a sensitivity analysis, this is not the case. It varies the input variables of a model to extreme values to analyze the effect on model's outcome [24]. Therefore, a sensitivity analysis is conducted in this research. The sensitivity analysis is performed on the input variables for which local decision-makers encounter practical problems. The analysis aims to verify if practical problems result in significant changes in model's outcome and determine which input variables have significant effect. Multiple sensitivity analyses are performed on input variables from which practical problems have been identified. The sensitivity analysis method used is a One At a Time (OAT) analysis.

In the OAT analysis, one input variable is systematically adjusted with a factor while all other variables remain constant. Applying this methodology to input variables makes it possible to distinguish and determine the relative impact of each input variable on variation of the model outputs [4]. As a result, this process eases the determination of the key input variable that significantly influences the variability in model's outcomes.

In the Dutch emission models, *traffic volume* based on vehicle's weight distribution is used. However, distribution based on vehicle's length is also frequently used. In the research, a sensitivity analysis is performed to determine the effect of using length distribution instead of weight distribution. For this, the conversion matrix of Fileradar is used. Fileradar researched the traffic volumes used in emissions models and developed a matrix to transform the vehicle classes' length distribution (L1, L2, L3) to weight distribution (L, M, Z). The conversion matrix is based on the total vehicle kilometers traveled throughout the Netherlands in 2019, public data sources about the vehicle fleet, and mileage. Adding and normalizing all vehicle kilometers yielded the conversion matrix presented in Table 3.4. A detailed description of the method and data of the conversion matrix is available in Appendix D.

Table 3.4: Conversion matrix vehicle classification

	L1	L2	L3
L	100%	67.61%	0%
M	0%	22.52%	18.61%
H	0%	9.88%	81.39%

As a starting point, data is used from the CIMLK monitoring tool, which contains data from municipalities of previous monitoring years. In particular, the data set used in this study corresponds to the monitoring year of 2021. The data from the monitoring tool consists of two essential components: the receptor and segment file. The receptor file contains all calculation points, and the segment file contains input data for these points, such as stagnation factor and traffic volume for different vehicle classes. The segment files are adjusted for the sensitivity analysis by applying factors to the analyzed input variables. Then, the modified segment file and the unmodified receptor CSV file are uploaded into the online calculation tool of CIMLK. CIMLK provides an online computational tool that is public for anyone to perform computational tasks related to air quality. The tool includes the same calculations performed in air quality monitoring.

From the tool, the results are sent per mail in which the calculated concentration of NO_2, $PM_{2.5}$, and PM_{10} are stated. The downside of the computation tool of CIMLK is that a limit of 9 computational tasks can be performed simultaneously, regardless of who is performing the calculations. Careful and accurate work must be done beforehand when uploading the computational tasks to ensure that the adjusted data in the files is correct.

4

Practical problems in the model: A problem analysis

This chapter elaborates on the results of interviews and surveys conducted. The practical problems faced by decision-makers in local government are discussed in more detail. The results regarding the practical problems of input variables are divided into two topics: air quality monitoring and nitrogen deposition. The calculations for the monitoring of the air quality is a reconstruction of the previous year and the deposition calculation is a worst-case approach of a project or activity.

4.1. Air Quality

Municipalities in focus areas and participants of the SLA are mandatory to deliver data for the monitoring of the air quality. Chapter 2 represents an overview of input variables for the emission model for air quality. This paragraph explores each input variable where, according to the results of the interviews and surveys, the practical problems lie. Figure 4.1 gives an overview of the input variables of air quality.

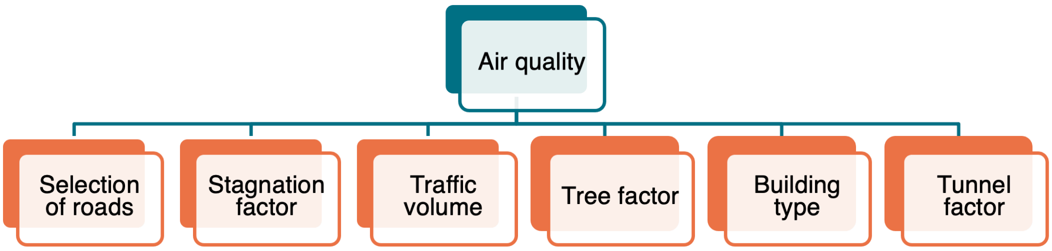

Figure 4.1: Input variables air quality

4.1.1. Selection of roads

As stated in Chapter 2, the laws and regulation regarding the monitoring of the air quality are not clear on which roads municipalities need to consider [42]. It only states agglomerations in focus areas are mandatory to collect data for monitoring. This guideline is open for interpretation as to which roads are concerned. According to Section 2.2 this is a form of linguistic uncertainty. In the interviews and survey the question is asked which roads are considered for the monitoring. Overall, the same roads used in the traffic model are used in the monitoring tool, except roads with less than 100 vehicles per day (*Survey: B, E, G, K, L, O* & *Interview: VI, VIII*). The reason for including all roads of the traffic model is to make all data available to the public (*Interview: VIII*). The follow-up question in the survey is related to the traffic model used. All participating municipalities in the research use a version of the traffic model Omnitrans, developed by Goudappel. However, traffic models may differ from each other depending on the preference and purpose from the municipality or metropolis. This is also reflected in the lower limit of roads included in the monitoring. Whether or not 30 km/h roads are included varies from municipality to municipality (*Survey: B, L*). A different approach is used by another municipality, where roads with a traffic volume of more than 1,000 vehicles per day are included (*Survey: O*). Bottom line, all the main roads are included in the monitoring, but there is variation in the lower-order roads included.

The respondents of the interviews and surveys did not state whether or not they expect these problems contributes to the uncertainty in the outcome of the model. In the results there is also unawareness by some decision-makers of which roads are included (*Survey: A, F & Interview: V, VI, VII*). They have no idea why there is chosen for the current *selection of roads* or how the decision was reached.

4.1.2. Stagnation factor

In the input variable *stagnation factor*, there is a lot of unawareness of how it is determined. Some respondents outsource the task to an environmental agency like DCMR or a consultancy firm (*Survey: G, O*). Reasons for this are the complexity of the calculation and limited time and manpower. The municipality of Maastricht, Ridderkerk, The Hague, and Lansingerland uses their traffic model to determine the *stagnation factor*. In the interviews and survey none of the respondents stated there are practical issues with the input variable. Only the municipality of Breda state that multiple estimates, such as the *stagnation factor*, are not completely precise. In addition, the company Fileradar does suspects there is a potential uncertainty in the input value. This is because it is derived from traffic model data rather than empirical data.

4.1.3. Traffic volume

The input variable *traffic volume* is mostly based on the traffic model in combination with loop measurements. Loop measurements determine *traffic volume* on the roads based on the length distribution of the vehicles, where the vehicle classes are L1, L2, and L3. Not every loop measurement has this functionality, therefore *traffic volume* cannot be determined everywhere in this way. Another method used, in the center of Rotterdam, is licence plate scans. Based on the licence plate, information about the type of car and weight class is gathered. This method gives an accurate distribution of the vehicle classes based on the vehicle's weight (L, M, Z, buses). However, it depends on the presence of license plate recognition cameras, which is not present everywhere.

All the participating municipalities in the survey used a traffic model from Goudappel. What is interesting to see is that some municipalities state the traffic volume is distributed by the vehicle's weight, and some state it is distributed by the vehicles' length. Utrecht also utilizes a traffic model provided by Goudappel. However, during their interview, they explicitly mentioned that the *traffic volume* is determined by vehicle length distribution rather than weight distribution. This stands in contrast to other municipalities that use a Goudappel traffic model, as they indicate the use of vehicle weight distribution for *traffic volume* calculations. Consequently, there is a discrepancy in the responses, making it unclear whether the traffic model predominantly relies on weight or length distribution for vehicle distribution (*Survey: B, E, G, J*).

In addition, some municipalities do not know the vehicle category used for *traffic volume* (*Survey: B, F, S*). Nonetheless, vehicle distribution based on vehicle's length causes potential error in the outcome of the emission model. The distribution based on length and weight is not uniform across all classes. Fileradar conducted a preliminary analysis of the weight and length distribution. From the analysis, it appeared that *traffic volume* in the monitoring overestimates the vehicle class middle heavy and heavy and underestimated the vehicle class light. Chapter 5 will explore this in more detail.

The larger municipalities such as Rotterdam, Utrecht, The Hague, and Amsterdam are planning to implement environmental zones or zero-emission zones for specific vehicle types, such as delivery vans (*Interview: VI, VII, VIII*; [41]). Therefore, the vehicle distribution must be accurate to determine the effects of zero-emission zones. With the distribution based on the length, it is difficult to distinguish between passenger cars and delivery vans (*Interview: VII, VIII*). This possibly adds to the uncertainty of the concentration calculation of nitrogen in local situations. Therefore, there is a demand from municipalities to have a more accurate distribution of vehicles.

4.1.4. Tree factor, building type & tunnel factor
For the input variables *tree factor*, *building type*, and *tunnel factor* default values are used in the concentration calculation, which are mentioned in Section 2.1.2. According to DCMR, practical problems and, thus, uncertainty lie in the local situation of municipalities because they are default values. The default values of CIMLK, such as *tree factor*, do not apply to local situations, and it is difficult to determine which factor fits which situation. Therefore, DCMR uses aerial photographs to determine the local situation of roads. The input variables *tree factor*, *building type*, and *tunnel factor* are part of a municipality's basic registration of roads. But the accuracy of the basic registration varies from municipality to municipality, and the better the basic registration, the more accurate the road traffic concentration calculation (*Interview: VIII*).

4.1.5. Emission factors
The EF of emission models also plays a part in the uncertainty (*Interview: V, VII, VIII*). As discussed in Chapter 2, EF are annually updated by TNO based on the average vehicle fleet of the Netherlands and the newest insights. The constant change in EF contributes to the uncertainty in the model. For the monitoring, you want to have the same established model and only change its input values over time to compare previous years. Due to the latest findings from EF, air quality standards within municipalities may unexpectedly be exceeded, even if this was not the case in the previous year (*Interview: VII*).

Additionally, a part of the uncertainty lies in EF since it does not represents the local situation in municipalities. The distribution of electric and regular vehicles in the Randstad[1] differs from the east of the Netherlands (*Interview: VII, VIII, IX*).

4.2. Nitrogen deposition
The nitrogen deposition calculations are generally worst-case scenarios to minimize the uncertainty of the model's outcome (*Interview: III, IV, VIII*). The calculations are performed when a permit is required for Natura2000 activities. The deposition calculations include future scenarios, making it challenging to estimate input values accurately. For input variables of nitrogen deposition, almost the same input variables apply to air quality. The difference is mainly in the data management approach. In Figure 4.2 the same input variables are stated as in Chapter 2. For nitrogen deposition practical problems are found for the same input variables as for the monitoring of air quality. The practical problems of the input variables *selection of roads*, *stagnation factor*, and *traffic volume* are stated in this section. For the input variables *shielding structure* and *tunnel factor* no practical problems are found. This section evaluates the practical problems related to input variables based on the results of the interviews.

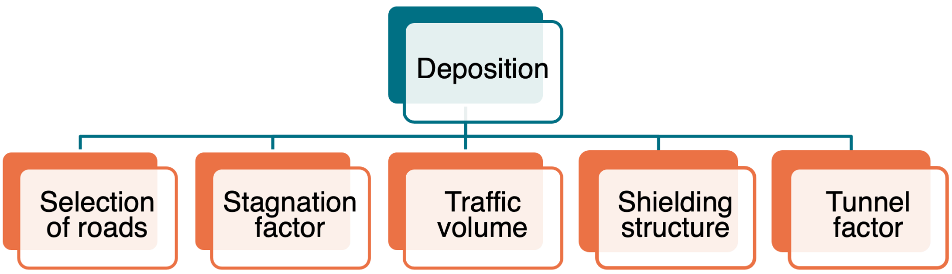

Figure 4.2: Input variables nitrogen deposition

4.2.1. Selection of roads
BIJ12[2] has written a guideline for how to handle input variables in AERIUS. According to the guideline, all roads that receive traffic from an activity or project should be considered in the deposition calculation, except when traffic merges into the prevailing traffic pattern [15]. This guideline is an abstract of

[1] The Randstad is a chain of cities in the western part of the Netherlands [6]

[2] BIJ12 is a Dutch research institute which supports provinces in the implementation of legal tasks and with knowledge, information, and data about the rural area and the physical environment

current jurisdiction of the Netherlands and is used by environmental agencies and municipalities for the calculation and to verify deposition calculations. However, the description of *selection of roads* is unclear and open for interpretation, which is according to Section 4.1.1 a form of linguistic uncertainty. The interviewees see the input variable *selection of roads* as a "grey area" in the nitrogen deposition calculations(*Interview: I, II, III, VI, VII, VIII, IV*).

Given the vagueness in BIJ12's description regarding roads to be included in the calculation, municipalities and environmental agencies have made their own guidelines. Two municipalities, Utrecht and Westland, have developed internal guidelines to consistently deal with this input variable within the projects and activities. Westland's guideline states when a project or activity takes place in the municipality, they include the roads to the nearest provincial road. The traffic volume of provincial roads is larger than the volume generated by a project or activity, therefore the traffic merges into the prevailing traffic pattern. This is Westland's interpretation of BIJ12's description.

Utrecht has based its guideline on the increase of traffic volume generated by a project or activity. If a project or activity leads to an increase of more than 250 vehicles per day on a given road, those roads are included in the calculation. Utrecht compares the absolute difference of the current situation to the future situation which includes the project or activity. Additionally, Utrecht employs a criterion related to the current situation. When there is a traffic volume increase of more than 5%, these roads are also included in the calculations. The decision to maintain the 250 vehicles per day threshold is derived from the margin of error of the used traffic model of Utrecht.

Delft does not have a general approach for the *selection of roads*. For each project or activity, they consider which roads may be relevant to consider in the calculations. When they are not sure about the delineation of the project, a consultancy firm is hired to make the decisions. The province of South Holland states the same and adds that hiring a consulting firm is a typical government response when they are unsure about the delineation of the project or activity.

Multiple participants of the interviews (*Interview: I, II, III, VI, VII, IX*) find it difficult to delineate the area for the deposition calculation. They all agree the guidelines are unclear, and all state it's a grey area in the deposition calculations.

4.2.2. Stagnation factor

For *stagnation factor*, no information is retrieved from the interviews. The same input variable is used in the air quality monitoring. For this research, the assumption is made the *stagnation factor* for deposition and air quality is calculated with the same method. Therefore, the results of the *stagnation factor* of air quality are also applicable to deposition.

4.2.3. Traffic volume

For *traffic volume*, the same approach applies as for air quality in subsection 4.1.3. A traffic model generates the *traffic volume* for the emission model. Another approach commonly used for smaller projects is the use of the CROW document *"future proof parking 2018"* for performing and checking the calculations (*Interview: II, III, VI*). The document states minimum and maximum key numbers with the average number of traffic movements from business parks and residential areas. Because the projects or activities are in the future, it is difficult to estimate the exact additional traffic generated from the projects on the current scene. Therefore, key numbers of the CROW document are used as a guideline for projects. From the document, the maximum value of traffic movements is used for *traffic volume* to minimize the uncertainty in the results of the deposition calculation (*Interview: II, III*).

The environmental agency Haaglanden and Westland uses the CROW document for checking the deposition calculations. For them, it is difficult to have a "feeling" whether the data inserted for *traffic volumes* are correct because they do not have a background in traffic engineering. Besides the key numbers of CROW, also experience numbers are used. The experience numbers come from businesses themselves, they can estimate how many traffic movements their business generates. However, this is difficult to check for the environmental agencies as well.

4.2.4. Shielding structures & tunnel factors

As stated in subsection 2.1.1 the *shielding structures* and *tunnel factors* are both boxes to check in the AERIUS Calculator. The interview results do not discuss practical issues related to these input variables.

4.3. Conclusion

This chapter identifies the perceived practical problems according to the participating municipalities of the interviews and survey. For both air quality and nitrogen deposition, practical problems are found. In Table 4.1, the input variables of the emission model are linked to the three types of uncertainties mentioned in Section 2.2. In the table, there are three different symbols used which represent to which emission model it is applicable. The triangle represents air quality, the cross nitrogen deposition, and the square both air quality and nitrogen deposition.

Input variable	Epistemic uncertainty	Linguistic uncertainty	Ambiguity uncertainty
Selection of roads		■	
Traffic volume	■		X
Stagnation factor	■		
Building type			▲
Tree factor			▲

Table 4.1: Type of uncertainties in input variables

The input variable *selection of roads* has a form of linguistic uncertainty in both emission models of air quality and deposition. For both models, there are unclear regulations or guidelines of which roads to include. In the deposition topic, multiple municipalities refer to *selection of roads* as a grey area in the calculations (*Interview: I, II, III, VI, VII, VIII, IV*).

Traffic volume contains a form of epistemic uncertainty. Both vehicle weight and length distributions are used in deposition calculations and in air quality monitoring. However, these are not equal to each other, leading to a mismatch of *traffic volume* in the vehicle classes. Using the *traffic volume* classification incorrectly may be due to a lack of data from the weight distribution or ignorance about which distribution to use. Either way, there is some form of epistemic uncertainty at play with this input variable.

The input variable *traffic volume* also contains ambiguity uncertainty for nitrogen deposition when the key number of the CROW document is used. The CROW document gives guidelines for *traffic volume* for certain situations (*Interview: II, III*). The applicability or adjustments of the key numbers are open to interpretation and depend on the calculation for the project or activity.

Most participants do not know how the input variable of *stagnation factor* is determined. This is because the task is outsourced to a consultancy firm or environmental agency. Therefore, epistemic uncertainty plays a role in the input variable of both nitrogen deposition and air quality.

The input variables *building type* and *tree factor* have practical problems related to ambiguity uncertainty. For both input variables, default values are used in the monitoring tool. Clear guidelines have been written about which factor applies. However, the factor depends on local situations (*Interview: VIII*). Thus, default factors inserted in the monitoring tool depend on the person assessing the location. Therefore, identical locations can have varying default factors. DCMR only stated that the input variables *building type* and *tree factor* have practical problems. The rest of the interview and survey participants did not mention it.

5 Sensitivity Analysis

Building upon the findings presented in Chapter 4, this chapter embarks on a comprehensive sensitivity analysis of the factors influencing air quality. The sensitivity analysis is conducted on the municipalities of Utrecht and Almere. Both municipalities participated in this research and clearly explained the data used in the monitoring tool. Moreover, the municipalities have different urban features, which creates a good mix for this research. Almere is a relatively new municipality with a modern city plan, and Utrecht has a historical city center and is located in the middle of the Netherlands. Both municipalities differ in road network and traffic volume according to the CIMLK data. Table 5.1 gives the key features of both municipalities. The total length stated in Table 5.1 includes all the roads in the municipality, such as the roads of residential areas. The traffic volume and stagnating traffic are given as the annual averages.

Table 5.1: Data key features Utrecht & Almere - data CIMLK 2021

	Utrecht	**Almere**
Total road length $[km]$	2,221	2,284
Road length included in CIMLK $[km]$	504	841
Traffic volume (L) *annual average* $[veh/day]$	15,615	6,269
Traffic volume (M) *annual average* $[veh/day]$	808	363
Traffic volume (Z) *annual average* $[veh/day]$	764	226
Stagnating traffic *annual average* $[veh/day]$	955	20

In this chapter, multiple sensitivity analysis are performed. The first analysis determines the effects of the individual input variables of *traffic volume* and *stagnation factor* in section 5.1. Moving forward, in Section 5.2 the conversion matrix of Fileradar is applied to determine the simultaneous effect of the vehicle classes on the NO_2 concentration. Section 5.3, analyses the implications of excluding specific roads within the monitoring tool. In Section 5.4, the effect of different *building types* on the NO_2 concentration, and in Section 5.5 the effect of the *tree factor* is investigated. At the end of the chapter, in Section 5.6, a conclusion is given.

5.1. Impact of Additional Traffic on Concentration Levels

In this sensitivity analysis, additional vehicles are added to the input variables *traffic volume* and *stagnation factor*. Here, *traffic volume* is considered individually across the vehicle classes: light, middle heavy, and heavy traffic. The inclusion of extra traffic allows for the evaluation of its impact on the outcome of the models concentration levels. In the case of Utrecht, additional traffic volumes of 100, 300, and 500 vehicles are added, while for Almere, traffic volumes of 50, 100, and 150 vehicles are added. The traffic volume and number of stagnant vehicles are higher in the municipality of Utrecht than in Almere, according to Table 5.1. As a result, Utrecht received larger additional vehicles.

Furthermore, the added vehicles are partly based on the effect of the conversion matrix (Table 5.2) on *traffic volume* of the individual vehicle classes. Appendix E, Table E.1 shows the differences in traffic volumes of the individual vehicle classes when the conversion matrix is applied to the traffic volume of Utrecht and Almere. When the matrix is used, there is an increase of 546 vehicles per day for light vehicles in Utrecht and 245 vehicles per day for Almere. The choice of added vehicles is based on the maximum increase in vehicles when applying the conversion matrix.

The *stagnation factor* is based on the fraction of the traffic volume, which has a speed lower than 15 km/h. The "new" *stagnation factor* is calculated based on added stagnating vehicles. The "new" *stagnation factor* is explained based on the example network in Figure 5.1. The left side of Figure 5.1 states the "original" network and the right side states the "new" network with the added stagnated vehicles. Every link in the network has a traffic volume and a *stagnation factor*. The number of stagnant vehicles is calculated by multiplying the traffic volume with the *stagnation factor*.

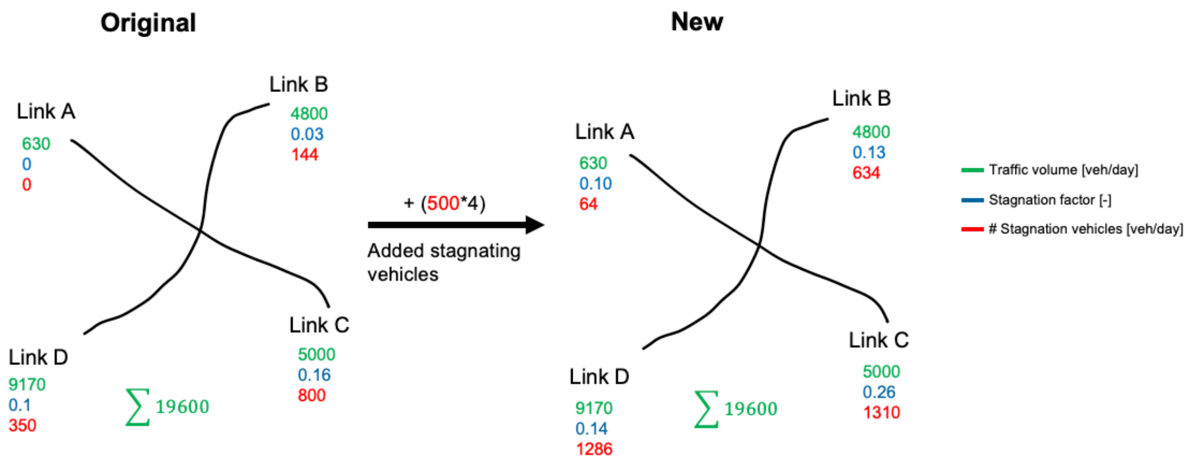

Figure 5.1: Explanation of calculating the "new" *stagnation factor*

In this example, 500 stagnating vehicles are added and evenly distributed across the network by multiplying the number of vehicles added by the number of links in the network. In the network, of Figure 5.1, there are four links; therefore, the number of stagnant vehicles added is multiplied by four. This leads to an additional 2000 vehicles per day of stagnating vehicles.

For Link A in Figure 5.1 the new number of stagnating vehicles is calculated with Equation 5.1. In the equation, the original stagnating vehicles are added to the new stagnating vehicles. The new stagnating vehicles are calculated by dividing the traffic volume by the network's total traffic volume and multiplying it with the 2000 added stagnating vehicles. This leads to 64 stagnating vehicles at link A in the "new" network.

$$Stagnating \quad vehicles \quad Link_A = 0 + (\frac{630}{19600}) * 2000 = 64 \tag{5.1}$$

Subsequently, the ”new” *stagnation factor* is calculated with Equation 5.2. Herein, the number of stagnated vehicles is divided by the traffic volume on that specific link. For link A this leads to a ”new” *stagnation factor* of 0.10. For the other links, the same method applies.

$$New \quad stagnation \quad factor \quad Link_A = \frac{64}{630} = 0.10 \tag{5.2}$$

The sensitivity analysis results are presented in a radar diagram. In the radar diagram, each axis shows the input variable stagnant traffic, light traffic, medium traffic, or heavy traffic. The blue lines in the diagram are the 100 additional vehicles, the yellow 300 additional vehicles, and the grey 500 additional vehicles. The results of the radar diagram show how sensitive the NO_2 concentration is to the individual vehicle class and stagnant traffic.

In Figure 5.2 and 5.3, the outcomes of the sensitivity analysis for Utrecht are presented. Figure 5.2 illustrates the impact of additional traffic on the total concentration of NO_2, while Figure 5.3 represents the NO_2 concentration specifically associated with road traffic. The calculation of NO_2 concentration from road traffic is determined by Equation 5.3, which accounts for a portion of the total NO_2 concentration attributed to traffic.

$$\begin{aligned} NO_2 \text{ concentration road traffic} = NO_2 \text{ SRM2 direct concentration} + NO_2 \text{ SRM1 direct concentration} \\ + NO_2 \text{ SRM concentration converted} \end{aligned} \tag{5.3}$$

According to the results, the introduction of 500 extra middle heavy and heavy vehicles leads to a NO_2 concentration from road traffic exceeding 10%. This result is higher than the 3% concentration increase when all sources are considered. In contrast, for stagnant traffic and light traffic, the increase in NO_2 concentrations for both classes remains below 2%. When less vehicles are added, the concentration increase is less significant. For the introduction of 300 extra vehicles, the concentration increase for middle heavy and heavy traffic is around the 6% and 8%.

The effect on light and stagnating traffic is less significant when extra vehicles are added. When 500 vehicles are added, for both light and stagnating traffic there is a NO_2 concentration from road traffic increases of approximately 2%. This is much lower compared with the vehicle class middle heavy and heavy traffic.

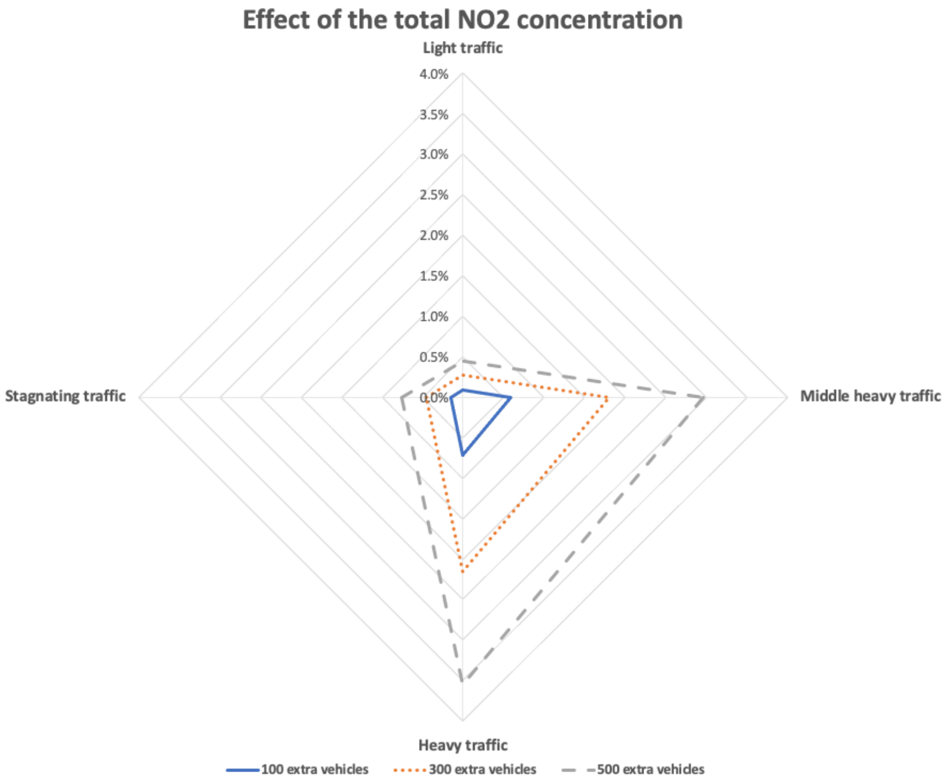

Figure 5.2: Effect of the total NO_2 concentration of Utrecht

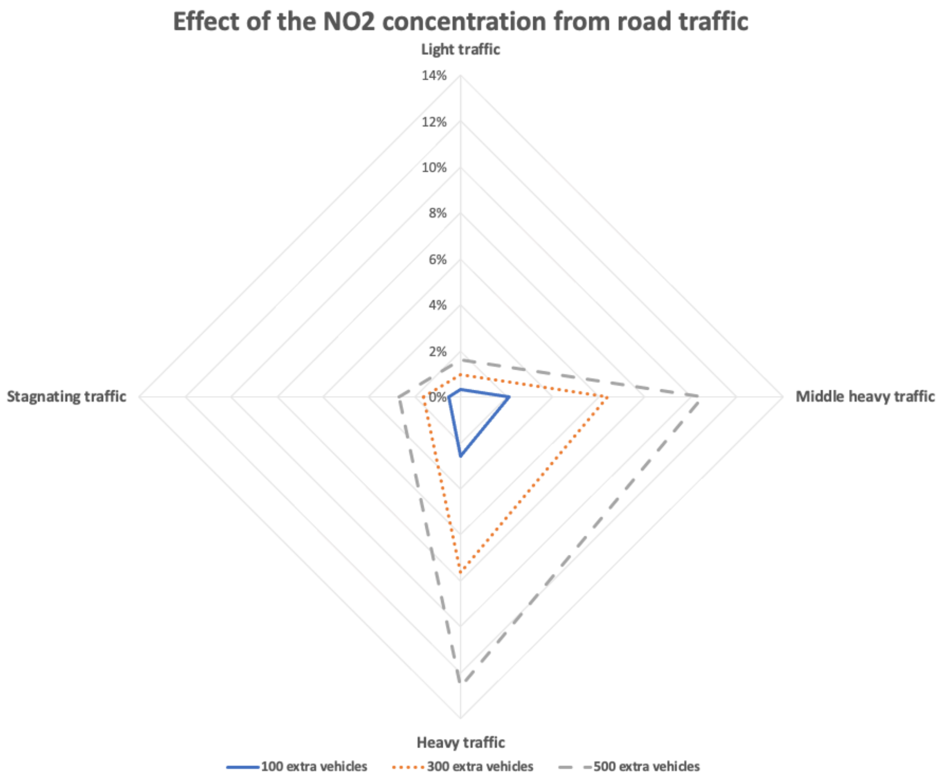

Figure 5.3: Effect of the NO_2 concentration road traffic of Utrecht

The analysis result of Almere is shown in figure 5.4 and 5.5. Figure 5.4 states the effect on the total NO_2 concentration, and Figure 5.5 states the effect on traffic contribution of NO_2. The radar diagram has the same shape as the results of Utrecht; the input values for medium and heavy traffic are more sensitive to additional traffic than light and stagnant traffic. The only difference compared with the results of Utrecht is that the concentrations of Almere are lower.

The results of the radar diagrams of Utrecht and Almere show that the vehicle classes middle heavy and heavy traffic are most sensitive to adjustments in traffic volume. On the vehicle class light and stagnant traffic, the adjustments in traffic volume have hardly any significant effect.

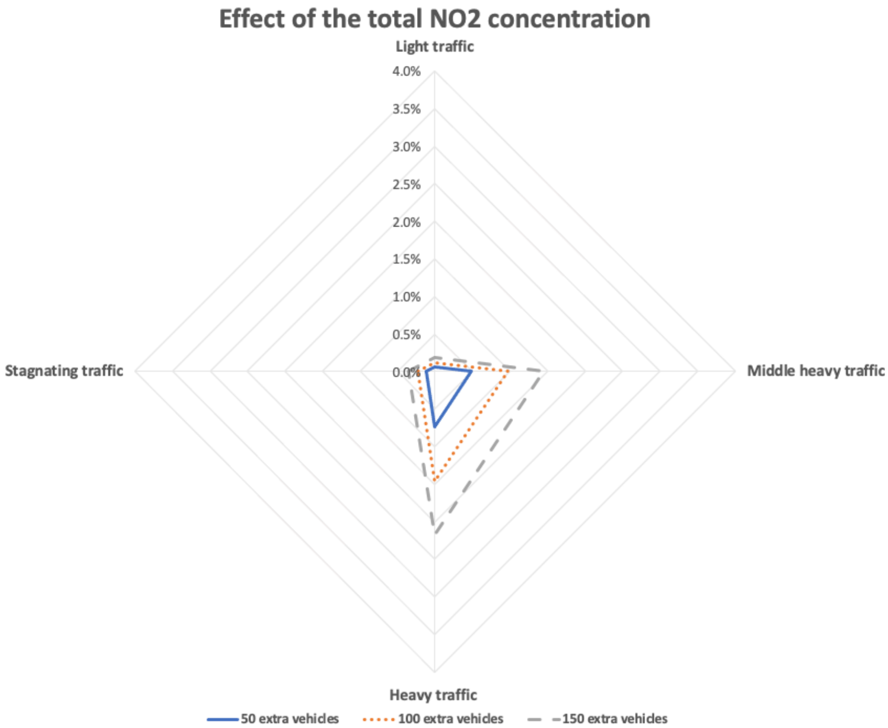

Figure 5.4: Effect of the total NO_2 concentration of Almere

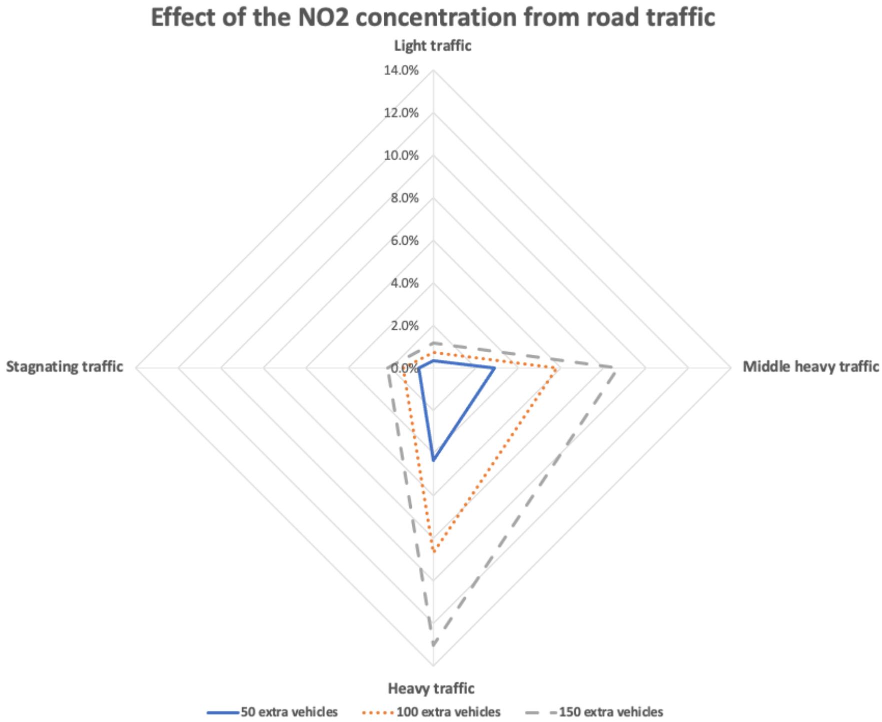

Figure 5.5: Effect of the NO_2 concentration road traffic of Almere

5.2. Impact of Underlying Vehicle Classification

This analysis determines the sensitivity of the interrelationship between the vehicle classes of light, middle heavy, and heavy traffic. The vehicle class can be determined based on the weight distribution or length distribution. The length of vehicles is usually determined through loop measurements on the road, but not all available loops can accurately measure vehicle length. Chapter 4 reveals that some municipalities use the weight distribution of vehicle's, while others use the length distribution, such as Utrecht and Almere. The emission model is based on the vehicle disribution of weight, consisting of light, middle heavy, heavy, and buses. In this analysis, the classification of buses is not considered. Buses are filled in separately in CIMLK and are, therefore, not part of the analysis below.

The vehicle distribution based on vehicle's length instead of weight can cause uncertainty in the outcome of the emission model. The categorization based on length and weight is not uniform across all classes. Fileradar conducted a preliminary weight and length distribution analysis by making a conversion Table (Table 5.2). Appendix D fully explains the method for generating the conversion matrix. Ideally, if the vehicle distribution based on length and weight were identical, the diagonal of the matrix would display a 100% value, as observed in the case of classes L and L1. Based on the table, middle heavy and heavy vehicle classes are overestimated in the emission model.

Table 5.2: Conversion matrix vehicle classification

	L1	**L2**	**L3**
L	100%	67.61%	0%
M	0%	22.52%	18.61%
H	0%	9.88%	81.39%

The matrix is applied to the data of *traffic volumes* from the municipalities of Utrecht and Almere. In Table 5.3, the results of mean concentration in $\mu g/m^3$ are stated for the vehicle classification based on the weight distribution (LMZ) and the length distribution (L123). For the two vehicle classifications the relative difference in percentages are calculated for total NO_2 concentration and NO_2 concentration from road traffic.

In Table 5.3, the results of the mean total NO_2 concentration and NO_2 concentration from road traffic is stated. For both municipalities, there is a decrease in concentration when the conversion matrix is applied. The total NO_2 concentration has a relatively low decrease between the 2-3% and the NO_2 concentration of road traffic a higher relative decrease between the 10-12%. The results of the analysis is inline with the analysis in Section 5.1. The middle heavy and heavy traffic are more sensitive for changes in *traffic volume* than light traffic. The concentration decreases when the conversion matrix is applied because the *traffic volume* of middle heavy traffic heavily decreases. When municipalities uses the length of the vehicles instead of the weight for the vehicle class, there is an overestimation of NO_2 concentration.

Table 5.3: sensitivity analysis of underlying vehicle classification in annual average

		Mean total NO_2 concentration $[\mu g/m^3]$	**Mean NO_2 concentration from road traffic** $[\mu g/m^3]$
Utrecht			
	L123	22.28	6.27
	LMZ	21.60	5.59
	relative difference	-3.05 %	-10.85 %
Almere			
	L123	12.31	2.05
	LMZ	12.04	1.79
	relative difference	-2.18 %	-12.85 %

5.3. Impact of Road Selection

From the results of Chapter 4, it is unclear which lower-order roads need to be included in the monitoring of air quality. This specifically involved 30 km/h roads within municipalities. Hence, in the sensitivity analysis regarding the *selection of roads*, the decision has been made to exclude all roads with a speed limit of 30 km/h from the segment file. This way, the contribution of 30 km/h roads can be determined. This approach is used since it is challenging to include extra roads in the monitoring without determining the traffic volumes. Excluding roads does not have the same effect as adding roads. But by considering the effect of fewer roads, it can be assumed that the sensitivity of adding roads is the inverse.

As stated before in Table 5.1, there is 503.9 km of roads included in the monitoring tool for Utrecht and 841 km for Almere. In Figure 5.6 an overview is given of the distribution of roads by speed limit for Utrecht and Almere inserted in the monitoring tool of CIMLK. From these roads included in the monitoring tool 5% are 30 km/h roads in Utrecht and 37% in Almere. These percentages correspond to the values in Table 5.4, where road length in km is shown by the distribution of speed limit.

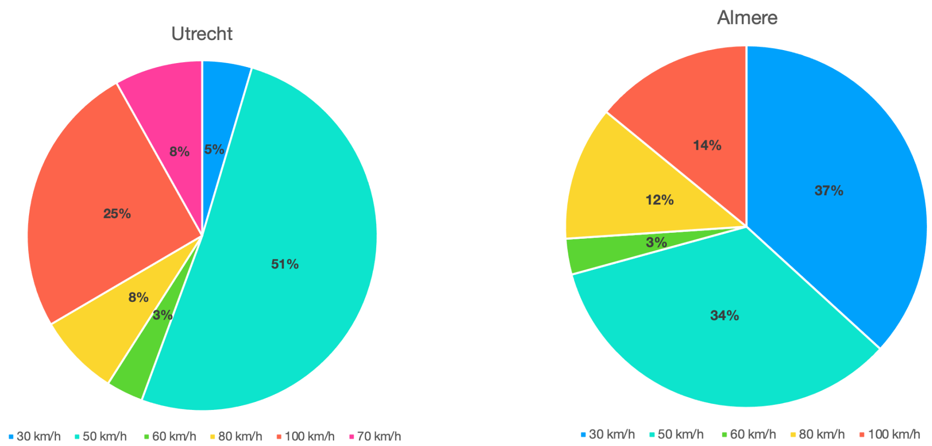

Figure 5.6: Distribution of roads by speed limit in CIMLK

Speed limit	Utrecht road length in CIMLK $[km]$	Almere road length in CIMLK $[km]$
30 km/h	23.1	309.4
50 km/h	257.2	285.5
60 km/h	17.2	26.9
70 km/h	41.0	0.0
80 km/h	38.0	100.8
100 km/h	127.5	118.4

Table 5.4: Road length in CIMLK

When comparing the road length of the municipalities in the monitoring tool (Table 5.4) with the total road length in the municipalities (Table 5.5), there are a lot of kilometers missing. Figure 5.7 shows in percentages how many roads are included in CIMLK compared to the total number of roads in the municipality. Almost all roads with speed limits greater than 70 km/h are included in the monitoring tool. Utrecht and Almere both include about 30% of 60 km/h roads in the monitoring tool. The difference between municipalities is in the 30 and 50 km/h roads. Almere includes more 30 and 50 km/h roads than Utrecht. In the monitoring tool, 20% of the 30 km/h roads and about 75% of the 50 km/h roads are included by Almere.

In contrast, Utrecht includes less than 5% of 30 km/h roads and less than 40% of 50 km/h roads. The difference between the number of 30 and 50 km/h roads included in the municipality's monitoring tool corresponds to the practical problem mentioned. For municipalities, it is unclear which low-order roads they should or should not include.

Speed limit	Utrecht total road length in CIMLK $[km]$	Almere total road length in CIMLK $[km]$
30 km/h	1142.9	1497.8
50 km/h	706.6	386.2
60 km/h	64.6	95.7
70 km/h	41.0	0.0
80 km/h	53.3	165
100 km/h	130.6	127.1

Table 5.5: Total road length of municipality

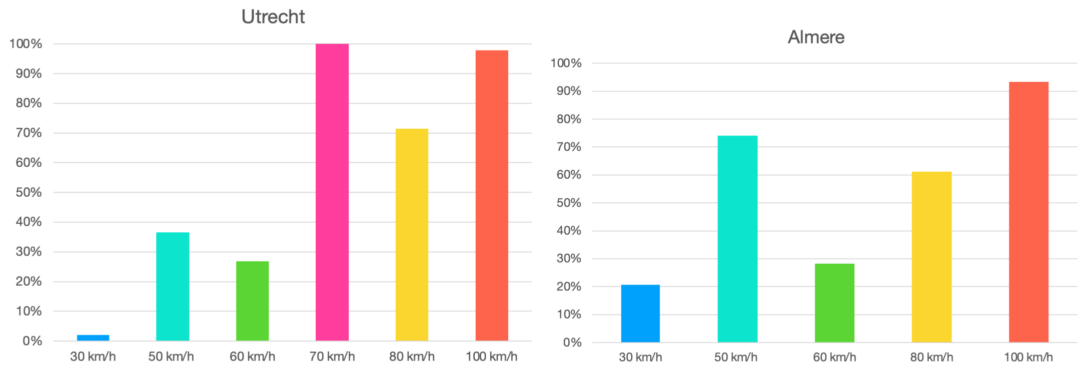

Figure 5.7: Percentage of total road length included in CIMLK

For the sensitivity analysis of the input variable *selection of roads*, the 30 km/h roads are excluded from the monitoring tool. For Utrecht this concerns 23 km and for Almere 309.4 km of roads. For both Utrecht and Almere the total NO_2 concentration and the concentration of road traffic decrease. The NO_2 concentration assigned to traffic decreases significantly between the 9% and 11% for Utrecht and Almere. This shows that when municipalities have chosen not to include 30 km/h roads in the monitoring, they miss about 10% of NO_2 concentration from traffic.

Table 5.6: sensitivity analysis selection of roads - annual averages

		Mean total NO_2 concentration $[\mu g/m^3]$	Mean NO_2 concentration from road traffic $[\mu g/m^3]$
Utrecht			
	With 30 km/h roads	22.28	6.27
	Without 30 km/h roads	21.60	5.59
	relative difference	-3.05 %	-10.85 %
Almere			
	With 30 km/h roads	12.31	2.05
	Without 30 km/h roads	12.12	1.86
	relative difference	-1.53 %	-9.44 %

5.4. Impact of the Building Type

One of the parameters considered when monitoring air quality is *building type*. As explained in Section 2.1.2, the SRM 1 calculation distinguishes four distinct *building types*. The presence of buildings alongside roads significantly impacts pollutant concentrations because it confines the airflow, affecting dispersion. This sensitivity analysis evaluates the influence of these four *building types* on NO_2 concentration. The receptor CSV file for municipalities provides information on both *building types* and *tree factors* at calculation points. One specific *building type* across all calculation points for each calculation task is applied to assess the influence of different *building types*. It's worth noting that apart from the *building type* variable, no alterations have been made to the CSV files regarding other input variables.

Table 5.7 presents the total NO_2 concentration and NO_2 concentration from traffic for both Utrecht and Almere. The results indicate that *building type* 2 exhibits the highest concentration, followed by *building type* 3, *building type* 1, and finally, *building type* 4. *Building type* 2 represents a small street canyon with buildings on both sides of the road, while building type 4 features buildings spread in the area. In the situation of building type 4, the airflow can move the NO_2 concentration more easily than in *building type* 2, where there can hardly be any airflow.

Table 5.7: Building type concentration - annual average

		Mean total NO_2 concentration $[\mu g/m^3]$	Mean NO_2 concentration from road traffic $[\mu g/m^3]$
Utrecht			
	Building type 1	22.384	6.371
	Building type 2	23.450	7.437
	Building type 3	23.018	7.006
	Building type 4	22.048	6.036
Almere			
	Building type 1	12.419	2.164
	Building type 2	12.747	2.492
	Building type 3	12.632	2.377
	Building type 4	12.307	2.053

The tables presented in 5.8 and 5.9 reveal the impact of various *building types* in Utrecht on NO_2 concentrations originating from traffic. They offer valuable insights into how different *building types* influence concentration levels in comparison to one another. For example, substituting *building type* 1 with *building type* 2 results in an increase of 16.73% in NO_2 concentration from traffic. Similarly, replacing *building type* 1 with *building type* 3 leads to a 9.97% increase in NO_2 concentration from traffic. This matrix demonstrates that the improper selection of *building types* can lead to significant fluctuations, either increasing or decreasing the concentration levels of NO_2.

The results concerning the total NO_2 concentration, as displayed in table 5.9, align with those observed for NO_2 concentration from traffic. The key distinction lies in the fact that the percentages are relatively lower in this context.

For the municipality of Almere the same sensitivity analysis is applied. The percentages of the NO_2 concentrations from *building types* from Almere corresponds to the percentages of Utrecht. The results of the sensitivity analysis can be found in Appendix F.

Table 5.8: NO_2 concentration from traffic relative to each other - Utrecht

from \ To	**Building type 1**	**Building type 2**	**Building type 3**	**Building type 4**
Building type 1		16.73%	9.97%	-5.26%
Building type 2	-14.33%		-5.80%	-18.84%
Building type 3	-9.06%	6.15%		-13.85%
Building type 4	5.55%	23.21%	16.07%	

Table 5.9: Total NO_2 concentration from traffic relative to each other - Utrecht

from \ To	**Building type 1**	**Building type 2**	**Building type 3**	**Building type 4**
Building type 1		4.76%	2.83%	-1.50%
Building type 2	-4.55%		-1.84%	-5.98%
Building type 3	-2.75%	1.88%		-4.21%
Building type 4	1.52%	6.36%	4.40%	

5.5. Impact of the Tree Factor

In the case of the *tree factor*, a default set of three values is utilized in the monitoring tool: 1.0, 1.25, and 1.5. Herein, a *tree factor* of 1.0 represents single trees near the road, and a factor of 1.5 represents a road where the leaves of the trees span at least one-third of the street width. This analysis follows a similar methodology as that employed for *building types*. The NO_2 concentration is initially assessed when applying a single *tree factor* across the municipality's roads. Table 5.10 states the concentration values for the three separate *tree factors* for both the municipality's of Utrecht and Almere.

The results indicate that a *tree factor* of 1.5 yields the highest NO_2 concentration, while a *tree factor* of 1.0 results in the lowest concentration. This outcome aligns with expectations because a high leaf density of the trees recreates a tunnel effect. In such a tunnel effect, NO_2 concentration tends to be higher than open areas, as air becomes trapped, reducing airflow. The same phenomenon happens when a *tree factor* of 1.5 is applied.

Table 5.10: Tree factor concentration - annual average

		Mean total NO_2 concentration $[\mu g/m^3]$	**Mean NO_2 concentration from road traffic $[\mu g/m^3]$**
Utrecht			
	Tree factor 1.0	21.988	5.975
	Tree factor 1.25	22.387	6.375
	Tree factor 1.5	22.780	6.767
Almere			
	Tree factor 1.0	12.299	2.044
	Tree factor 1.25	12.426	2.171
	Tree factor 1.5	12.553	2.298

The relative differences in NO_2 concentration from different *tree factors* are calculated for Utrecht and Almere. Table 5.11 and 5.12 presents the relative differences in concentration for Utrecht. For the total NO_2 concentration and the NO_2 concentration from traffic, the largest increase and decrease in concentration is when a factor of 1.0 is used instead of 1.5 or vice versa. When a factor of 1.0 is used instead of 1.5, there's an underestimation of NO_2 concentration from road traffic by approximately -11.70%. Conversely, when 1.5 is used instead of 1.0, it overestimates the NO_2 concentration with 13.26%. The change in NO_2 concentration is lower when a *tree factor* of 1.0 is used instead of 1.25. The results of the sensitivity analysis for Almere and Utrecht are similar to each other. Almost the same increase in concentration applies to the factors. Therefore, the results of the sensitivity analysis for the *tree factor* of Almere can be found in Appendix F.

Table 5.11: NO_2 concentration from traffic relative to each other - Utrecht

from \ To	**Tree factor 1.0**	**Tree factor 1.25**	**Tree factor 1.5**
Tree factor 1.0		6.69%	13.26%
Tree factor 1.25	-6.27%		6.15%
Tree factor 1.5	-11.70%	-5.79%	

Table 5.12: Total NO_2 concentration relative to each other - Utrecht

from / To	Tree factor 1.0	Tree factor 1.25	Tree factor 1.5
Tree factor 1.0		1.81%	3.60%
Tree factor 1.25	-1.78%		1.76%
Tree factor 1.5	-3.48%	-1.73%	

5.6. Conclusion

In this chapter, multiple sensitivity analyses are conducted on the input variables of air quality monitoring. The analysis results create a ranking of the input variables from most sensitive to least sensitive for changes in the input values. Table 5.13 states the ranking of the input variables with the relative difference from the original values in CIMLK with the most significant change in the input values. The ranking is based on the NO_2 concentration from road traffic.

Ranking	Input variables	Type of uncertainty	Relative difference NO_2 from road traffic [%]
1	Building type	Ambiguity	$+23\%$
2	Tree factor	Ambiguity	$+13\%$
3	Traffic volume: - Simultaneous traffic - Heavy traffic - Middle heavy traffic - Light traffic	Epistemic	 -11% to -13% $+12\%$ to $+13\%$ $+9\%$ to $+11\%$ $+1\%$ to $+2\%$
4	Selection of roads	Linguistic	-9% to -11%
5	Stagnation factor	Epistemic	$+2\%$ to $+2.5\%$

Table 5.13: Ranking input variables based on sensitivity for NO_2 concentration from road traffic

The input variable *building type* is the most sensitive input variable when the extreme values of the analysis are taken. There is an increase of 23% in the NO_2 concentration from road traffic when *building type* 4 is used instead of 2. However, it is important to note that the effect of the ”incorrect” input of *building type* varies concerning which *building type* is inserted in the monitoring tool. Namely, when *building type* 3 is used instead of type 2, there is an increase of 6% in the outcome of the NO_2 concentration from the model.

The *tree factor* has the second highest effect on the NO_2 concentration from road traffic. The effect depends on which *tree factor* is originally used in the monitoring tool. A concentration increase of 13% occurs when a *tree factor* of 1.0 is originally inserted while the correct value is 1.5 instead.

For the *traffic volume*, two types of sensitivity analysis are performed. The first analysis focuses on the changes in individual vehicle classes, and the second analyses the simultaneous effect of the vehicle classes. When changing the vehicle class's *traffic volume* simultaneously by the conversion matrix, the NO_2 concentration from traffic is overestimated between 11% and 13%, depending on the municipality. From the individual vehicle classes, heavy traffic has the largest effect on the concentration. When 500 vehicles are added to the class, there is an increase between 12% and 13%. For the vehicle class middle heavy traffic, the increase is between 9% and 11%. Adding extra vehicles to the vehicle class light did not significantly affect the NO_2 concentration.

The input variable *selection of roads* is ranked second to last from all the input variables. However, the input variable significantly affects the NO_2 concentration from road traffic. Omitting the 30 km/h roads results in a reduction between 9% and 11%. The input variable *stagnation factor* has the least effect on the NO_2 concentration. When adding extra stagnant vehicles to the sensitivity analysis, there is an increase of less than 2.5% in NO_2 concentration from road traffic.

From the sensitivity analysis results, it can be concluded that changes in the input values significantly affect the outcome of the NO_2 concentration for the air quality monitoring.

6

Interpretation & Discussion

This chapter discusses the results of the problem analysis and the sensitivity analysis. In Section 6.1, the results of this research are interpreted, and in Section 6.2, the implications. Section 6.3 discusses the methodology, and the last Section, 6.4, describes the research limitations.

6.1. Interpretation of results

The purpose of this research is to identify the practical problems related to input variables of emission models used by municipalities for air quality and nitrogen deposition calculations. The study reveals several significant practical problems associated with input variables of emission models, particularly focused on air quality monitoring. These problems include linguistic uncertainty in the input variable *selection of roads*, epistemic uncertainty in the input variable of *traffic volume* and *stagnation factor*, and ambiguity uncertainty in the input variable of *building type* and *tree factor*.

The studies mentioned in Chapter 2.3, which are based on theoretical findings, primarily use methods such as sensitivity analyses to determine the most sensitive input variable of the emission model. The emission models discussed in Chapter 2.3 are different from those used in the Netherlands, with different input variables and internal parameters such as EF. EF varies per emission model and is based on the vehicle characteristics of the specific country. Therefore, the results of this research cannot be compared with other studies. However, Dellaert and Dröge (2017) researched the uncertainties in activity data and EF used in emission registration of the Netherlands [7]. The limitation of Dellaert and Dröge (2017) research is that it only focuses on epistemic uncertainty and does not consider the data management process of various municipalities. In this research, the focus is on identifying the practical problems decision-makers from municipalities face when using emission models. The following section discusses the practical problems associated with input variables.

Selection of Roads

The regulations on the *selection of roads* are vague and unclear, leading to varying guidelines among municipalities. For air quality, the *Besluit Kwaliteit Leefomgeving*[1] regulation states *"The municipal executive board of a municipality [...] in a focus area [...] collects data on traffic volumes on roads managed by the municipality"* [42]. However, the regulation does not specify which specific roads the municipalities need to consider. For nitrogen deposition, BIJ12 states that all roads receiving traffic from an activity or project should be considered in the deposition calculation, except when traffic merges into the prevailing traffic pattern [15]. However, the description of BIJ12 for the input variable *selection of roads* is unclear, making it difficult for municipalities to determine when traffic merges into the prevailing traffic pattern. As a result, decision makers in different municipalities consider the input

[1] Besluit Kwaliteit Leefomgeving: contains rules on environmental values, instruction rules, assessment rules and rules for monitoring in the Netherlands

variable *selection of roads* a grey area in nitrogen deposition calculations.

This form of linguistic uncertainty results in inconsistencies in the monitoring of air quality and nitrogen deposition. Municipalities have individually established their own guidelines, and these guidelines vary from one municipality to another. The results of the analysis, for the input variable *selection of roads*, shows that 30 and 50 km/h roads included in the monitoring tool of Utrecht and Almere differ. This means that different municipalities may monitor air quality differently despite the written regulations and guidelines.

Traffic Volume & Stagnation Factor

The input variable of *traffic volume* has epistemic uncertainty due to the use of different data sources and the lack of knowledge of decision-makers. The length or weight distribution is used in the monitoring tool for the vehicle classes of the *traffic volume*. However, according to the conversion matrix of Fileradar, these vehicle distributions are not equal, which results in an overestimation of NO_2 concentration. Epistemic uncertainty is related to knowledge uncertainty, which can range from perfect knowledge of the phenomenon or model to total ignorance [8]. It is unclear whether the incorrect use of the distribution of vehicle class is due to the lack of data or the lack of knowledge of the decision-maker.

As for *stagnation factor*, decision-makers are unaware of how the input variable is established. This relates to the lack of knowledge within epistemic uncertainty. However, the incorrect use of the *stagnation factor* does not significantly impact the NO_2 concentration. Initially, it was expected that the NO_2 concentration would increase when additional stagnant vehicles are added. But the definition of *stagnation factor* is not a factor of stationary vehicles due to congestion but is a factor of traffic volume with a speed lower than 15 km/h. Since the *stagnation factor* only has a certain fraction of influence on traffic volume, changes contribute little to the outcome of NO_2 concentration of the model.

Building Type & Tree Factor

Ambiguity uncertainty is introduced by the input variables *building type* and *tree factor*. For both input variables, default values are used in air quality monitoring tool. Only DCMR stated practical problems for these two input variables. It is difficult to determine which default value applies to a specific location. The default value used depends on the interpretation of the local situations. The incorrect use of the variables significantly impacts the NO_2 concentration. *Building type* and *tree factor* are the most sensitive input variables of the emission model of air quality. However, the result strongly depends on the original default value used in the monitoring tool.

Based on the results of the sensitivity analyses, the *building type* and *tree factor* are the most sensitive input variables. This was unexpected as decision-makers did not experience problems with these input variables. From this result, it can be interpreted that there is a knowledge difference between the different municipalities and organizations dealing with air quality monitoring. According to Ascough et al. (2008), the different levels of expertise and knowledge also lead to different ways of understanding environmental management problems [2].

6.2. Implications

This study contributes significantly to environmental modeling by addressing and analyzing practical problems related to emission models used in the Netherlands. Municipalities are of particular interest as they are required to provide annual traffic data for the monitoring of air quality. The emphasis is placed on keeping NO_2 concentrations below the threshold of $40 \quad \mu g/m^3$, with the expectation that this threshold may be reduced to $10 \quad \mu g/m^3$ once the EU aligns with the WHO standards. This change will likely lead to exceeding NO_2 standards in several municipalities.

During initial interviews, input variables were not specifically identified as a potential source of uncertainty affecting model outcomes. Respondents often regarded models as inherently uncertain and approximations of reality. Nonetheless, the interviewees do not realize that inaccuracies in input data can lead to significant consequences for model results, as evidenced by the sensitivity analyses in Chapter 5. This study serves as a wake-up call for municipalities, highlighting that the practical problems they encounter can substantially impact the outcomes of environmental models.

Fileradar's elaborated case study on the joint effect of practical problems substantiates this. Multiple scenarios of different municipalities are investigated. For this research, the specific example of Capelle is considered. For the main road in Capelle, south westbound, the analysis looked at what the municipality entered in the monitoring tool and what should have been entered according to available traffic data from Fileradar. The analysis shows that the values entered for *traffic volumes* are too low, the *stagnation factor* is too high, and the wrong *building type* was entered. The entered data of the municipality was corrected and recalculated using CIMLK's calculation tool. The NO_2 concentration calculated using the "new" input values comes out higher than the original file from the monitoring tool.

- Total NO_2 concentration: "new" value is 23.267 and "old" value is 20.909
- NO_2 concentration from traffic: "new" value is 2.066 and "old" value is 0.822

For the total NO_2 concentration, "new" values are 11% higher, and for the NO_2 concentration from road traffic it is 151% higher. This indicates the simultaneous effect of inserting "incorrect" input values has a large effect on the outcome of NO_2 concentration from the emission model.

For practitioners, especially those within municipalities, the research findings underscore the importance of adopting clear guidelines and maintaining consistent approaches when gathering data and selecting input variables for emission models. Reducing uncertainties in these practical aspects can significantly enhance policy decisions' accuracy and improve air quality monitoring.

Furthermore, the study contributes to the current literature by identifying the different types of uncertainties that play a role in the practical problems of input variables. As stated earlier, the current literature focuses on the theoretical findings regarding the uncertainty of the model parameters. By conducting research from the users of the model side, a link is brought between theoretical uncertainties and practical problems.

Overall, this master's thesis provides valuable insights into practical problems associated with emission model input variables. This research has contributed to understanding these problems and highlights the need for clear guidelines, standardized methods, and attention to uncertainties in air quality models.

6.3. Discussion of methodology

Prior to this study, no research had been conducted on the practical problems that decision-makers face while utilizing the Dutch emission models. To gain insights into the practical problems associated with both nitrogen deposition and air quality, interviews were conducted with several municipalities. Ultimately, the focus of this study was directed towards the input variables of air quality. The reasons are twofold: municipalities are required to upload annual air quality data into the monitoring tool, and deposition calculations are project- and activity dependent. Additionally, deposition calculations contain more assumptions regarding future traffic conditions, making them challenging to investigate thoroughly.

The scope of this research is to identify the practical problems regarding input variables of the emission model used by decision-makers. However, the study does not examine the impact of the location of the calculation points on the model outcome of nitrogen concentration. Herein, the assumption is made the calculation points in the monitoring tool are at the correct location. This assumption is made because of the time span of the project.

In this research, a sensitivity analysis was performed to validate the practical problems of the input variables and to understand their influence on the model results. In studies from Kouridis et al. (2010) and Kioutsioukis et al. (2004), the sensitivity analysis acts as a screening tool to identify input variables that have the greatest influence on the model outcome [26, 23]. However, in this study the problem analysis is used as a screening tool instead of the sensitivity analysis. The sensitivity analysis is used as a method to asses the robustness of the model's outcome. A robust emission model output indicates that minor input value variations lead to negligible fluctuations in the output, implying relatively low uncertainty in the output. Conversely, substantial changes in model output indicate greater sensitivity to input variations. According to Uusitalo et al. (2015) this is because it is unrealistic to assume that the variables used in the model would be exactly those that take place in real-life. Additionally, if small differences in these values cause large differences in the outcome, the outcome is bound to be rather uncertain [43]. Based on the sensitivity analysis results, it can be deduced that the input variables of air quality emission model lack robustness. Variations in the input variables result in notable differences in the model's outcomes. The only input variable that exhibits robustness is the *stagnation factor*. Nevertheless, this research did not establish the level of uncertainty associated with the input variables.

6.4. Limitation of the Research

The emission model uses different calculation points for SRM1 and SRM2 to monitor air quality. One limitation of this study is that it does not consider the location of the calculation points. RIVM has issued technical descriptions of the calculation methods for SRM1 and SRM2, specifying when to apply each method and how far calculation points should be from the road [44, 47]. Although the interviews and survey did not identify the calculation points as a practical problem, they can contribute to the uncertainty of the model's output. Fileradar is researching the calculation points of SRM1 and SRM2 and has found that incorrect use of these points can result in differences in NO_2 concentration.

During the sensitivity analysis for *selection of roads*, the focus is on excluding roads from the monitoring tool rather than adding new roads. When assessing the impact of excluded roads, it is important to note that this impact might not be replicated when additional roads are incorporated. Although the analysis indicates that lower-order roads are commonly absent from the monitoring, the effect of including these roads needs to be determined.

Furthermore, the study did not include a case study for a specific municipality. A municipality case study would allow for a detailed analysis of the data used and the simultaneous effect of the practical problems together. While the results of the analysis of Fileradar in section 6.2 show the impact of the joint effect from practical problems, this example is limited for one specific road and not for all roads entered in the monitoring tool. To determine the complete effect of practical problems in a municipality, all roads must be considered.

7 Conclusion & Recommendations

In this chapter, the conclusion and recommendations of the research is stated. First, the main research question is answered in paragraph 7.1, and recommendations are given for further research in paragraph 7.2.

7.1. Conclusion

This study aimed to determine all the practical problems of local governments related to input variables of the Dutch emission models for nitrogen. The main research question to be answered is:

"What are the practical problems associated with input variables in the Dutch emission models, and how do these problems impact the decision-making process of local governments?"

The problem analysis revealed several practical problems related to input variables of the nitrogen emission models. For both nitrogen deposition and air quality monitoring, the perceived practical problems were related to the input variables *selection of roads*, *stagnation factor*, and the *traffic volume* of the vehicle classes light, middle heavy, and heavy vehicles. Furthermore, specifically for air quality, practical problems were also found for the input variables of *building type* and *tree factor*.

The perceived problems were related to three types of uncertainties: linguistic, epistemic, and ambiguity. For the input variables, linguistic and ambiguity uncertainty were more common than epistemic uncertainty. The guidelines and regulations regarding input variables were vague and open to interpretation, leading to different approaches across municipalities. The input variable *selection of roads* indicates this for air quality and nitrogen deposition. In the deposition calculations, the vagueness of the description of *selection of roads* leads to a grey area, which was confirmed by the municipalities that participated in the interviews of this research.

The effects of these practical problems on the NO_2 concentration were determined with sensitivity analysis for Utrecht and Almere. From the results, the *building type* is the most sensitive input variable and *stagnation factor* the least. The other input variables *traffic volume*, *selection of roads*, and *tree factor* have an average effect of 10% at the NO_2 concentration from road traffic. Compared to the other input variables of the air quality model, the effect of *stagnation factor* is relatively low. When 500 stagnant vehicles were added, there is an effect of 2% on the NO_2 concentration from road traffic. From this, it can be concluded the NO_2 concentration is not sensitive to the input variable *stagnation factor*.

Municipalities in NO_2 focus areas were obliged to deliver traffic data to CIMLK for annual air quality monitoring. Since each municipality is responsible for its own data, there were variations in assumptions and methodologies among them, resulting in varying quality of data. The quality of input data is directly linked to its impact on the model's outcomes. The results of the sensitivity analysis confirm that the air quality emission model is highly sensitive to changes in input variables. As a result, some municipalities have more accurate air quality concentrations than others. In this research, only the isolated effect of a change in one of the input variables is investigated. However, the joint effect of "incorrect" input of variables is not researched. When a municipality delivers "incorrect" data for multiple input values, this could potentially lead to bigger variations in the NO_2 concentration.

Generally, municipalities were not aware of the impact of "inaccurate" input of variables on the outcomes of the emissions model. Prior to this study, users of the model stated that they do not think that variations in the input variable contribute to uncertainty in the model's outcomes because a model is a abstraction of reality. However, this research shows that the variation in input variable significantly affects the model's outcomes. In fact, the better the model works, the closer the approximation is to reality.

Incorrect input to the emissions model results in overestimation or underestimation of the municipality's NO_2 concentration. The extent of overestimation or underestimation significantly influences the decisions made by decision-makers; depending on whether NO_2 concentrations were higher or lower, decision-makers may choose different courses of action.

7.2. Recommendations

In this section, the first recommendations are given to solve the practical problems of the input variables. After this, recommendations are given for further research based on the research limitations stated in Section 6.4.

7.2.1. Recommendations for practical problems

With regards to practical problems, three types of uncertainties play a role - epistemic, linguistic, and ambiguity. To mitigate each type of uncertainty, specific recommendations are provided.

Epistemic uncertainty is related to a lack of knowledge and data. To counter it, more empirical data should be used. Currently, *traffic volume* and *stagnation factor* are mainly determined by traffic models. However, better estimates can be made through the use of empirical data in the form of loop measurements and floating car data. Vehicle's weight and length distribution are both used for *traffic volume*. When municipalities use length distribution, it is recommended to use Fileradar's conversion matrix since they have done research on vehicle distribution in the Netherlands. At the moment there is no other conversion matrix available in the Netherlands to convert the vehicle distribution from length to weight.

Linguistic uncertainty is related to vague definitions of input variables of the emission model. Regulations and guidelines regarding the input variable *selection of roads* leave much to personal interpretation, resulting in different approaches between municipalities. The regulations for monitoring air quality and nitrogen deposition should be clarified. This can be achieved by establishing consistent guidelines across municipalities on which low-order roads to include in air quality monitoring. Furthermore a clear, standardized approach needs to be developed for the delineation of projects to reduce the grey area for nitrogen deposition. This will ensure that the same guidelines are consistently implemented in the calculations.

Ambiguity uncertainty in the input variables of *building type* and *tree factor* is more difficult to mitigate since it depends on how the user of the model interprets the local situation. Clear guidelines and illustrations are used in the report by Velze and Wesseling (2014) to demonstrate which default value applies to which situation [44]. Nevertheless, the wrong input variables are still used in practice.
The input variables *building type* and *tree factor* are part of the road characteristics which will not change quickly over time. Therefore, more time must be spent after this study to evaluate and adjust the entered factors. A method to ensure the correct default values is to create a mathematical model with the guidelines of Velze and Wesseling (2014) as constraints. As a result, it does not depend on the interpretation of the user of the model.

Overall, within municipalities, more awareness is needed for these three types of uncertainties. This research is intended to raise awareness among all municipalities and organizations participating in data delivery for air quality monitoring. Variations and ”incorrect” use of input values significantly impact the outcome of the monitoring tool for air quality. Sharing this research with the SLA can create more awareness. By sharing the outcomes of this research with the SLA, more attention can be paid to this topic at future conferences, and the recommendations in the above paragraphs can be applied.

7.2.2. Further research

The research conducted a sensitivity analysis to address the practical problems outlined in the problem analysis. The results of the sensitivity analysis show the degree of robustness of various input variables and their impact on the output. However, the absence of determining the uncertainty of the input variables limits the study. To overcome this limitation, an uncertainty analysis for the same set of input variables subjected to sensitivity analysis is advisable. The most advisable method for conducting an uncertainty analysis is to use a Monte Carlo simulation. With this method, the uncertainty of an input variable and its impact on the output can be assessed more accurately. Previous studies by Kioutsioukis et al. (2004) and Holnicki and Nahorski (2015) have used the Monte Carlo simulation to determine uncertainties of input variables and EF of the emission model [23, 19]. The method is also used in the study of Dellaert and Dröge (2017) to determine the uncertainty of the activity data and EF of the emission registration in the Netherlands. Therefore, using this method to determine the uncertainty of the input variables from the Dutch emission models is most advisable.

This study has a limitation regarding the sensitivity analysis method used for the input variable *selection of roads*. It is recommended to re-evaluate the sensitivity analysis or conduct an uncertainty analysis for this input variable. This study omitted roads from the monitoring to see their effect. For a follow-up study, the effect of adding additional roads to the monitoring needs to be examined. However, it is challenging to obtain data from roads not included in the monitoring since no data is available. Therefore, it is recommended to conduct a case study for a specific municipality. The measurement of *traffic volumes* and *stagnation factors* should be carried out to obtain data that can be used in the monitoring tool to determine the effect of including extra roads.

In addition, a comprehensive study should be conducted for each road segment to verify the accuracy of the placement of calculation points used in the SRM methods. This study did not analyze whether the calculation points are placed in the correct location for the monitoring of air quality. However, it is recommended to analyze the effect of the calculation point in combination with using the correct SRM method to determine its effect on the outcome. Such research will provide valuable insights into how the arrangement of calculation points affects NO_2 concentrations.

Finally, municipalities should evaluate input variables in the monitoring tool. In Section 6.2, the case study performed by Fileradar for the main street in Capelle is discussed. For the evaluation of the joint effect of input variables, municipalities can use the same approach. By following a step-by-step approach, municipalities can obtain accurate and relevant input variables for their monitoring tool and ensure that the NO_2 concentration is recalculated with the updated parameters.

Step 1: Evaluate *Traffic Volume*

- Gather data on the volume of traffic using loop measurements.
- Use a conversion matrix to translate the *traffic volume* data from loop measurements into the distribution of vehicle classes based on vehicle weight.

Step 2: Determine the *Stagnation Factor*

- Use floating car data to determine the average speed of the traffic.
- Use this speed to establish the *stagnation factor*.

Step 3: Check *Building Type* and *Tree Factor*

- Check the guidelines of Velze and Wesseling (2014) from RIVM to verify the type of building and the *tree factor*.

- Use a mathematical model to evaluate the default factors of the *building type* and *tree factor* by inserting the guideline of Velze and Wesseling (2014) as constraints [44].

Step 4: Make adjustments in the monitoring tool

- Incorporate the necessary adjustments into the monitoring tool based on the information obtained in the previous steps.
- Recalculate the NO_2 concentration using the modified input values.

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A

Uncertainties in EF and activity data

NFR	Fuel type	Uncertainty activity data	Uncertainty implied emission factors					
			NO_x	SO_x	NH_3	PM_{10}	$PM_{2.5}$	NMVOC
1A3bi Passenger Cars	Petrol	5%	20%	20%	200%	200%	200%	100%
	Diesel	5%	20%	20%	100%	50%	50%	100%
	LPG	5%	20%		200%	200%	200%	50%
1A3bii Light duty vehicles	Petrol	5%	20%	20%		200%	200%	50%
	Diesel	5%	20%	20%		50%	50%	100%
	LPG	5%				200%	200%	
1A3biii Heavy duty vehicles	Petrol	10%	20%	20%		200%	200%	
	Diesel	10%	20%	20%	100%	50%	50%	100%
	LPG	10%				200%	200%	
1A3biii Buses	Natural gas	5%						
	Petrol	5%	20%	20%		200%	200%	
	Diesel	5%	20%	20%		50%	50%	
	LPG	5%				200%	200%	
1A3biv Mopeds & motorcycles	Petrol	20%	200%	20%		500%	500%	500%
	Diesel	20%	100%	20%		500%	500%	

Figure A.1: Uncertainties estimates for road transport - Dellaert and Dröge (2017)

B

Semi-structured interview questions

There are three parts in the set-up of the semi-structured interview; global questions, in-house nitrogen calculations, outsourcing nitrogen calculations, and monitoring of the air quality. The interview questions are based on the literature review and the objective of the research.

Global questions

- Which methods do you use to determine emission of nitrogen from road traffic?
- For which purpose do you use AERIUS of nitrogen calculations?
- What is the process from the moment such a nitrogen calculation has to be done?
- Do you perform the calculations yourselves or is it outsourced?

In-house nitrogen deposition calculations

- What are the required input data for the calculation with AERIUS? How is the data collected?
- Which traffic model is used for generating the data input?
- Are there any dilemmas or grey areas in the nitrogen deposition calculation?
- Do you know what uncertainties play a role in use process of AERIUS?
- Is there a certain strategy to deal with the uncertainties in the calculation?
- How are the results evaluated?
- Are there certain pain points in the process for determining the deposition?

Outsourcing of nitrogen deposition calculations

- Do you indicate which input data should be included in calculations?
- Which traffic model is used for generating the data input?
- Who validates the calculation of the consulting firm?
- Did it ever occur that the calculation was rejected? What are the reasons for this?
- Do you get insight into the uncertainties and assumptions that played a role in the calculation?
- Do you have an internal strategy for dealing with uncertainties?

Monitoring of the air quality

- What is the reason for the monitoring of the air quality from road traffic?
- What data do you provide for the monitoring of the air quality?
- Which traffic model is used?
- To whom will the data be sent?
- What criteria are used to determine the selection of roads for monitoring purposes?
- Are there certain pain points in the process?

C
Survey Questions

Municipal Air Quality Survey
Welcome. The purpose of this survey is to gain insight into why organizations (municipalities) are affiliated with the Schone Lucht Akkoord (SLA) and how data is collected for the CIMLK. For my research, I specifically focus on emissions from road traffic.

The data from this research will be used for my graduation project at TU Delft.

1. Is your organization affiliated with the SLA?
2. What type of data do you use for air quality monitoring?
3. Who collects the data for monitoring?
4. How do you determine the stagnation factors?
5. Which roads are included in the air quality monitoring?
6. How are vehicle intensities broken down by vehicle class?
7. In your opinion, where is the greatest uncertainty in determining air quality?
8. Do you have any suggestions for improving the air quality determination process?

D Conversion matrix

In the research, the conversion matrix of Fileradar is used to convert the distribution of traffic based on length classes (L1, L2, L3) into weight classes (L, M, Z). The following conversion matrix is used for this purpose:

Table D.1: Conversion matrix vehicle classification

	L1	L2	L3
L	100%	67.61%	0%
M	0%	22.52%	18.61%
Z	0%	9.88%	81.39%

The approach followed by Fileradar in establishing this matrix is as follows: The definitions of L, M, and Z are based on the report by Ligterink et al. (2021). The following definitions are used for the classification of vehicles:

- Light traffic (L): Passenger cars, delivery vans, and motorcycles.
- Medium-weight road traffic (M): Trucks with a maximum mass of 20 tons and coaches.
- Heavy road traffic (Z): Tractor-trailer combinations and trucks with a maximum mass greater than 20 tons.
- Bus: Public transportation.

Buses are a separate classification in the air quality monitoring of CIMLK and are entered separately from the LMZ distribution. Therefore, buses are not part of the LMZ vs. L123 analysis. The definitions of L1, L2, L3 are based on the classification used by NDW:

- L1: Vehicles <5.6m
- L2: Vehicles <12.2m
- L3: Vehicles >=12.2m

The approach aims to categorize all vehicle kilometers traveled on Dutch roads by all types of vehicles into a 3x3 matrix of [L1 L2 L3] x [L M Z]. The categorization is based on 2019 data, utilizing the following data sources: CBS, Basisbestand Goederenvervoer (BBGV), and RDW. RDW contains information about the length, empty weight, and load capacity of individual vehicles and trailers, along with data such as emission class (Euro norm) and the number of axles. BBGV contains data on freight journeys based on surveys. For each vehicle category, including passenger cars, delivery vans, trucks, tractors, campers, caravans, coaches, and special vehicles, the length classification is converted into weight classification based on the number of vehicle kilometers traveled in 2019.

For passenger cars, this is done as follows: According to the CBS, all passenger cars together covered 110.37 billion kilometers in 2019. According to TNO's definition, all passenger cars are considered 'light vehicles.' According to the CBS definition, only a very small percentage of passenger cars fall under length categories longer than 5.6m. Therefore, all vehicle kilometers traveled by passenger cars are counted as [L1] x [L]. For delivery vans, the subdivision of delivery vans is based on the Basisbestand Goederenvervoer (BBGV) from 2019. This database includes nearly 150,000 registered trips of delivery vans, which have been scaled up to account for the total traffic performance of all delivery vans in the Netherlands. For each trip, it is known whether it was made with a delivery van <5.6m or >5.6m. According to TNO's definition, delivery vans are considered 'light vehicles.' There are no delivery vans longer than 12.2m. Therefore, vehicle kilometers are categorized as [L1] x [L] or [L2] x [L].

For trucks, the BBGV and RDW are used. In the BBGV, the vehicle class is not determined. Based on the number of axles, Euro norms, and load capacity class, an estimate is made of the vehicle length. For each trip in the BBGV, the vehicle length and maximum weight (load capacity + empty vehicle weight) are estimated based on medians from RDW for vehicles with the same number of axles, Euro norm, and load capacity class. To classify a trip into the correct position in the matrix, it is first determined whether the length is L2 or L3 (L1 does not occur). Then, the weight class is determined: 'heavy' = tractor - trailer or freight with estimated max weight > 20 tons, 'medium-weight' = others. The scaled length of the trip is then added as vehicle kilometers in [L2/L3] x [M/Z].

For campers and caravans, statistics on kilometers traveled by the ANWB are used. According to this research, more than 1.8 million caravan trips and 643 thousand camper trips are made per year. For each trip, a rough estimate of 200 vehicle kilometers within the country's borders is used (either to an inland campsite and back or up to the border and back). From RDW data on the length of campers and cars+caravans, most fall into the length category L2. Both campers and cars with caravans fall under 'light vehicles' according to TNO's definition. In total, this amounts to over 478 million vehicle kilometers, which are counted in [L2] x [L].

According to the CBS, in 2019, tour buses in the Netherlands traveled a total of 153.8 million kilometers. These kilometers are categorized as [L2] x [M].

The approach for various types of vehicles results in the conversion matrix in Table D.1.

Source: *Fileradar (2023) - Traffic Effects*

E

Differences in municipalities when applying conversion matrix

Table E.1: Difference in annual average traffic volume when applying conversion matrix

		Traffic volume [veh/day]	Traffic volume conversion matrix [veh/day]	Difference [veh/day]
Utrecht				
	Light traffic	15,615	16,161	546
	Middle heavy traffic	808	325	-483
	Heavy Traffic	764	702	-62
Almere				
	Light traffic	6,269	6,514	245
	Middle heavy traffic	363	124	-239
	Heavy Traffic	226	220	-6

F

Results SA Building type and tree factor - Almere

Table F.1: NO_2 concentration from traffic relative to each other - Almere

	Building type 1	**Building type 2**	**Building type 3**	**Building type 4**
Building type 1		15.16%	9.84%	-5.13%
Building type 2	-13.16%		-4.61%	-17.62%
Building type 3	-8.96%	4.84%		-13.63%
Building type 4	5.41%	21.38%	15.78%	

Table F.2: Total NO_2 concentration from traffic relative to each other - Almere

	Building type 1	**Building type 2**	**Building type 3**	**Building type 4**
Building type 1		2.64%	1.72%	-0.90%
Building type 2	-2.57%		-0.90%	-3.45%
Building type 3	-1.69 %	0.91%		-2.57%
Building type 4	0.91%	3.58%	2.64%	

Table F.3: NO2 concentration from traffic relative to each other - Almere

	Tree factor 1.0	**Tree factor 1.25**	**Tree factor 1.5**
Tree factor 1.0		6.21%	12.43%
Tree factor 1.25	-5.85%		5.85%
Tree factor 1.5	-11.05%	-5.53%	

Table F.4: Total NO2 concentration relative to each other - Almere

	Tree factor 1.0	**Tree factor 1.25**	**Tree factor 1.5**
Tree factor 1.0		1.03%	2.07%
Tree factor 1.25	-1.02%		1.02%
Tree factor 1.5	-2.02%	-1.01%	

G

Scientific Paper

Nitrogen Emission Models in the Netherlands - The identification of practical problems in the input variables for road traffic by local governments

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October 11, 2023

Abstract: Nowadays, many decision-makers rely on models to help them make informed decisions. This is also true for environmental models used to monitor nitrogen deposition and air quality in the Netherlands. These models involve different types of uncertainties. While most literature on the topic focuses on theoretical uncertainties related to the model's parameters, such as emission factors, the variation of input variables is also a crucial factor that impacts the model's outcome. The users of the model experience practical problems that lead to linguistic, ambiguity, and epistemic uncertainty in the input variables. To determine the sensitivity of input variables, individual sensitivity analysis are conducted. The analysis reveals that the *building type* is the most sensitive input variable for air quality monitoring, while the *stagnation factor* is the least sensitive. The sensitivity of the input variables has not only an effect on the outcome of the emission model but also has further consequences. Local governments use the emission models to determine whether the limit values of NO_2 for air quality are exceeded at a specific location. When the limit values are exceeded, measures need to be taken by local governments. In this study, recommendations are given regarding the practical problems and for further research in this area.

Keywords: emission model, practical problems, input values, sensitivity analysis, types of uncertainty

1 Introduction

Currently, the Netherlands is facing a nitrogen crisis, several measures have been taken to reduce nitrogen emissions. Emission models in the Netherlands are pivotal in computing nitrogen concentration levels for air quality and assessing nitrogen deposition on Natura2000 areas. Specifically, two distinct emission models are mandated for these calculations. The AERIUS Calculator is employed for nitrogen deposition calculations, while the Standard Calculation Method (SRM) is utilized for assessing air quality. These emission models are instrumental in computing pollutant levels originating from both the traffic and agriculture sectors. However, it's important to note that this research focuses exclusively on road traffic, as it is the largest contributor to NO_2 emissions (Emissieregistratie, 2023).

Current literature, such as studies conducted by Kühlwein and Friedrich (2000) and Dey, Caulfield, and Ghosh (2019), focuses on determining the uncertainty of the input variables and parameters through uncertainty and sensitivity analysis. These findings are based on theoretical research, where emphasis is on epistemic uncertainty. However, practical problems faced by decision-makers of local governments when using the emission models are not covered in the literature. In the Netherlands, there are different users of the emission models, with varying levels of experience. This potentially result in practical problems when inputting values into the models.

Practical problems are defined as challenges and unclear guidelines when using emission models, which lead to variations in model outcomes. Local governments in the Netherlands are responsible for data management of the input variables for the emission models. As the models become more specialized, municipalities face problems with filling in traffic data in the monitoring tool and checking deposition calculations. This research aims to identify the practical problems decision-makers encounter when using emission models for nitrogen deposition and air quality. Hereafter, it is assessed how practical problems related to the input variables affect the model's outcome. Based on this studies result, recommendation are provided for developing a more effective process for estimating road traffic emissions.

2 Dutch Emission Model

2.1 Air quality

Municipalities located in focus areas are required to monitor air quality. Focus areas are locations with high concentrations of NO_2 or/and PM_{10}. The municipalities must submit annual data regarding road traffic to the monitoring tool of Centraal Instrument Monitoring LuchtKwaliteit (CIMLK).

The SRM method, developed by TNO, is used to monitor air quality and deposition calculations. The air quality model uses two SRM methods: SRM 1 and SRM 2. The SRM 1 method calculates the concentration of pollutants near urban roads. One of the characteristics of an SRM 1 calculation is the presence of buildings within tens of meters of the road. Buildings affect the concentration of pollutants by restricting airflow between them. In contrast, the SRM 2 calculation is applied to highways and country roads, where air pollutants are not trapped between buildings but are carried away by the wind (van Velze & Wesseling, 2014).

The input variables for air quality consist of the *selection of roads*, *stagnation factor*, *traffic volume*, *tree factor*, *building type*, and *tunnel factor*. For the input variable *selection of roads* the regulation for air quality monitoring states that *"The municipal executive board of a municipality [...] in a focus area [...] collects data on traffic volumes on roads managed by the municipality"* (Staat, 2023). Herein, it is not clear which roads municipalities needs to consider. The classification of the *traffic volume* is based on the weight of the vehicles; light vehicles, middle heavy vehicles, heavy vehicles and buses (RIVM, 2022). The *stagnation factor* is derived from the proportion of traffic volume with a speed lower than 15 km/h and is entered as a factor in the monitoring tool. The *tree factor*, *building type*, and *tunnel factor* are default factors.

2.2 Nitrogen Deposition

The AERIUS Calculator emission model, developed by RIVM, is used to calculate nitrogen deposition. It determines the deposition of pollutants on nitrogen-sensitive areas (Natura2000 areas) resulting from an activity. The calculations are performed when a permit is required for Natura2000 activities (Informatiepunt Leefomgeving, 2023). The AERIUS model consists of two methods: the Operational Priority Substances Model (OPS) and SRM 2. The OPS model estimates the distribution and deposition of substances, except for road traffic up to a 5 km distance. The concentration of air pollution from road traffic within 5 km of the road is calculated by SRM 2, which is then converted to deposition using OPS. OPS is used for concentration and deposition calculations for distances greater than 5 km. The computational range of AERIUS is 25 km from the pollution source (Fung-A-Loi et al., 2023).

The input variables for nitrogen deposition are the same as for air quality, with the exception of the *tree factor* and *building type*. The deposition calculations do not consider *tree factor* and *building type* but take into account the *shielding structures*, such as noise barriers alongside the roads. The input variables for nitrogen deposition are *selection of roads*, *stagnation factor*, *traffic volume*, *shielding structure*, and *tunnel factor*. The definition of the input variable *selection of roads* differs from the emission model for air quality. For the *selection of roads* all roads that receive traffic from an activity or project should be considered in the deposition calculation, except when traffic merges into the prevailing traffic pattern (Expertiseteam Stikstof en Natura 2000 van BIJ12, 2023).

3 Methodologies

3.1 Interview

The methodology used for the interviews is based on the guideline of Adeoye-Olatunde and Olenik (2021). For this research, the order of the method is adjusted. The first step is to determine the objective of the interview. For the interviews, the objective is to determine the practical problems for both the nitrogen deposition model and the air quality monitoring. For the interview questions, there are four themes considered:

- the process of the model
- input data
- uncertainties in model output
- grey areas in the method

Interview questions are established based on the objectives and the themes, which is the second step in the guideline of Adeoye-Olatunde and Olenik (2021). All the interviews are semi-structured. This method is chosen to have more flexibility to deviate from the standard questions since the goal is to analyze the potential uncertainties in the input data of the emission model. Semi-structured interviews are used when the goal is to understand better the person's perspective instead of a generalized understanding of a phenomenon. The interviews are conducted until data saturation is achieved, meaning that no additional interviews are conducted once no new value-added information is obtained from them (Quantilope, 2022). Nine interviews are conducted with municipalities, environmental agencies, and the province of South Holland.

For the content analysis of the interviews, the software MAXQDA is used to code the data. A hybrid method of deductive and inductive coding is used for determining the coding. A disadvantage of deductive coding is that you may miss critical insights because of the narrow focus approach of predetermined codes (Drew, 2023). Combining the two methods allows specific topics raised in the interviews to be coded. The danger of the hybrid method is that too many codes are created, making the analysis unclear. Therefore, an iterative approach is used to determine the codes. This mitigates the limitation of the hybrid approach.

The two main codes are air quality and nitrogen deposition. Sub-codes are created for these two codes linked to the emission models' input variables. The table below gives an overview of the codes used in the content analysis.

Table 1: Codes content analysis

Main codes	sub codes
Air quality	
	Selection of roads
	Intensities
	Stagnation factor
	Traffic model
	Emission factors
	Tree factor & building type
Nitrogen Deposition	
	Selection of roads (fineness & radius)
	Intensities
	Traffic model
	Shielding structure
	Emission factors

3.2 Survey

Additionally, surveys are conducted during the annual Schone Lucht Akkoord (SLA)[1] conference in Amsterdam. The SLA is involved in assessing air quality in various sectors in the Netherlands, including mobility. The survey is specifically related to air quality monitoring and included questions on the data use age and uncertainty of the different input variables of the monitoring tool for air quality. In total 20 municipalities filled in the survey.

3.3 Sensitivity Analysis

The aim of the research is to identify practical problems of input variables for Dutch emission models and determine their effects on the model's outcome. One At a Time (OAT) analysis is used to perform multiple sensitivity analyses on input variables with practical issues from air quality monitoring. In the OAT

[1] The SLA is a voluntary agreement between several municipalities, provinces, and the state to improve air quality in the Netherlands permanently

analysis, one input variable is systematically adjusted with a factor while all other variables remain constant. Applying this methodology to several input variables makes it possible to distinguish and determine the relative impact of each input variable on the variation of the model outputs (Battelle Memorial Institute, 2023). Consequently, this procedure facilitates the identification of the most critical input variable contributing to the variability observed in the model outputs. In the research, different types of OAT analysis are performed.

The data for the sensitivity analysis is obtained from the CIMLK monitoring tool, which contains data from previous monitoring years. The tool has two essential components: the receptor and segment file. The segment files are adjusted for the sensitivity analysis by applying factors to the analyzed input variables. Both the modified segment file and the unmodified receptor CSV file are uploaded into the online calculation tool of CIMLK, which provides an online computational tool for anyone to perform computational tasks related to air quality. The limitation of the monitoring tool of CIMLK is the limited capacity of nine simultaneous computation tasks in total.

3.4 Case study

This research involves a sensitivity analysis of two municipalities: Utrecht and Almere. Both municipalities have participated in this research, and they have distinct urban features. Almere is a relatively new municipality that follows a modern city plan, while Utrecht has a historic city center and is situated in the middle of the Netherlands. According to the CIMLK data, both municipalities have varied road networks and traffic volumes. Table 2 provides key information on both municipalities. The total length stated in Table 2 includes all the roads in the municipality, such as the roads of residential areas. The traffic volume and stagnating traffic are given as the annual average.

Table 2: Data key features Utrecht & Almere - data CIMLK 2021

	Utrecht	**Almere**
Total road length $[km]$	2,221	2,284
Road length included in CIMLK $[km]$	504	841
Traffic volume (L) *annual average* $[veh/day]$	15,615	6,269
Traffic volume (M) *annual average* $[veh/day]$	808	363
Traffic volume (Z) *annual average* $[veh/day]$	764	226
Stagnating traffic *annual average* $[veh/day]$	955	20

4 Results

4.1 Practical Problems

The results of interviews and surveys reveal practical problems with the nitrogen deposition emission models and air quality monitoring. These problems are common to both emission models. The guidelines and regulations regarding the *selection of roads* as input variables are unclear and vague. Municipalities are unsure which lower-order roads to consider in the monitoring tool. The Staat (2023) states *"The municipal executive board of a municipality [...] in a focus area [...] collects data on traffic volumes on roads managed by the municipality"*. The same applies to the deposition calculations. The guidelines of BIJ12 are unclear and are, according to decision-makers, grey areas in the calculation. The input variable of *selection of roads* creates linguistic uncertainty in both emission models.

The input variable of *traffic volume* is classified based on the vehicle's weight (LMZ) or length distribution (L123). The NO_2 concentration in both emission models is based on the vehicle's weight (Expertiseteam Stikstof en Natura 2000 van BIJ12, 2023; van Velze & Wesseling, 2014). In practice, both distributions are used. However, the distributions are not equal to each other. The conversion matrix of length to weight vehicle classification in Table 3 shows that the vehicle class middle heavy and heavy are overestimated, while the vehicle class light is underestimated. This input variable creates epistemic uncertainty, which is related to a lack of knowledge or data.

Table 3: Conversion matrix vehicle classification

	L1	L2	L3
L	100%	67.61%	0%
M	0%	22.52%	18.61%
H	0%	9.88%	81.39%

The *stagnation factor* is another input variable that has epistemic uncertainty. Most municipalities' decision-makers are not aware of how the *stagnation factor* is determined, and it is usually outsourced to consultancy firms or environmental agencies. Therefore, decision-makers need to gain knowledge of how the *stagnation factor* is determined.

For the *building type* and *tree factor* of the monitoring of air quality, only the environmental agency DCMR stated practical problems. These factors are default values that do not apply to local situations. It is difficult to determine which factor applies to each situation, and the use of default values depends on how the model's user interprets the local situation. Additionally, the input variables of *tree factor* and *building type* are part of a municipality's basic registration of roads, but the accuracy of this registration varies from municipality to municipality. The better the basic registration, the more accurate the road traffic concentration calculation (*DCMR, 2023*).

For the other input variables, *shielding structure* and *tunnel factor*, no practical problems are identified during the interviews and surveys.

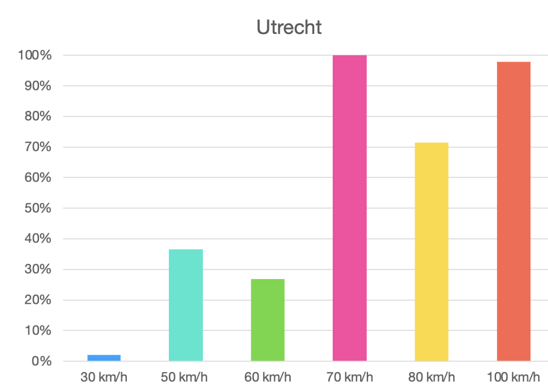
4.2 Sensitivity Analysis

Sensitivity analyses are conducted on input variables where practical problems arise. The analysis is performed on air quality monitoring data from Utrecht and Almere.

4.2.1 Selection of roads

The main practical problem with regards to the *selection of roads* input variable is determining which low-order roads should be included or excluded in the monitoring tool. When comparing the percentages of roads included in the monitoring tool with the total kilometers of roads in the municipality itself for both Utrecht and Almere, it becomes evident that many kilometers are missing from the monitoring tool. There is 503.9 km of roads included in the monitoring tool for Utrecht and 841 km for Almere. Utrecht has in total 2,221 kilometer of road length and Almere 2,284 kilometer. Figure 1 shows in percentages how many roads are included in CIMLK compared to the total number of roads in the municipality. Utrecht includes less than 5% of 30 km/h roads and less than 40% of 50 km/h roads. The difference between the number of 30 and 50 km/h roads included in the municipality's monitoring tool corresponds to the practical problem mentioned in Section 4.1. For municipalities, it is unclear which low-order roads they should or should not include.

To analyze the sensitivity of the *selection of roads*, the 30 km/h roads are excluded from the monitoring tool to observe its impact on the model's outcome of annual average NO_2 concentration from road traffic. The results for Utrecht and Almere are tabulated in Table 4. In both municipalities, there is a reduction of approximately 10% in the NO_2 concentration when the 30 km/h roads are excluded.



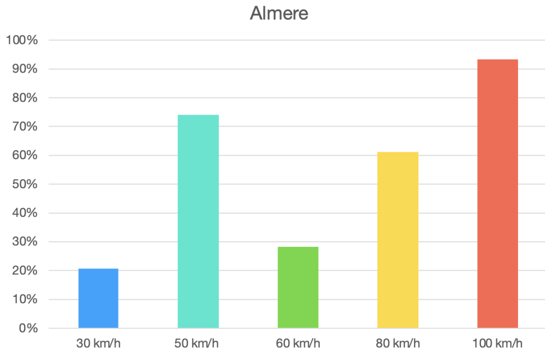


Figure 1: Percentage of total road length included in CIMLK

Table 4: sensitivity analysis selection of roads - annual averages

		Mean total NO_2 concentration $[\mu g/m^3]$
Utrecht		
	With 30 km/h roads	6.27
	Without 30 km/h roads	5.59
	relative difference	-10.85 %
Almere		
	With 30 km/h roads	2.05
	Without 30 km/h roads	1.86
	relative difference	-9.44 %

4.2.2 Traffic Volume & Stagnation Factor

In this section, two sensitivity analyses are presented for *traffic volume*. The first analysis evaluates the impact of additional traffic on the individual vehicle classification of light, middle heavy, and heavy traffic. The second analysis focuses on the impact of the underlying vehicle classification.

In the first analysis, extra vehicles are added to the input variables *traffic volume* and *stagnation factor*. The traffic volume is considered individually across vehicle classes: light, middle heavy, and heavy traffic. Additional traffic is included to evaluate its impact on the models' concentration levels. For Utrecht, the traffic volume is increased by 100, 300, and 500 vehicles, while for Almere, the traffic volume is increased by 50, 100, and 150 vehicles. The choice for the added vehicles are based on the traffic volume in the municipalities. Utrecht has higher traffic volumes for the vehicle classes than Almere.

The effect of the additional vehicles on the annual average NO_2 concentration from road traffic is shown in Figure 2 for Utrecht and Almere, respectively. In both municipalities, light traffic and stagnated vehicles have less impact on the NO_2 concentration than middle heavy and heavy traffic. For instance, when 500 vehicles are added in Utrecht, the concentration increases by more than 10% for middle heavy traffic and more than 12% for heavy traffic. Similarly, when 300 vehicles are added in Almere, there is a concentration increase of more than 8% for middle heavy traffic and more than 12% for heavy traffic. However, the effect on *stagnation factor* and light traffic is less significant, with a concentration increase staying below 2%.

The second analysis is related to the underlying vehicle classification of the traffic volume. As mentioned in Section 4.1, the use of the vehicle's length distribution leads to an overestimation of middle heavy and heavy traffic and an underestimation of light traffic when the conversion matrix is applied. The same conversion matrix of Table 3 is used for the sensitivity analysis of the underlying vehicle classification. The results of both Utrecht and Almere are presented in Table 5. The analysis shows that the annual average NO_2 concentration from road traffic decreases between 11% and 13%. The concentration decreases when the conversion matrix is applied because the *traffic volume* of middle heavy traffic heavily decreases. The concentration is more sensitive to changes in the *traffic volume* of middle heavy and heavy traffic than light traffic. Using the length of vehicles instead of their weight for the vehicle class leads to an overestimation of the NO_2 concentration.

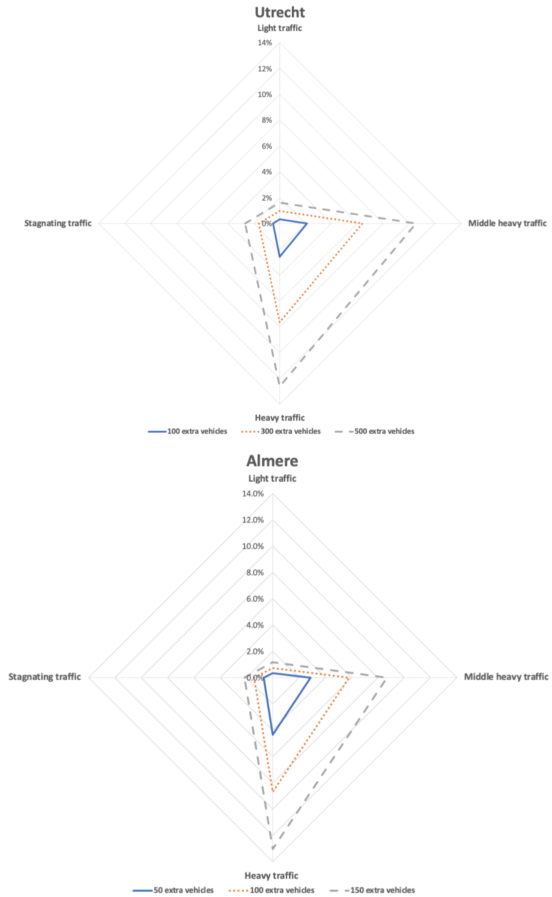


Figure 2: Effect of the NO_2 concentration from road traffic

Table 5: sensitivity analysis Traffic volume - conversion matrix (annual averages)

		Mean total NO_2 concentration $[\mu g/m^3]$
Utrecht		
	L123	6.27
	LMZ	5.59
	relative difference	-10.85 %
Almere		
	L123	2.05
	LMZ	1.79
	relative difference	-12.85 %

4.2.3 Building Type & Tree Factor

The monitoring tool uses default values for the *building type* and *tree factor*. The presence of buildings alongside roads significantly impacts pollutant concentrations because it confines the airflow, affecting dispersion. For the *tree factor*, the same applies only in the form of a tunnel effect when the leaves of the trees span the street width.

The study conducted a sensitivity analysis to evaluate the impact of the building types and tree factors on the annual average NO_2 concentration resulting from road traffic. Table 6 presents the results of the *building type*, and Table 7 the results of the *tree factor*. The sensitivity analysis of the *building type* and *tree factor* is carried out for Utrecht and Almere. This paper does not include the results of Almere for the sensitivity analysis of *building type* and the *tree factor* because the results are almost the same as Utrecht.

Table 6: NO_2 concentration from traffic relative to each other - Utrecht

	Building type 1	**Building type 2**	**Building type 3**	**Building type 4**
Building type 1		16.73%	9.97%	-5.26%
Building type 2	-14.33%		-5.80%	-18.84%
Building type 3	-9.06%	6.15%		-13.85%
Building type 4	5.55%	23.21%	16.07%	

Table 7: NO_2 concentration from road traffic relative to each other - Utrecht

	Tree factor 1.0	**Tree factor 1.25**	**Tree factor 1.5**
Tree factor 1.0		6.69%	13.26%
Tree factor 1.25	-6.27%		6.15%
Tree factor 1.5	-11.70%	-5.79%	

5 Discussion

5.1 Implications

This study makes a significant contribution to environmental modeling by addressing and analyzing practical problems related to emission models used in the Netherlands. The study is particularly important for municipalities, as they are required to provide annual traffic data for the monitoring of air quality. The emphasis is placed on keeping NO_2 concentrations below the threshold of $40 \quad \mu g/m^3$, with the expectation that this threshold may be reduced to $10 \quad \mu g/m^3$ once the European Union aligns with the WHO standards. Such a change is expected to exceed NO_2 values within municipalities.

During the initial interviews, input variables were not specifically identified as a potential source of uncertainty affecting model outcomes. Respondents often regarded models as inherently uncertain and approximations of real-life. However, the study highlights that inaccuracies in input data can have substantial repercussions on model outcomes. This serves as a wake-up call for municipalities, emphasizing that the practical problems they encounter can substantially impact the outcomes of emission models.

For practitioners, especially those within municipalities, the research findings highlight the importance of adopting clear guidelines and maintaining consistent approaches when gathering data and selecting input variables for emission models. Reducing uncertainties in these practical problems can significantly enhance policy decisions' accuracy and improve air quality monitoring.

5.2 Limitations

This study uses an OAT sensitivity analysis to determine how practical problems affect the outcome of the NO_2 model. In most literature, a combined method of a sensitivity and uncertainty analysis is used to determine the uncertainty of the most critical input variables. In this study, the semi-structured interviews and survey serve as a problem analysis to identify the practical problems. Based on the result of the problem analysis, the sensitivity analysis are performed. The results of the sensitivity analysis provide valuable insights into the robustness and inherent uncertainty of these input variables (Saltelli, Tarantola, Campolongo, & Ratto, 2004). Based on the sensitivity analysis results, it can be deduced that the input variables of the air quality emission model lack robustness. Variations in the input variables result in notable differences in the model's outcomes. The only input variable that exhibits robustness is the *stagnation factor*. Nevertheless, this research did not establish the level of uncertainty associated with the input variables.

Another limitation is that the study does not examine the joint effect of practical problems within a municipality. The study only determines the individual effect of practical problems on the input variables. Based on this research, Fileradar conducted a case study on the main street in Capelle. The municipality's entered data was corrected and recalculated using CIMLK's calculation tool. The "new" input values showed a higher NO_2 concentration than the original file from the monitoring tool. The model's outcome of NO_2 concentration from road traffic was 151% higher with the "new" values compared to the original file.

6 Conclusion and recommendations

6.1 Conclusion

The analysis conducted revealed several practical problems associated with the input variables of the nitrogen emission models. When it comes to nitrogen deposition and air quality monitoring, the perceived practical problems were related to the input variables *selection of roads*, *stagnation factor*, and *traffic volume* for vehicle classes like light, middle heavy, and heavy vehicles. Additionally, practical problems were also found with the input variables of *building type* and *tree factor* in the case of air quality.

The perceived problems are related to three types of uncertainties: linguistic, epistemic, and ambiguity. The guidelines and regulations regarding the input variables are vague, open to interpretation, and lead to different approaches by municipalities. The input variable *selection of roads* indicates this for air quality and nitrogen deposition.

The sensitivity analysis was conducted for Utrecht and Almere to determine the effects of practical problems on the NO_2 concentration. The results showed that *building type* is the most sensitive input variable, whereas *stagnation factor* is the least.

Municipalities in NO_2 focus areas are required and responsible to supply traffic data to CIMLK for annual air quality monitoring. As a result, there are variations in assumptions and methodologies among them, resulting in varying data quality. The quality of the input data is directly linked to its impact on the model's outcomes. Generally, municipalities are not aware of the impact of the "inaccurate" input of the variables on the outcomes of the emissions model. However, the sensitivity analysis results confirm that the air quality emission model is highly sensitive to changes in input values. Consequently, some municipalities have more accurate air quality concentrations than others.

Incorrect input to the emissions model results in overestimation or underestimation of the municipality's NO_2 concentration. The extent of overestimation or underestimation significantly influences the decisions made by decision-makers; depending on whether NO_2 concentrations were higher or lower, decision-makers may choose different courses of action.

6.2 Recommendation

6.2.1 Practical problems

Practical problems arise from three types of uncertainty: epistemic, linguistic, and ambiguity. Mitigating strategies for each type are recommended.

Epistemic Uncertainty: Epistemic uncertainty refers to the uncertainty that arises due to a lack of knowledge and data. To address this, it is important to incorporate more empirical data, such as loop measurements and floating car data. This can result in more accurate estimates of input variables such as *traffic volume* and *stagnation factor*.

Linguistic Uncertainty: Linguistic uncertainty arises due to vague definitions of input variables in the emission model. To reduce this uncertainty, it is crucial to clarify the regulations for air quality and nitrogen deposition monitoring, and establish consistent guidelines across municipalities.

Ambiguity Uncertainty: Ambiguity uncertainty pertains to input variables such as *building type* and *tree factor*, where interpretation depends on local circumstances. Despite clear guidelines and illustrations in the RIVM report (van Velze & Wesseling, 2014), incorrect variables are still used in practice. Therefore, it is essential to enter these factors accurately for existing roads in the monitoring tool, as they are road characteristics that change infrequently. Post-study evaluation and adjustment of these entered values is crucial to ensure accurate monitoring.

It's essential for municipalities to be more aware of the practical problems related to air quality monitoring. This research serves as a wake-up call for all organizations involved in data delivery for air quality. The accuracy of monitoring tools is significantly impacted by variations and incorrect input values. Sharing this research with the SLA[2] (Schone Lucht Akkoord) can increase awareness and attention to these practical problems. By implementing the recommendations provided, these practical problems can be resolved more effectively.

6.2.2 Further research

The study has some limitations, and there are several areas that require further research. To address these limitations, it is recommended conducting an uncertainty analysis using a Monte Carlo simulation for the same set of input values subjected to sensitivity analysis. This will enable a more precise assessment of the uncertainty of the input values and their impact on the output.

Another recommendations for municipalities is to reevaluate the input values in the monitoring tool and make adjustments based on the provided recommendations. This process should involve:

- Evaluating traffic volume through loop measurements.
- Determining average speed through floating car data.
- Ensuring building type and tree factor conforms to guidelines.

[2] The SLA is a voluntary agreement between several municipalities, provinces, and the state aimed at permanently improving air quality in the Netherlands

- Making necessary adjustments in the monitoring tool based on the obtained information.
- Recalculating NO_2 concentrations using the modified input values.

By following these recommendations, municipalities can mitigate uncertainties in input values and improve the accuracy of air quality concentration estimates. This will help them make well-informed decisions regarding air quality measures.

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