# Cost-Benefit Analysis of pipeline transport in the Antwerp – Ruhr region

A societal and financial Cost-Benefit Analysis for new pipeline infrastructure in the Antwerp – Ruhr trajectory.

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# Acknowledgements

This document is the result of my research on cost-benefit analysis for potential pipeline infrastructure between the port of Antwerp to clusters in Flanders, the Netherlands and the Ruhr area in North-Rhine Westfalen.

This would not have been possible without the guidance of my thesis committee. The questions, advice and feedback from my thesis committee encouraged me to carry out this challenging but exciting topic. For that reason, I would like to thank Bert van Wee, Arjan van Binsbergen, Jan Anne Annema as my supervisors from the TU Delft and Martijn van Ruiten from Hydrex.

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This thesis forms the climax of my studies at the TU Delft, I started my bachelor's degree in the summer of 2016 and now I aspire to finish my master's degree early 2023. Looking back, it was a good decision to enroll to the TU Delft, I will enjoy the knowledge and skills I gained in my education at the TU Delft for the rest of my professional career.

# Summary

The Flemish government has the goal to maintain the quality of their transport infrastructure, while improving the sustainability and increase the liveability for its citizens. These goals were formulated in the vision for mobility 2040. To meet the goals, one option identified by the Flemish government is a new pipeline system between the port of Antwerp and the Ruhr area in Germany. The societal relevance for this research lies in substantiating if the pipeline option should be stimulated by the Flemish government. The scientific relevance is derived from the fact that pipeline transport is often excluded from transport appraisal research.

Based on this problem statement the main research question is: *"To what extent will a new pipeline system for liquid bulk transport be socially and financially beneficial in the Antwerp - Ruhr trajectory?"*

The approach to answer the research question is to carry out a Societal Cost-Benefit Analysis and a Financial Cost-Benefit analysis. CBA is an economic evaluation method, often used in ex-ante transport appraisal capable of identifying and monetize effects. In the base case alternative current policy and trends are projected for the transport modes, road, rail, and inland water transport. The project alternative investigates the effects because of the new pipeline infrastructure. The project alternative considers three trajectories of pipeline systems (North, Central and South, see figure 0.1).

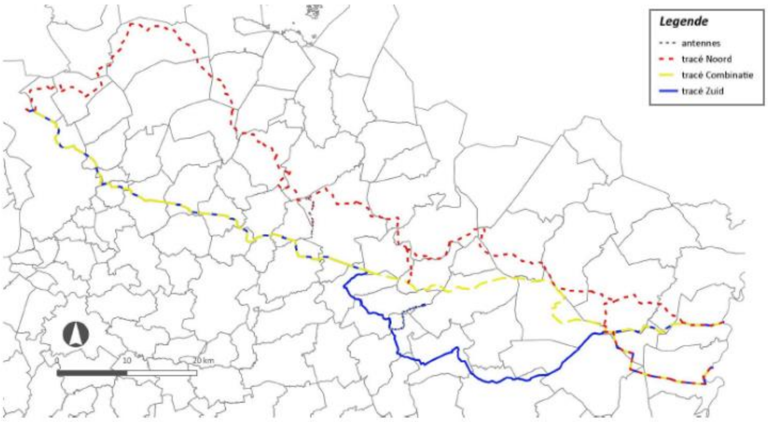

Figure 0.1: Considered trajectories of the substrate pipeline (Departement omgeving, 2020).

The CBAs will have an appraisal period from 2025 to 2055, where in the project alternative the construction phase of the pipeline will take five years starting from 2025.

To estimate the modal shift effects a mode choice model is used. First, data on transport volumes between origins and destinations for the base year 2010 was acquired from the Flemish department of Mobility. Next, a volume growth model was produced for three transport growth scenarios (low, medium, high), based on forecasts and prognosis. The mode choice model is a multinomial logit model, where the utility function of the transport modes considers fixed costs and variable costs (distance and travel time). The parameters in the utility function are calibrated for the base case alternative based on the acquired data from the Flemish department of Mobility. For pipeline transport no origin-destination data could be acquired, therefore utility function scenarios are applied, based on the calibrated parameters for the base case alternative. The hypothesis based on literature research for the pipeline transport parameters is that the fixed costs are higher, while the variable costs for pipeline transport are lower compared to the other three transport modes. The outcome of the (dis)utility per transport mode and origin-destination pairs is used in a multinomial logit function to estimate the mode choice distribution of transport in the years of the appraisal period.

The output of the mode choice model in the base case alternative and for the utility function scenarios in the project alternative are shown in figure 0.2 below.

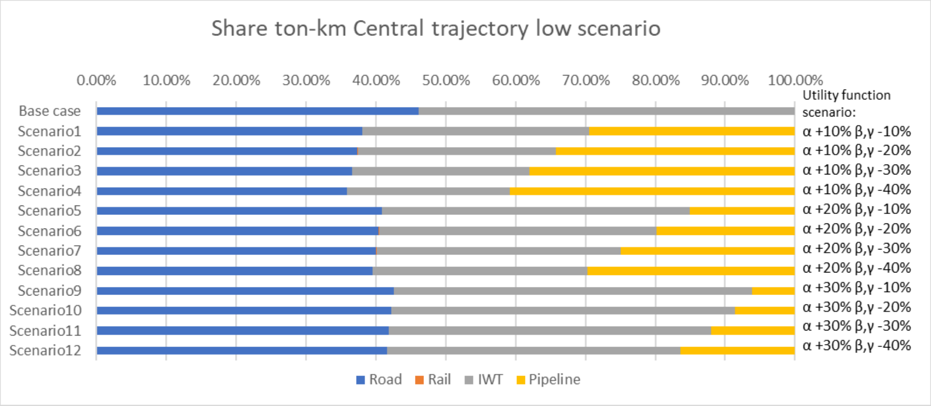

Figure 0.2: Share in ton-km Central trajectory low scenario.

Figure 0.2 displays the results for the project alternative in the different utility function scenarios. The mode choice model estimates that in certain scenarios, dependent on the trajectory and utility function scenario for pipeline transport, a considerable uptake in pipeline transport occurs at the expense of IWT and to a lesser extent of road transport.
The mode choice model's output allows to monetize certain effects in the CBAs, especially the external costs of transport in the SCBA use the estimates on assigned ton-kms from the mode choice model. In the FCBA the assigned volume is partially used to estimate the costs of operation and tariffs.

The research concluded that the Central trajectory is the most attractive trajectory from a transport perspective, as it is the shortest trajectory. The North trajectory is significantly longer in distance, while the South trajectory is fairly similar compared to the Central trajectory. The results of the CBAs for the Central trajectory are shown in table 0.1. The table displays a low growth scenario and four reasonable utility function scenarios (will be addressed later in the next section).

Table 0.1: CBA results Central trajectory low growth scenario.

| | | | | |
|---|---|---|---|---|
| **Central trajectory** | | | | |
| **Growth volume scenario: low** | | | | |
| **Discount rate: 4.5%** | | | | |
| **NPV (in million euro)** | | | | |
| **Project effects** | **Scenario 5** | **Scenario 6** | **Scenario 7** | **Scenario 8** |
| **Change in investment costs** | | | | |
| Construction costs | € -837.6 | € -837.6 | € -837.6 | € -837.6 |
| Loss of space costs | € -115.9 | € -115.9 | € -115.9 | € -115.9 |
| **Change in operational costs** | | | | |
| Energy | € -37.5 | € -48.3 | € -59.7 | € -70.4 |
| Personnel | € -127.0 | € -127.0 | € -127.0 | € -127.0 |
| Maintenance costs | € -347.9 | € -347.9 | € -347.9 | € -347.9 |
| Costs of service | € -127.0 | € -127.0 | € -127.0 | € -127.0 |
| Tonkm (million tonkm) | 19,969,864,057 | 25,829,793,380 | 31,906,419,621 | 37,443,128,612 |
| Volume (tons) | 126,090,643 | 154,148,254 | 183,009,466 | 209,691,900 |
| **Change in revenues** | € 1,465.8 | € 1,476.6 | € 1,487.9 | € 1,498.7 |
| **NPV FCBA** | € -127.1 | € -127.1 | € -127.1 | € -127.1 |
| **Change in external effects** | | | | |
| Air pollution | € 111.0 | € 148.9 | € 188.1 | € 223.7 |
| Climate change costs | € 34.4 | € 43.5 | € 52.8 | € 61.5 |
| Congestion costs | € 37.5 | € 42.9 | € 48.5 | € 54.0 |
| Noise costs | € 19.1 | € 21.9 | € 24.7 | € 27.6 |
| Safety | € 61.5 | € 71.3 | € 81.4 | € 91.3 |
| Loss of habitat costs | € 9.1 | € 12.4 | € 15.7 | € 18.8 |
| **NPV SCBA** | € 272.6 | € 340.8 | € 411.2 | € 477.0 |
| Change in transit time benefits | 0 | 0 | 0 | 0 |
| Change in toll and tax revenues | 0 | 0 | 0 | - |

The NPVs for the SCBA scenarios are positive, the reductions in external costs for society due to the modal shift to pipeline have a positive impact on society. Pipeline transport offers more sustainable transport in terms of external costs per ton-km than the other considered transport modes.

The NPVs of the FCBA scenarios are all negative and the same in the different scenarios. The reason for this is that due to a lack of information, the operational revenues are levelled to the operation costs. Meaning the revenues are calculated based on a transport tariff without margins for the operator. The negative NPV is the result of the remaining depreciation of the pipeline infrastructure lifespan. Therefore, the transport tariffs for pipeline transport provide more insights.
The tariffs are calculated by the operational costs divided by the assigned transport volume (in €/ton-km). Figure 0.3 displays the calculated transport tariffs compared to the red line, which is the estimated tariff of a prior feasibility study by a pipeline operator in the similar geographical scope of this research. Utility function scenarios 5 to 8 indicate a tariff that is balanced around the tariff in the feasibility study. Concluding that these scenarios are the most reasonable to reality (and therefore included in table 0.1).

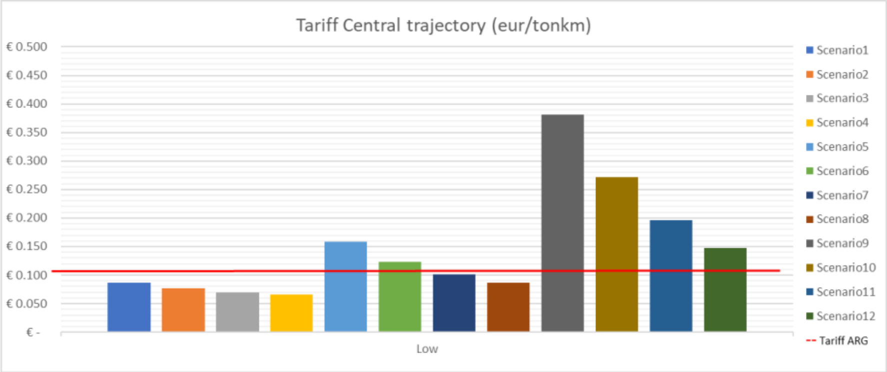

Figure 0.3: Tariffs Central trajectory low growth scenario.

The main conclusion regarding the research question is that there is uncertainty to judge or conclude that pipeline transport is a social and financial desired transport option. The SCBA concludes that a shift to pipeline transport can offer gains for society. The foremost reductions in external cost factors of transport are in air pollution, climate change costs, congestion and safety costs when modal shift to pipeline transport takes place (see table 0.1). Though, the gains for society and the effect of the pipeline infrastructure on nature and local residents (in terms of risk contour area, dispossession due to right of way procedures etc.) should be noted in the trade-off amid the potential societal gains.
The FCBA indicates that there are promising scenarios, where pipeline transport can offer competitive transport. However, to what extent the modal shift occurs is uncertain. The followed approach to estimate a mode choice model with limited aggregate data and even missing data can be suitable for exploratory research, however the required assumptions and missing data make the results of the mode choice model prone to under or overestimation of the modal shift. The conducted sensitivity analysis indicated that changes to the uncalibrated dispersion factor for pipeline transport affects the outcome of the evaluation methods significantly.

This also leads to the foremost recommendation that the Flemish government should insist on more relevant information and data from companies who insist on new pipeline infrastructure to substantiate the need of this infrastructure. Furthermore, the research was limited to one project alternative. In order to make a comprehensive decision which transport alternative the Flemish government should invest/stimulate, more research is necessary and this research offers a methodology to carry this out. Based on the combined information a trade-off should be made what option is most beneficial to society from the government’s perspective.

# Contents

# List of abbreviations

ARRRA – Antwerp, Rotterdam, Rhine, Ruhr Area

BCR – Benefit Cost Ratio (also referred to as B/C ratio)

CBA – Cost-Benefit Analysis

CO2 – Carbon dioxide

CRD – Causal Relation Diagram

EU – European Union

FCBA – Financial Cost-Benefit Analysis

GDP – Gross Domestic Product

GHG – Green house gas

GRUP – Spatial planning research program, 'gewestelijk ruimtelijk uitvoeringsplan'

IRR – Internal Rate of Return

IWT – Inland water transport

MNL – Multi-nominal logit

MOW – Department of Mobiliteit & Openbare Werken (Department of Mobility and Public Works)

NOx – Nitrogen Oxides

NPV – Net Present Value

NRMM – Non-road mobile machinery

NRW – North-Rhine Westfalen

NST - Nomenclature uniforme des marchandises pour les Statistiques de Transport, Revisée; Statistical Classification of Economic Activities

NSTR - Nomenclature uniforme des marchandises pour les Statistiques de Transport, Revisée; Statistical Classification of Economic Activities

NUTS - Nomenclature of Territorial Units for Statistics

OD – Origin-Destination (matrix)

OSM – Open Street Map

PM – Particulate Matter

RMSE – Root Mean Square Error

ROW – Right of Way

RQ – Research Question

SCBA – Societal Cost-Benefit Analysis

SE – Standard Error

SO2 – Sulphur dioxide

SQ - Sub question

SSE – Sum of Squared Error

Svrm – Strategisch vrachtmodel

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# 1. Introduction, Research questions and methodology

*December 2020, the Flemish government approved the start of an infrastructural reconnaissance project (GRUP, gewestelijk ruimtelijk uitvoeringsplan) for reserving substrate pipeline area in municipalities across the Flemish region of Belgium. The GRUP process is a reconnaissance procedure required for reserving land in extensive projects. This project is initiated to research the possibility for a future pipeline from the port city of Antwerp to the industrialised German area of Ruhr* (Dugernier et al., 2016)*. The GRUP for the potential pipeline was initiated because, according to relevant (chemical) companies there was extensive demand in pipeline transport, and there was no designated space left for the construction of substrate pipelines in the Flanders region. Thus, a new spatial planning programmed was necessary to reserve land for a substrate pipeline.*

*The potential pipeline should flow from the industrialised banks of the port of Antwerp towards the Ruhr area (Germany) in the east. Therefore, crossing the border with the Netherlands in the southern part of the province of Limburg. Meanwhile the potential pipeline shall connect industries around the Albertkanaal in Flanders* (Departement Omgeving, 2020)*.*

In 2021 the Flemish department of Mobility & Public Works (hereafter MOW; Mobiliteit en Openbare Werken), drafted a report with the vision on mobility in the year 2040. In this report the department states that Flanders has a unique and dense transport network, consisting of dense road, water and rail networks. The opportunity to transport via this network needs to be preserved, but also be sustainable in the future (Vlaamse overheid, 2021). The vision for more sustainable transport is not only pursued by the Flemish government, also the European Union published their 'Green Deal' for sustainable and even climate neutral transport in 2050 (European Commission, 2019).

This study aims to research the role of freight transport and freight transport alternatives, especially the new substrate pipeline, in reaching the goals of the Flemish government to make transport more sustainable within the trajectory of Antwerp and Ruhr region in Germany. This study will investigate the current state of transport modes in the trajectory Antwerp – Ruhr and analyse the (societal) effects of a sustainable transport project alternative by executing a social cost-benefit analysis (hereafter, SCBA) and financial cost-benefit analysis (hereafter, FCBA). Where some effects in the CBAs will be based on the estimates of a mode choice model.
The main objective is to provide insights in (and mainly quantify) the cost-effectiveness of a pipeline project. Therefore, this research is putting a scientific substantiation on the question if pipeline transport is a cost-effective transport mode for liquid bulk goods in the Antwerp - Ruhr region. The approach for quantifying the substantiation will be by estimating modal shares via the creation of a mode choice model.

In the remaining part of chapter the problem definition and research questions will be discussed, followed by the study area, scope and methodology. At last the reader can find a reading guide for this document.

## 1.1 Problem definition and Research questions

The previous paragraph started with the notice of a spatial planning project (GRUP) for a potential pipeline. However, the cause of this research lies in the sustainable transport goals of the Flemish government. Therefore, the Flemish government, to be more specific the departments of Omgeving and MOW, are the problem owners. This governmental body is designated to deal with transport and transport appraisal. The problem owner has both, the interest to do so as the (political) power and decisiveness to act. In the previous paragraph the goal of the problem owner is already stated, where freight transport is a part of mobility that is emitting a significant portion of GHGs and other emissions. In relation with the mobility vision for 2050 in Flanders, sustainable developments in this sector will be inevitable for reducing emissions to zero.

Furthermore, Flanders' government and residents strive to live in a healthy and pleasant environment. Where zero emissions, zero fatalities, fluent and seamless infrastructure are core goals of the mobility vision for 2050 (Vlaamse overheid, 2021).
Based on the goals of the problem owner their problem definition can be formulated as follows: *"Which transport alternative should the Flemish government stimulate or invest in to reach the goals for mobility and environment by 2050?"*.

In order to reach the goals for mobility and environment, different alternatives should be researched and considered, pipeline transport is one of those alternatives where reductions in emissions and living environment can be achieved according to the Flemish government (Departement Omgeving, 2019). Building on that, the relevance for this study lies in the societal importance. Public investments, expected costs and benefits for society should be estimated thoroughly.
Scientific relevance can be found in the already introduced transport alternative, the substrate pipeline, as well. The Flemish government considers this as a transport alternative, however little research has been performed on this transport mode in combination with transport project appraisal. The research in to transport appraisal and transport mode alternatives is mostly limited to a select amount of transport modes, often excluding pipeline transport as the pipeline is commodity and location specific (de Jong, 2013).
At last, technological development in sustainability is moving at pace, the demand in sustainable applications for different transport modes is rising, thus an update on new applicable techniques or alternatives is deemed useful.

As the problem and relevance of this study is more defined the research questions are introduced. The main research question is formulated as follows:

*RQ: "To what extent will a new pipeline system for liquid bulk transport be socially and financially beneficial in the Antwerp - Ruhr trajectory?*

To answer the research question above the following sub questions (SQ) are formulated:

- *SQ1: What transport alternatives and (i.e., technical) configurations are relevant in the geographical scope of the research?*
- *SQ2: What are characteristics of the transport mode configurations and how can these be modelled?*
- *SQ3: What is the current share per transport mode in the geographical scope?*
- *SQ4: What will be the effect on the share per transport mode after introducing pipeline as a transport alternative?*
- *SQ5: What are the estimated social and financial effects of the project alternative?*

In *SQ1* the goal is to identify all relevant alternatives including the transport mode alternatives that can contribute to the sustainability goals. SCBA is the proposed method to estimate the effects of transport in a social perspective, and a FCBA will be carried out to analyse the financial feasibility of the project alternative. In general, the first steps of a CBA are to analyse the current situation (base case) and the project alternatives.
Next, *SQ2*, the characteristics of all relevant transport are investigated. This is necessary to be able to model the transport modes in a mode choice model for *SQ4*. In *SQ3* the current modal split is estimated via aggregate data from the Flemish department of MOW. With this information a base case is established, the input for a zero alternative in an (S)CBA.
The base case (also zero alternative) and the project alternatives can be put in the modal split model.

The change in mode choice after introducing a transport alternative in the modal split model will be the basis to answer *SQ4*. Consequently, the effects that arise from the introduction of the alternative form the input for the effects in the SCBA for *SQ5*. In the SCBA all relevant societal effects from the different alternatives will be estimated and the FCBA covers the project alternative from an investors/operator perspective. The effects in both evaluations will be over the appraisal period of 2025 to 2055. The combined results of both evaluation methods will be interpreted to answer the *RQ*.

## 1.2 Study area & Scope

In the previous paragraphs the cause for this research and the proposed research questions are discussed. In this paragraph the study area and scope are elaborated on, as the study area is specific to a region (and trajectory) a defined scope is necessary.

As stated, the problem definition for the Flemish government lies in the investigation to find and stimulate transport options that suit the mobility goals for 2050. In this study the focus lies on a geographical area, the trajectory of the port of Antwerp to the Ruhr area including connections from the port of Antwerp to the industrialised Albertkanaal.
Next to a limitation in geographic area, the study is also limiting itself to a select group of transport products, namely goods that fit in ‘industrial bulk goods’ or ‘liquid bulk’. To be more specific the products this research is focussing on are products that fit in the international NST product code (*Nomenclature uniforme des marchandises pour les Statistiques de Transport, Revisée*; Statistical Classification of Economic Activities) categories of 2, 7 and 8 (Centraal Bureau voor de Statistiek, n.d.). Where NST2 products include coal and lignite, crude petroleum and natural gas. NST7 products include cokes and refined petroleum products. And NST8 products are chemicals, chemical products, man-made fibers, rubber and plastic products and nuclear fuel (Centraal Bureau voor de Statistiek, n.d.). In section 2.1 these products are discussed in more detail.

From the literature study and background research, Chapter 2, can be concluded that there are four transport modes capable for transporting products that fit in the geographical context of the trajectory Flanders – Ruhr and are capable of transporting the NST2, 7 and 8 category. Those transport modes are road, rail, inland water and pipeline transport. Other transport modes such as nautical shipping or air transport are no competitors for this trajectory based on the geographical context and logistic characteristics of the transport modes.
Currently, the four mentioned transport modes operate in the geographical scope of this research. The base case alternative in this research includes three transport modes: road, rail and inland water transport. The project alternative adds the new pipeline, so there will be four transport modes in the project alternative. Sustainable developments and new technical configurations for inland water vessels or trucks such as hybridization or electrification of these transport modes are not included in this research due to time constraints. This does not imply that suchlike sustainable developments for other transport modes are deemed not efficient or cost-effective. The main focus of this research lies in the justification of the potential pipeline GRUP for the problem owner, the Flemish government.

At last, the research is limited to a time period, namely the appraisal period which is also embedded in the evaluation method CBA. This research will use an appraisal period of 30 years, from 2025 to 2055. Infrastructure often lasts for long periods but covering more than 30 years in a CBA is unpractical. Next to this, the time frame of 2025 to 2055 fits well in the policy window where sustainability goals have to be achieved. This will be discussed in detail in section 3.1.

## 1.3 Methodology & Research approach

In this paragraph the research approach and methodology are proposed. This section starts with a general applied method, the literature or desk research. Then, Cost-Benefit Analysis is shortly discussed and the more specific SCBA and FCBA evaluation methods are discussed more in depth. Thereafter, the proposed method for estimating some of the effects and estimate modal shares of transport modes are discussed in the mode choice model.

### 1.3.1. Desk research

Desk research provides a general approach to a project. In the desk research focus will be set on gathering information and data that is published. With the use of literature, a clearer understanding of aspects in the field of the research is aspired. The literature this research will focus on can be found in published reports of transport in the observed regions, the available transport modes, infrastructure, infrastructural plans, policies and policy plans related to transport in the observed regions and also sustainable development for transport modes e.g., technical measures to reduce emissions and their applicability to the relevant transport modes.

Furthermore, the role of the desk research is to highlight where sources of information are missing. In case of missing information or a lack of literature it is important to define ways to gather the missing data or find a suitable method to work around the missing information. This desk research has revealed that there was a need for origin destination data. This data was not publicly accessible, therefore another approach was made to gain this origin and destination data.

Information and literature will be acquired via different sources. Scientific papers, journals but also useful 'grey literature', e.g., fact sheets of institutions, policy effect reports and other non-scientific sources will be used.
In the research primary sources for scientific research are Google Scholar and Scopus. Also, the TU Delft library provides articles and books who can be used for this research.
The desk research will be primarily used for defining the current state of the spatial planning project in Flanders, the transport network and characteristics of transport modes, therefore answering *SQ1* and *SQ2*. Furthermore, desk research will be used for input in the mode choice model, that requires extensive input, see 1.3.3.

### 1.3.2 Cost-Benefit Analysis

Cost-Benefit analysis (CBA) is an evaluation method with the basis of theory lying in microeconomics and welfare theory, it has the aim to estimate the social welfare effect of projects (Mouter, 2014). The CBA is used to compare current situations (zero alternative) to project alternatives, therefore it is a tool to support the decision process and commonly used in ex-ante transport appraisal (Beria et al., 2012).

CBA is valuing expected effects in monetary terms. The valuation of effects is mainly based on a willingness to pay, for example a reduction in travel time. Or a willingness to accept, usually a negative impact or a loss, e.g., noise, air pollution or a loss of biodiversity (Dodgson et al., 2009). In CBA these impacts are divided over society. The perspective in doing so can be divided in two perspectives. First the Pareto criterion, which states that "the social welfare effect of a project is positive if it makes someone better off without making anyone worse off" (Nyborg, 2014). This perspective of Pareto efficiency seems fair, as there eventually only be winners. However, the Pareto criterion has limitations. The Pareto criterion is difficult to operationalise, the gains or losses must be aggregated for each person, combined with various difficulties including increasing policy costs and burdens in information (Boardman et al., 2018). Furthermore, there is the so-called Kaldor-Hicks compensation test, this states that the social welfare effect is positive if the gains exceed the losses.

Potentially, the gainers may compensate the losers (Mouter, 2014). However, verification if compensation has taken place is not required in CBA.

As a CBA is trying to monetize impacts, some impacts are not obvious for monetisation.

Furthermore, the CBA considers that costs and benefits may occur in different years to come by using a net present value (NPV). The first reason to use a NPV, is that a new road takes some time built and has periodic maintenance costs for example. This also implies that benefits only occur after completion, which is not immediate. A time period with costs and benefits can capture more than a single snapshot. The second reason for applying a NPV is that a euro today is worth more than a euro in the future, due to inflation (Mouter, 2014). Furthermore, one could argue that by doing nothing, the money could be saved with interest from a bank or invested in other projects with higher returns on investment. Therefore a NPV uses a discount rate, to account for inflation, risk and missed opportunities (Romijn & Renes, 2013).

Romijn & Renes (2013) have published the guidance on how to perform a CBA, this step-by-step plan will be followed as well. In Appendix A this step-by-step plan is discussed. This paragraph will continue with the SCBA and FCBA as extensions of the CBA and discuss specific steps and deviations.

### *Societal and Financial Cost-Benefit Analysis*

In this study a SCBA and FCBA will be carried out. The SCBA and FCBA can be seen as an extension of CBA, where SCBA has a more multi-actor perspective (Haezendonck, 2007). SCBA is appraising projects from a social perspective, where the profit for society is considered, opposed to seeing the project as a profit from a company's perspective in FCBA (Eijgenraam et al., 2000). (S)CBA can include different impacts and effects and consider the gains or losses for society, which is useful for this research. Since the realisation of transport policies will result in numerous effects. The SCBA can organise these effects over the time frame of the appraisal period and support in the decision-making process.

To further specify the SCBA, Eijgenraam et al (2000) distinguishes two SCBA types, a partial and a comprehensive SCBA. These differ on the aspect of evaluated project effects. A partial SCBA will limit itself to the direct project effects, while a comprehensive also includes the indirect effects. Example is that the comprehensive SCBA will also include the impact of a project on the economy, instead of only the direct effects in the partial SCBA.
This research will perform a partial SCBA, as the case for this pipeline project is still at the analysis stage, it is deemed necessary to research the headlines and review project alternatives on the same perspective. Furthermore, the available data and time make a partial SCBA more suitable.
The FCBA will be carried out to analyse the financial result of the project alternative, the project alternative will be compared to the base case scenario (Eijgenraam et al., 2000). The made investments in the project alternative should result in benefits over the appraisal period.

So, FCBA will preliminarily focus on financial-economic aspects, therefore including investment costs for construction, costs of operation and analyse revenue streams. While SCBA identifies effects for society, which are preliminary external effects caused by transport activities, think of safety, air pollution and climate change.
Some effects will be monetized using data and sources about the effects, think of construction costs for the pipeline. While for other effects the results of the mode choice model will be used (discussed in-depth in the next section). External effects from transport, such as the emission of CO2, can be estimated based on the assigned volume and ton-kilometres from the mode choice model combined with a market price or shadow price per ton-km for the externality.

The SCBA and FCBA will contribute to answer *SQ5* and in doing so *SQ3* and *SQ4* will be answered as well. By interpreting the SCBA an answer can be given to the main research question.
In Appendix A a more detailed description of CBA is provided, including limitations of CBA as an evaluation method.

### 1.3.3 Mode choice model

Mode choice or modal splits models describe the distribution of the total freight demand over the available transport modes (de Jong, 2013). Added to this, a mode choice model can estimate the potential shift in transport modes shares when characteristics of the modes change. That aspect is very useful as this research will use this shift in share to estimate effects in the CBAs. Furthermore, the mode choice model assigns transport (or volume) to the project alternative. To what extent this mode choice occurs affects the estimated revenue streams for the project alternative in the FCBA.

Mode choice modelling can be seen as form of discrete choice modelling, it is either yes or no (0 or 1) (de Jong, 2013). The decision maker chooses one transport mode, and the other mode(s) is not used. This is mostly the case in passenger transport, in freight transport the concept is different as one can decide to ship batches of products with different transport modes.
Furthermore, a distinction in mode choice models can be made with aggregate and disaggregate data collection. In aggregate data collection the aggregate of decision makers is the unit of observation, while in disaggregate data collection the decision maker is the unit of observation (de Jong, 2013). Disaggregate data collection is less common in freight transport than in passenger transport. Reason for this is that companies do not wish to share sensitive commercial information (de Jong, 2013). Therefore, the proposed approach will be an aggregate mode choice model. Aggregate model split models have a quite simple structure and do not require extensive amounts of data (Winston, 1983).

A simple binomial logit model can be specified as in formula 1.1 below (de Jong, 2013)(Winston, 1983):

$$\log\frac{S_i}{S_j} = \beta_0 + \beta_1(P_i - P_j) + \textstyle\sum_W \beta_W(x_{iw} - x_{jw}) \qquad (1.1)$$

Where:
$S_i/S_j$ is the ratio of the market share of mode *i* compared to mode *j*.
$P_i$ and $P_j$ the transport costs of the modes.
$X_{iw} - X_{jw}$ are the differences between the characteristics (*w= 1, 2, …, W*) of the two modes.
β are coefficients and determined by estimating a model. In this specific example $\beta_0$ could be a specific constant for a transport mode, while $\beta_1$… $\beta_W$ must be determined based on the model data and corresponding to a choice maker's perspective.

In this research the following approach is used to develop a mode choice model. This is the four-stage model, which is frequently used in passenger transport modelling, but can also be applied to freight transport. The four-stage model consists of four steps (de Dios Ortuzar & Willumsen, 2011):

- Trip generation
- Trip distribution
- Mode choice
- Assignment

In the first two steps, the generation and distribution of freight transport, data and information is required. Therefore, this research acquired aggregated origin-destination (hereafter, OD) data from the Flemish department of MOW. The same data is used in the Flemish freight transport model 'Strategisch vervoermodel Vlaanderen' (Svrm) (van Houwe et al., 2019). The OD data in this model dates from the year 2010 and displays the number of tons transported within Flanders and between Flanders and North-Rhine Westfalen for three transport modes, road, rail and IWT. Also, the different NST product types can be distinguished. The aggregated data from the Flemish freight transport model indicates overall transported tons between OD pairs and implies there are no individual trips to distinguish. This kind of OD data is suitable for the estimation for aggregate mode choice models (Tavasszy & De Jong, 2013)

To define the mode choice literature research is necessary to describe the characteristics of the transport mode and certain input is necessary to model mode choice over the appraisal period. First, the impedance matrix is set up, this includes the distance between the OD pairs for the different transport modes and the matching travel time. The travel times and distances between OD pairs will be derived using data and tools.
Second, the acquired OD data is used is combined with demand forecasts and a growth factor model to estimate the volume of transport in the appraisal period. The expected growth (or decline) in transport will be modelled for the entire appraisal period and based on social economic reports and prognosis.
Third, the utility function is set up for the multinomial logit model. A multinomial logit (MNL) model will be used as this research includes more than two transport modes (de Jong, 2013). See formula 1.2 below.

$$\Pr(m) = \frac{\exp\,(V_m^{\mu m})}{\sum_{n=1}^{N} \exp\,(V_n^{\mu n})} \qquad (1.2)$$

Where:
Pr = probability of mode m
$V_m$ = utility of mode m
$V_n$ = sum of utility for mode n=1 to N
μ = the dispersion factor per transport mode

The MNL model calculates the shares of the different transport modes per OD pair. The MNL model considers the total volume of transport per OD pair (including the prognosed growth or decline based on the base year) and estimates the share per transport mode for every year. That means the MNL model does not assumes a modal share in the base year and allocates the growth or decline in volume, but the MNL estimates the share of the transport mode per year based on the total volume of the year during the appraisal period.
The utility function used in this research is based on Jourquin (2016). Jourquin proposes a linear deterrence function containing a factor for fixed costs and variable costs in distance and travel time.

$$V_{m,p,r} = 2\alpha_{m,p,r} FC_{p.m} + \beta_{m,r} D_m + \gamma_{m,r} TT_m \qquad (1.3)$$

Where:
V = the (dis)utility of the total deterrence function
FC = fixed costs
D = distance
TT = travel time
m = transport mode
r = region
p = product type (NST product category)
α = parameter for fixed costs
β = parameter for distance
γ = parameter for travel time

Thereafter, the parameters in the utility function need to be calibrated, for the included transport modes. The level of aggregation in the data does not allow to use specific software such as Biogeme to examine logit models. The optimization of the modal split models will be done via an iterative algorithm to create sub-optimal solutions, further on a solver program within Microsoft Excel is used to reach optimal solutions. For the mode pipeline transport no OD data could be acquired and therefore a theoretical approach is required. The hypothesis is that the mode pipeline has a higher fixed costs than IWT, rail and road transport, but the variable costs for distance and travel time in formula 1.3 are lower. Substantiation of the hypothesis above are based on the analysis made in section 2.5, where all considered transport modes are qualitatively scored based on certain transport characteristics. Based on this hypothesis multiple scenarios are set up, where the research also strives to identify which scenarios are more reasonable than other scenarios.
When these steps have been completed, the (dis)utility for transport is calculated for the base year. This (dis)utility for transport now needs to be calculated for every year in the appraisal period, therefore a cost figure development matrix needs to be constructed. Therefore, prognosis and past cost figure development will be consulted.
At last, the results of utility function will be put in the MNL model from formula 1.2 resulting in the assigned transport volume for the different years in the appraisal period. These volumes can be calculated to ton-kilometres per transport mode and used for calculating effects in the CBAs.

The modal split will be important for answering SQ3 and SQ4, where the modal split and mode choice estimations will be answered. And the output of the mode choice model will be the input of the FCBA and SCBA, therefore the model is part of answering *SQ5*.

## 1.4 Structure of the report

This section illustrates the structure of this research, which is related to the methodology, research questions and sub-questions from Chapter 1. Figure 1.1 visualizes the structure of the research, including the chapters and their corresponding research and sub question.

In the first phase, the focus of this study is on the problem analysis and the theoretical context. Via desk research the current state of transport in the study area is researched. This will take place in Chapter 2 ‘Context & Background’ and will answer *SQ1* and *SQ2*. Chapter 3 will elaborate on the CBA, the project definitions, alternatives and expected effects. The input from the desk research will form the knowledge to model the different transport alternatives in Chapter 4 ‘Mode choice answering *SQ3* and *SQ4*. The resulting SCBA and FCBA in Chapter 5 will be used for interpretation of the results and eventually answer *SQ5*. In Chapter 6 the results will be interpreted, reviewed and eventually a conclusion is made to answer the main research question.

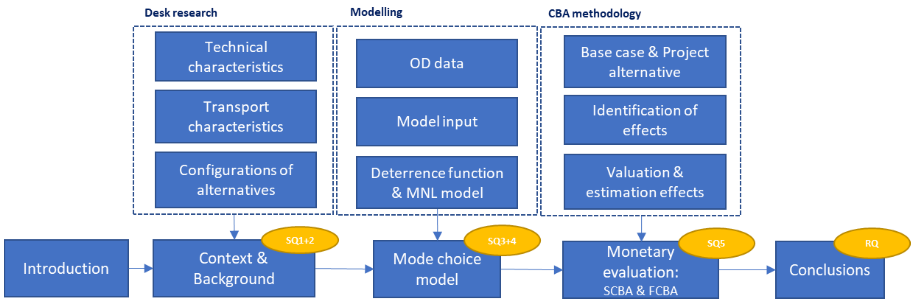

Figure 1.1: Overview of the research.

# 2. Context & Background

In this section the context and background are elaborated on. The current market is analysed together with the location of supply and demand, transport infrastructure and related transport alternatives.

## 2.1 Market segment

To research the market segment in question, first the scoped type of products is followed. The NST product categories 2, 7 and 8. These product categories form typical bulk goods. Bulk goods are characterised by high quantity and relative low value per weight. Especially non-road transport, such as rail, nautical shipping and inland water transport are often used for bulk transport (ITF, 2022). Another non-road transport mode is pipeline transport, which can transport high volume products (ITF, 2022).

The NST product categories form a classification to put certain products under a NST category. However, the product categories can be extensive, next to the fact that different products have different appearances as in state of matter. Therefore, table 2.1 is made, which also indicates the state of matter of the products.

Table 2.1: NST products overview (Eurostat, n.d.-d).

| **NST** | **Detailed products** | **State of matter**[1] |
|---|---|---|
| **2** | Coal and Lignite | S |
| | Crude petroleum | L |
| | Natural gas | G |
| **7** | Coke oven products, briquettes, ovoids, and solid fuels | S |
| | Liquid refined petroleum | L |
| | Gaseous, liquefied, or compressed petroleum products | G/L |
| | Solid or waxy refined petroleum products | S/L |
| **8** | Basic chemical products | G/L |
| | Basic organic chemical products | G |
| | Nitrogen compounds and fertilizers | G |
| | Basic plastics | S |
| | Pharmaceuticals and parachemicals | N/A |
| | Rubber or plastic products | S |
| | Nuclear fuel | N/A |

The state of matter of a product can influence the mode choice. Products that appear in a solid state of matter are less likely to be transported via pipeline in the geographical scope and product type scope of this research. Transport of solid-state products via pipeline is possible with slurry pipelines.

Considering the study area, the hinterland of the port of Antwerp, four transport modes are capable to transport the observed transport products: road, rail, inland water transport and pipelines. Nautical shipping would be unlikely due to the geographical characteristics of the study area. And air transport with high transport costs per unit and low volumes is not suitable for bulk transport (Rodrigue, 2020). More about the logistic characteristics of these transport modes will be discussed in chapter 2.5.

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[1] S stands for Solid, L stand for Liquid, G for Gaseous.

## 2.2 Identification of Demand and Supply

The four identified transport modes have extensive networks in the study area, there are numerous kilometres of roads, waterways, railway lines and even pipelines. Among and around these infrastructural networks multiple (petro)chemical companies are situated in the region of Antwerp, Albertkanaal and North-Rhine Westfalen. In the table below an overview of (petro)chemical companies in the hinterland of the port of Antwerp are shown with a direct pipeline connection to or from the port of Antwerp (or Port of Rotterdam).

Table 2.2: Chemical companies (ARG, n.d.).

| Company | Location of plant |
|---|---|
| Basell Polyolefine GmbH | Wesseling (D); Germany |
| BASF Antwerpen N.V. | Antwerp (B); Belgium |
| BP Refining & Petrochemicals GmbH | Gelsenkirchen (D); Germany |
| BRASKEM Europe GmbH | Wesseling (D); Germany |
| Celanese Emulsions B.V. | Geleen (NL); Netherlands |
| Deutsche Infineum GmbH | Cologne (D); Germany |
| DOW Benelux B.V. | Terneuzen (NL) via Antwerp (B); Belgium |
| ExxonMobil Petroleum & Chemical N.V. | Meerhout/Antwerp (B); Belgium |
| INEOS Manufacturing Belgium N.V. | Geel (B); Belgium |
| INEOS Manufacturing Deutschland GmbH | Cologne (D); Germany |
| INEOS N.V. | Antwerp C2 Terminal (B); Belgium |
| INOVYN Deutschland GmbH | Rheinberg (D); Germany |
| Inovyn Manufacturing Belgium N.V. | Antwerp (B); Belgium |
| OXEA Deutschland GmbH | Oberhausen (D); Germany |
| SABIC Petrochemicals B.V. | Geleen (NL); Netherlands |
| Shell Chemicals Europe B.V. | Rotterdam (NL) via Antwerp (B); Belgium |
| TOTAL Olefins N.V. | Antwerp (B); Belgium |
| Vynova Belgium N.V. | Tessenderlo (B); Belgium |
| Borealis | Beringen (B) |

With the use of the table above important clusters can be identified in Flanders and North-Rhine Westfalen. Where as expected, the clusters in Flanders are situated around the port of Antwerp as one of the largest chemical ports in North-West Europe and around the Albertkanaal. In Germany the large chemical parks are somewhat scattered around NRW, where Cologne, Gelsenkirchen, Marle and Wesseling are examples. Figure 2.1 indicates the location of the (petro)chemical plants and the existing pipeline infrastructure from ARG.
Appendix B provides a summary of operating pipelines in the ARRRA region.

Figure 2.1: Clusters location and Pipeline network (PPS, n.d.).

The identified locations of the (petro)chemical clusters can be linked to socio-economic NUTS zones in Belgium and NRW. The NUTS zones are a hierarchical system to divide geographical marked zones and attach socio-economic activities/data to the territory (Eurostat, n.d.-c). There are three hierarchical levels, NUTS1, NUTS2 and NUTS3. NUTS1 represents the major socio-economic regions, NUTS2 divides NUTS1 zones into smaller finer zones and at last NUTS3 which are the smallest regions.
In table 2.3 the clusters are linked to their corresponding NUTS2 or NUTS3 zone.

Table 2.3: Clusters and NUTS zone (own creation).

| **Region** | **Cluster** | **NUTS2 or NUTS3 zone** | **District** |
|---|---|---|---|
| **Flanders** | | | |
| | Antwerpen | BE211 | Antwerpen |
| | Geel | BE213 | Turnhout |
| | Meerhout | BE213 | Turnhout |
| | Tessenderloo | BE221 | Hasselt |
| **Zuid-Limburg** | | | |
| | Chemelot Sittard-Geleen | NL423* | Zuid-Limburg |
| **North-Rhine Westfalen** | | | |
| | Cologne | DEA23 | Cologne |
| | Dormagen | DEA1 | Dusseldorf |
| | Gelsenkirchen | DEA3 | Münster |
| | Godorf | DEA23 | Köln |
| | Knapsack | DEA27 | Rhein Erft Kreis |
| | Leverkusen | DEA24 | Leverkusen |
| | Marl | DEA3 | Münster |
| | Oberhausen | DEA1 | Oberhausen |
| | Rheinberg | DEA1 | Dusseldorf |
| | Wesseling | DEA27 | Rhein Erft Kreis |

*: no OD data is acquired for Dutch NUTS zones.

To work with the identified NUTS zones, origin-destination (OD) data is acquired for the transport volumes between the NUTS zones in Flanders and NRW. The OD data is originating from the Flemish department of Mobility and describes transport volumes in the year 2010 for all NST product categories of three transport modes: road, rail and inland water transport. This implies there is no data about pipeline transport in this dataset.
With the use of the data set and the filtered NUTS zones, the size of the transport streams can be calculated in the base year. The total volume is close to 29 million tons and the majority of the volume has the destination in Flanders. The transport stream of NST8 products forms the largest product group with over 15 million tonnes.

Table 2.4: Transported tons to observed NUTS zones in Flanders and NRW (own creation).

| | **Flanders** | **NRW** |
|---|---|---|
| **NST2** | 4.056.376 | 2.356.348 |
| **NST7** | 4.751.746 | 1.933.167 |
| **NST8** | 12.655.619 | 2.980.003 |

Furthermore, the data allows to calculate the modal share. It shows that road transport is significantly larger than the two other modes of transport among all three NST product categories. The share of IWT ranges between 25% and 34%, but the share of rail transport is remarkably low for all three product categories.

Table 2.5: Modal share base year ton-% (own creation).

| **Modal split base year** | **Road** | **Rail** | **IWT** |
|---|---|---|---|
| **NST2** | 65.94% | 0.03% | 34.04% |
| **NST7** | 74.11% | 0.87% | 25.01% |
| **NST8** | 66.90% | 4.20% | 28.90% |

Another remarkable sign is the variation in modal share between national transport in Flanders itself (national transport) and international transport (Flanders to North-Rhine Westfalen and from North-Rhine Westfalen to Flanders).

Table 2.6: Modal share (inter)national transport ton-% (own creation).

| **Flanders** | | | | **Flanders to NRW** | | | | **NRW to Flanders** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Modal split** | **Road** | **Rail** | **IWT** | **Modal split** | **Road** | **Rail** | **IWT** | **Modal split** | **Road** | **Rail** | **IWT** |
| **NST2** | 80.77% | 0.04% | 19.18% | **NST2** | 39.85% | 0.00% | 60.15% | **NST2** | 51.69% | 0.01% | 48.30% |
| **NST7** | 77.46% | 0.17% | 22.36% | **NST7** | 67.23% | 2.79% | 29.98% | **NST7** | 62.97% | 0.05% | 36.99% |
| **NST8** | 82.17% | 0.38% | 17.45% | **NST8** | 39.62% | 11.87% | 48.51% | **NST8** | 40.41% | 9.90% | 49.69% |

The table indicates that for national road transport is even more dominant than in the overall modal split. While the share of rail and inland water transport is above the mode share in international transport.
There can be various explanations why shares differ, product types, volumes, lead times, cost per unit etc. A general aspect is that distance-based behaviour does affect the mode choice (Rodrigue, 2020). Economies of scale and a decreasing transport cost per unit can benefit modes of transport that handle larger volumes over longer distances, rail transport and inland water vessels form an example in that case (Planco, 2007).

An important note is that the acquired data only splits the transported goods on NST category. As shown in paragraph 2.1 the NST categories are collection of multiple products, and every group of products can again be split into more specific products. The limitation of the current data is that it is only possible to split on NST category, it is not possible to further identify where subcategories of specific product streams move between OD pairs. The characteristics of the different products can affect the mode choice, the limitation of the data should be considered in the results of this research.

## 2.3 Future market

Now the market segment, suppliers and demand are located in the study area, the next step is to assess which products are missing from the future demand prognosis and which products demand more or new pipelines in the future.

During the period 2007-2016 the transport of different substances and number of substances remained quite stable in Belgium (van der Bauwhede, Dugernier, et al., 2018. Based on this research, there were no bottlenecks in sight for the near future and no immediate demand for radical changes to the transport network. However, long term future demands based on different scenarios and expert interviews indicated a need for different products in the study area (van der Bauwhede, Dugernier, et al., 2018:

- Natural gas: Belgium is dependent on gas from import, the Netherlands is reducing its production from Groningen. So, import from other countries (i.e., Norway or Russia) or via LNG terminals is necessary. Dependency of natural gas from Russia has shown to be vulnerable for European countries during the course of 2022 (and 2023).
- Chemicals: propene and propylene pipelines are a priority based on research and interviews. Propylene/Propene form an essential factor for production facilities in north-west Europe.

- Other gaseous products: oxygen, hydrogen, carbon dioxide and nitrogen, where nitrogen is a must have according to interviews (van der Bauwhede, Dugernier, et al., 2018. Hydrogen and carbon dioxide might play an important role in the future energy transition, the products may be a potential growth market for pipeline transport.

In conclusion, the report of van der Bauwhede, Dugernier, et al. (2018), the demand for gas, chemicals and gas products including renewables are expected to increase in the future. A sidenote should be made that the demand prognosis made by van der Bauwhede, Dugernier, et al. (2018) were made without quantitative research but based on interviews with experts. Dugernier et al. (2016) also concludes that future demand could arise in gas, essential products for industries as propene and propylene and renewable products as hydrogen, nitrogen, oxygen and carbon dioxide.

## 2.4 Infrastructure

In this paragraph the information from observed zones/clusters and the corresponding figures are combined with the available infrastructure. Section 2.2 noted that the OD relations for rail transport were remarkably low and to a lesser degree for IWT as well. By identifying the transport infrastructure options to certain clusters, this section tries to further clarify the interaction between the NUTS zones from the observed data.

By doing so, figure 2.2 is constructed. The figure includes three infrastructures, pipelines, railroads, and inland waterways. Regular roads for trucks and cars are not included as the density of roads would create an unclear figure.

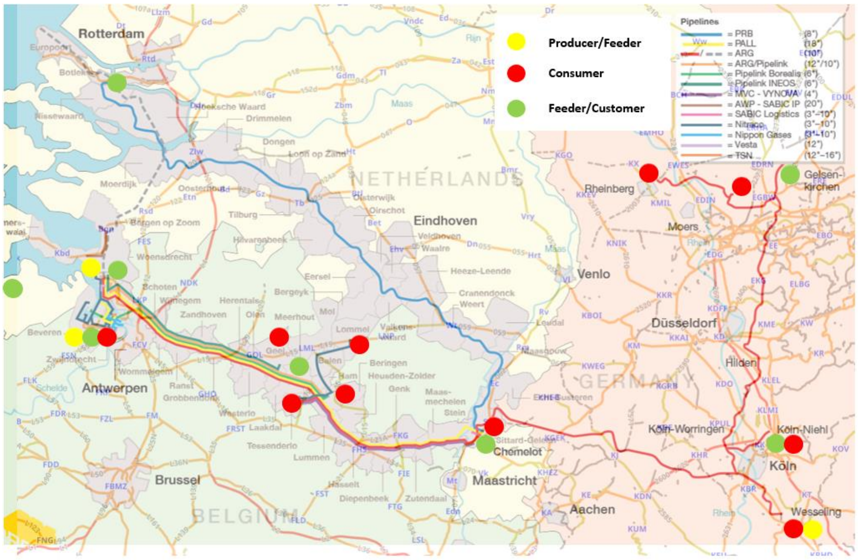

Figure 2.2: Combined infrastructures in the ARRRA region (PPS, n.d.) (Beyssac, n.d.)(edited).

From figure 2.2 multiple conclusions can be made about connectivity between regions.
First, the Albertkanaal is well connected via roads, pipelines and the inland canal. In Flanders four major pipeline systems are situated (AT Osborne, 2018). Furthermore, there are multiple branches of the railway system that connect industries around the Albertkanaal. Examples for towns and industrial zones connected to the railway system are Geel, Meerhout, Beringen, Tessenderloo and Genk. Along a certain part of the Albertkanaal a parallel railway is connecting industries in Geel, Meerhout and Olen (Beyssac, n.d.).

Second, the Ruhr area is less connected to the port of Antwerp and intermediate areas. Currently, there is only one (ethylene) pipeline connecting the port of Antwerp with industrialised zones in the

Ruhr area (Port of Antwerp, n.d.). Via rail the Ruhr area is connected to the port of Antwerp via two train routes. The Montzenroute via Wallonia and the Brabantroute via the Netherlands (Spit et al., 2017). The reason for the limited amount of railroad routes between the port of Antwerp and Ruhr can be found in the geographical context, due to height differences crossing the hills in the Ardennes and Zuid-Limburg there are not many routes fit for heavy cargo trains. Furthermore, there are technical and economic reasons, where building railroads are costly, the trains run on different widths in different countries, the same applies for safety systems, power systems etc. (Spit et al., 2017). Other railroad routes to Germany go through the Netherlands, think of the Betuweroute.

To reach certain areas by inland water vessels in the Ruhr area, there are also limited options to reach the industrial zones in NRW. Via Antwerp an inland water vessel could go via the Albertkanaal to Maastricht and follow the river Maas up to Nijmegen and run on the Rhine. However, this route is longer than travelling from Antwerp via Rotterdam up the Rhine (Bureau Voorlichting Binnenvaart, n.d.). For many clusters in the Albertkanaal the same applies as well, clusters such as Hasselt, Geel and Meerhout, the inland waterway route via Rotterdam and the Rhine is quicker than via the Maas (Bureau Voorlichting Binnenvaart, n.d.).
Concluding, rail and inland water transport are limited by geographical reasons and the limitations of the infrastructure. This can be indication why road transport has the largest share in transported tons from this geographical and infrastructural perspective. As other characteristics of the transport mode affect the mode choice as well. Pipeline connections between Ruhr and the seaports in Belgium and the Netherlands are limited as well, though there is no data available which tell the demand of clusters and occupancy of current pipeline networks.

## 2.5 Transport mode overview

In the transport mode overview, the performance of the different transport modes over logistic characteristics are reviewed. The overview of different transport modes and their performance is important to understand the characteristics, which will aid in developing a modal split model.

The overview will be made by comparing the transport modes with transport and logistic indicators. The following nine indicators are bundled from different literature sources (Christiansen et al., 2004; Rodrigue, 2020; Verweij et al., 2009).

- Range of product options
- Volume or capacity of the transport mode (in relation to the average shipment size)
- Distance covered
- Transport time required (e.g., operational speed)
- Service/Flexibility (door-to-door service)
- Reliability (on-time performance, accidents, risk of damage, weather)
- Accessibility
- Transport cost per unit

Based on the literature and the indicators discussed above a table is constructed. The table indicates on a qualitative scale the performance per transport mode.

Table 2.7: Performance transport modes logistic indicators (own creation).

| Mode | Range of product options | Capacity | Distance covered | Time | Service | Reliability | Accessibility | Transport cost per unit |
|---|---|---|---|---|---|---|---|---|
| **Truck** | Extensive | Low | Short to moderate | High | High | Moderate | High | High |
| **Pipeline** | Limited | (very) high | Long | Low | Medium | High | Low | Very low |
| **IWT** | Moderate | High | Moderate to long | Low | Low | Moderate | Moderate | Low |
| **Rail** | Extensive | Moderate | Moderate to long | Moderate | Low | High | Moderate | Low |

In the remainder of this section the indicators are shortly discussed with relation to the transport modes.

First the range of product options, with this indicator the versatility of product options a transport mode can carry is meant. Trucks can transport multiple types of products from bulk to parcels, and that largely applies to inland water vessels and trains as well (Smirnov & Smirnova, 2019). For pipelines the variety in products is limited as they are primarily transporting liquid bulk products (not concerning, slurry, capsule pipelines for city logistics or a hyperloop concept) (Smirnov & Smirnova, 2019) (NEA & Haskoning, 1993).

Second, the capacity of transport modes differs significantly. A regular truck carrying liquid bulk cargo is transporting between 13 to 20 tons, compared to the other transport modes this is significantly less. Inland water vessels transport has capacities between 1200 tons for smaller inland vessels and can go up to more than 3000 tons for large inland vessels. This number is close to the average of 2800 tons in rail transport (van der Meulen et al., 2020). For pipelines the throughput can be very large depending on the diameter of the pipe, the pressure and number of compressors. Natural gas pipelines can transport billions of cubic meters per year (Energy Charter Secretariat, 2006).

Third, covered distance by the transport mode, with this indicator a rule-of-thumb of the general trip length is meant. In general trucks perform better at the short to moderate distances, while rail, inland water transport and pipelines range from several hundred kilometres to over several thousand kilometres (Rodrigue, 2020).

Then the travel time and correlated speed of operation of the transport modes. The travel time is partially dependent on the operating speed and the available infrastructure for a transport mode. Truck transport is the quickest transport mode, with high operating speeds (65-100 km/hr) and a dense transport network of roads, trucks tend to be the quickest transport mode. Rail transport has a moderate operating speed, around 40 km/hr, followed by inland water vessels with an operating speed ranging between 10 to 25 km/hr (van Essen, Croezen, et al., 2003)(Rodrigue, 2020). Pipeline is the slowest transport mode of the four considered (Verweij et al., 2009), however the speed of pipelines is dependent on multiple factors, like the product itself, temperature, the amount of pressure and the amount of pressure stations. The operating speed of pipelines is between 5-13 km/h. Therefore, expressing the capacity in terms of kilogram or volume per hour can be more applicable.

The indicator service gathers several aspects, think of door-to-door service and flexibility. Where trucks can directly deliver door-to-door, this is much more difficult for the other modes. The density of infrastructure for trucks is significantly higher than the number of waterways or railroad tracks. Not to speak of the effort it costs to connect every facility to a pipeline, however in case the pipeline

is connected to a facility around the clock transport from origin to destination without hick-ups is possible.
In terms or reliability the indicator comprises, the risk of damages during transport, on-time performance, accidents and external factors like the weather or low water levels. Road transport can count of high on-time performance rates, although congestion takes place. However, the mode is also the most prone to accidents for example. Rail, pipeline and IWT count as safer modes of transport, while presenting quite high on-time performance as well. The pipeline is characterized as safest transport mode, as the pipeline has no interaction with other traffic. Research by the TRAIL institute (1996) equates the safety in average number of incidents per million tons transported. This research indicates a 0.02 incidents per million tons between 1986 and 1991, compared to other transport modes the pipeline scores better compared to other modes (barge 0.15, rail 1.26 and road 0.66) (Janssens, 2007).
Accessibility is the degree of ease to use a transport mode. Pipelines are often privately owned and not easy to access, while the threshold to use the road network is low. For rail and inland water transport the accessibility is rated in between the two modes.
At last, the indicator price, this is often indicated as the cost per unit and has relation to most of the indicators discussed in this paragraph. Speed, door-to-door delivery, distance, wages, toll etc. all affect the cost. However, the cost per unit function differs per transport mode over the covered distance (Rodrigue, 2020). Road transport tends to have lower cost over short distances, while the cost per unit for transport mode like maritime and rail increase at a lower rate than road transport. At certain distances the cost functions of transport modes will cross, and theoretical break-even points arise (Rodrigue, 2020). The theory assumes that distances of different transport modes match and are interchangeable, in reality distances do not match, and modes are bounded to infrastructure such as ports and terminals for ships. Speaking of the cost per transport unit, trucks have the steepest cost function, while rail and inland water transport have a less increasing cost function. The costs for transporting a unit via a pipeline is lowest (Goor & van Amstel, 2003).

## 2.6 Conclusion

In chapter 2 the background and context of the research is clarified, and the problem is further analysed.
The first section clarified the focus on what kind of products this research is focussing on together with the market segments and what transport modes fit to the scoped products. In this research there are four transport modes considered that fit to the products: truck, rail, inland water and pipeline transport.

Further on this chapter did research into the current demand and supply locations in the observed area. Where with the help of (grey) literature and data from the Flemish government a conclusion can be made that the reviewed bulk products are transported between certain clusters, where in Flanders the port of Antwerp and around the Albertkanaal important clusters are situated and in North-Rhine Westfalen the clusters are much more scattered in the region and often close to the river Rhine. For these clusters, a reconnaissance was made to identify which products may have increased demand in the future, which are natural gas, propene/propylene, nitrogen and renewables such as carbon dioxide and hydrogen.

Moreover, an infrastructure analysis showed that there are extensive infrastructure networks in the ARRRA region. Especially between the ports of Antwerp and Rotterdam and the Albertkanaal all transport modes are well represented. What strikes is that the Ruhr area is only reachable via one pipeline system from the port of Antwerp, while the port of Rotterdam has multiple connections (mainly oil products).

Furthermore the infrastructure analysis looked in to rail and inland waterway connections, where was noticed that two rail road routes were in use to reach the Ruhr area and the river Maas is bypassed for many origin and destination pairs and the longer route via the Rhine is opted.
Based on the data from the Flemish government for the transported tons between origins and destinations in Belgium and NRW, the data tells that road transport is the most dominant mode. In respect to the infrastructure analysis this is a logical effect, as road transport enjoys a very dense network compared to the other transport modes reviewed.

At last, the different transport mode under review in this research are put in an overview. The goal of this overview was to make clear that all transport modes have different characteristics, therefore one transport has totally different performances on logistic indicators than the other transport mode. This overview will aid in developing the modal split model as the characteristics of the different transport modes should be representative for the model.

# 3. Cost-Benefit analysis: SCBA & FCBA

CBA is the evaluation method used in this research to mainly quantify and monetize the effects of transport appraisal. CBA consists of eight documented steps by Romijn & Renes (2013). The first step of a (S)CBA prescribed a problem analysis, which is stated in the introduction. This chapter continues with following steps, section 3.1 discusses the project definitions. The base case alternative in 3.2 and the outline of the project alternative in 3.3. Then, 3.4 and 3.5 focus on the project effects and valuation of the effects.

## 3.1 Project definitions

In this section the project definitions are discussed, this includes the appraisal period and the applied discount rate.

### 3.1.1 Appraisal period

In the scope (section 1.2) the appraisal period was already shortly touched up on. The appraisal period in the CBAs is set for 2025 to 2055, starting in 2025 for financial year 0 and end in 2055 for financial year 30. Usually, the time period is dependent on the economic life span of the project (Mouter, n.d.-c). In this research the transport appraisal considers the addition of pipeline infrastructure in the project alternative. Infrastructures for transport modes such as roads, canals, pipelines etcetera are built for the long term. The infrastructure should last for decades with appropriate maintenance. The economic life span of pipeline infrastructure is assumed to be 30 years (Capiau, 2010). For the project alternative is assumed that the construction time of pipeline infrastructure takes 5 years starting in 2025 and the means the pipeline is operational in 2030. Meaning that the pipeline is operational for 26 years.

There is no clear standard on the time horizon for infrastructure projects, however the economic life span forms a guideline. Policy wise the time frame 2025 to 2055 is also an interesting period as the Flemish government and European Union have set emissions goals towards 2050.

### 3.1.2 Discount rate

Large infrastructural project generates benefits and costs over time, these benefits and costs do not all appear at the same time. Furthermore, the value of money devaluates over time due to inflations. Therefore, benefits and costs are calculated against a discount rate, when all costs and benefits are calculated to the discount rate over time the nett present value can be calculated (Eijgenraam et al., 2000) (Mouter, n.d.-a).

The discount rate consists of two components, the standard risk which is based on expected returns on investments of 3% (van Ewijk et al., 2015). This is also referred to as the ‘systematic risk’ of ‘macroeconomic risk’.

In addition to the systematic risk, also project risk is included as large public investments, especially in infrastructure projects. This includes the high investment costs at the start of a project, so called sunk costs, but also fixed costs across the time horizon of the project regardless of the use. For this project risk 1.5% is added, which comes down to a discount rate of 4.5% in this research (van Ewijk et al., 2015).

## 3.2 Base case alternative

This alternative will be the base case alternative (also called zero alternative), which implies that the other alternatives are compared to this base case. Therefore, this alternative is rather important. The base case alternative will be seen from the perspective of the Flemish government. Therefore, it is assumed current and projected policies are executed and part of the base case alternative. This means the base case alternative does not include any investments or stimulation programs other

then what is currently known. One of the plans and wishes is that modal shift is encouraged. Furthermore, the Flemish government has initiated subsidies concerning certain inland water vessels for after treatment installations (Agentschap Innoveren & Ondernemen, n.d.).
Another essential aspect of the base scenario is the expected autonomous development of the transport modes in terms of sustainability and efficiency. Road transport has been in a quick development concerning certification of diesel engines, the EURO-norms, follow each other in rapid succession (every 3-5 years since the millennium). The norms focus on pollutants as NOx, PM and CO. While the contrary occurs with inland shipping vessels, the ships and engines are technically and financially viable for longer periods, which decreases the speed of sustainable development. The latest norm in non-road mobile machinery (NRMM) is the stage V norm set by the EU, which is the successor of the CCR-II norm of 2007 (Ecorys, 2015).
The base case alternative will take this the different rates in development into account and adapt effects of transport modes in the SCBA.

In this base case alternative three transport modalities will be reviewed as the zero alternative. This will be road, rail, and inland water transport. As there will be no additional pipeline this mode will not be included, furthermore data about pipeline transport is not acquired as mentioned in the previous section.

### 3.2.1 Base case assumptions

The base case alternative is based on some assumptions, which will be mentioned and explained below. These assumptions and expectations will form an important part of the estimated effects. For this base case alternative, the assumptions will cover the following areas as social economic figures, transport demand prognosis, expected effects of current policy and expected effects in the transport market.

At first economic growth, there is an expected growth of the GDP in Belgium in the period of 2017 to 2030. The Belgian institute for prognosis, Prognos, mentions an added value in the production of Belgium of 2 to 2.4% in the period for 2017 and 2027 (Vanherle et al., 2007). The added value is a method to estimate the GDP growth of a country. An added value of 2 to 2.4% would indicate a GDP growth of 4%, which is quite high. Also, demographics show an increase. Demographics are an indicator to expect an increase in transport movements of people, but also of transport. A growing population cause higher demands in the future, thus more transport movements.
To deal with the rates of economic growth, increase in transport movements a growth model will be used (section 4.2). The growth model will use a factor to increase the production and attraction of the observed NUTS zones. A growth model is a simple and effective method, as it requires not much information and data. Sensitivity and scenario analysis will be performed to see what effects other growth rates have on the estimated effects.

Next to socio-economic indicators, the development of transport modes in terms of sustainability is considered. Transport modes become more efficient in terms of energy usage and the norms for emissions become stricter as well as stated in the begin of this section.
In IWT the renewal rate for engines is an important aspect. The renewal rate of inland water vessels is long, a ship can last up to a hundred years while an engine of an inland vessel will last for 25 to 30 years (Sap & Komduur, 2012). Therefore, an average renewal rate of engines would be at around 4% per year in a favourable case, in practice the number of new engines in the IWT market lies around 200 a year (NEA et al., 2011). Compared to road transport, where trucks depreciate much faster, the renewal rate appears to be around 20% (as in every five years). For the renewal rate and technical improvements made to engines for ships and trucks a decrease in pollutants can be expected.

Rail transport is far ahead in terms of electrification among transport modes, most trains are powered with electric locomotives. The trend for rail is that the emissions will not significantly increase or decrease, and emissions will remain proportional to the usage of the transport mode in this base case alternative (Vanherle et al., 2007). Therefore, the choice is made to have no increase or expected decrease in emissions for rail transport.

Inland water transport will deal with a renewal rate for engines as new engines must comply with the current NRMM stage V regulations. The renewal rate is expected at 3-4% per year, this will largely affect the reduction of pollutants as NOx, CO, SO2 and products that cause ozone (Klein, 2018) (Vanherle et al., 2007). The NRMM stage V regulations require large reductions in emissions to new engines. Respectively this will cause reductions of 30%, 10%, 35% and close to 40% between 2005 and 2030. Furthermore, it is expected that engines become 23-24% more efficient in 2040 compared to 2010 (NEA et al., 2011)
An increase in transport is expected to increase the total sum of emitted CO2, close to 30% more in 2030 than in 2005 (Vanherle et al., 2007).
Overall the decrease in emissions for inland water transport for the base case alternative is estimated at 0.5% per year. This figure is based on the historic figures from EMOSS (Vanherle et al., 2007) and the report by NEA et al. (2011).

Between 1990 and 2006 the ton-kilometres of road transport increased with 80% in Belgium, within that same period the emission of CO2 increased with about 30%. This shows that the trend of increasing ton-kilometres and emission of CO2 is decoupled or in other proportions (Boschmans et al., 2022). Renewal rates for new trucks, engine regulations and rules and measures like road pricing for road transport develop over time. The expectation is that trucks also develop over time and gradually decrease emissions at 0.85% per year. This figure is based on Boschmans et al. (2022), where the gradual decrease in emissions for transport between 2000 and 2019 is extrapolated.

In short, the base case alternative does include three modes of transport, road, rail and inland water transport. For these three modes a development in terms of sustainability will be used in the estimation for external effects, especially in terms of the emission of pollutants and GHGs.  transport and this means that the expected external costs will reduce over time per unit of transport.

## 3.3 Project alternative: Pipeline

In this section the project alternative, a new pipeline between the port of Antwerp and the east border of Belgium is introduced and the project outline is discussed. First the project outline is discussed, this includes the trajectory of the pipeline system, expected costs and land use. Second, the operation of a pipeline, then the energy use and emissions and the operational costs. At last, the modelling approach for the project alternative is discussed.

### 3.3.1 Project outline

The project alternative in this research considers a new pipeline system. In the introduction this project alternative was already cited. As the process for a potential permit is still at a beginning phase, therefore it is inevitable to make assumptions about the project outline.
At first, the trajectory of the substrate pipeline is still to be determined. The current permit process considers three trajectories with varying implications for the surroundings. In essence the substrate pipeline will cover trajectories over different lengths and cover a general width of 45 metres on Flanders’ territory. The three trajectories are called North, Central and South. These different trajectories form a part of the total project alternative but will be assessed individually in this research. The trajectories are visualized in the figure below:

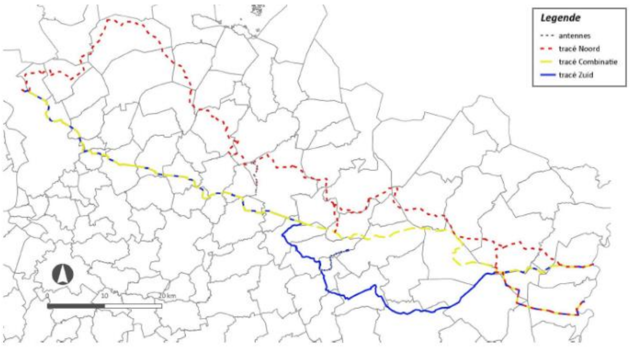

Figure 3.1: Considered trajectories of the substrate pipeline (Departement omgeving, 2020).

The pipeline will connect to the industrial zones in the Albertkanaal near Geel, Meerhout and Tessenderloo. Furthermore, the pipeline(s) should flow to the border of the Netherlands, from there clusters in the Netherlands and Germany should be connected to these pipelines.
As there are currently three trajectories currently in scope for the GRUP, these three trajectories do differ in length and in terms of land they will cross. This will have an impact on building costs and land use costs. For this alternative it is assumed that the building phase of the pipeline(s) will start in 2025 and the pipeline is fully operational from 2030.

First, the building and construction costs will be discussed. The capital expenditures will be made for the pipeline itself and the required compressor stations. Costs consist of materials, labour, miscellaneous costs, and the right of way (ROW) costs (Molnar, 2022).
Typically in gas and LNG transport by pipelines the material costs account up to one third of the pipeline and over half of the costs for compressor stations. Labour costs make up close to half of the costs for pipeline construction and close to a third for compressor stations.
Miscellaneous costs comprise a wide variety of facets, such as costs made for engineering, supervisions, freight, surveying and even taxes (Molnar, 2022).
At last the ROW costs include acquiring the land used for the pipeline (in this research loss of space) and rights-of-way.

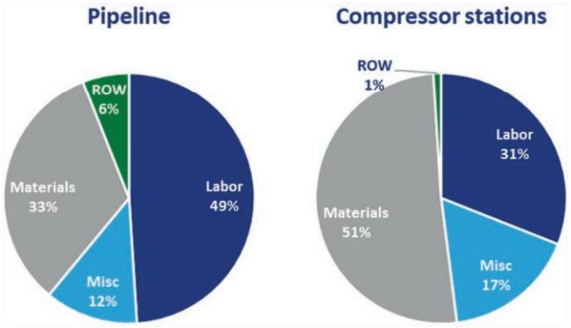

Figure 3.2: Capital expenditures distribution for constructing pipelines (Molnar, 2022).

The construction costs consist of these various aspects. For this project alternative the pipeline trajectory will be capable of accommodating 6 to 8 pipelines Dugernier et al., 2016. It is expected the pipelines transport different products, which will affect the configuration and design of the pipes, thus the construction costs. Table 3.1 displays the construction costs and exploitation costs per kilometre for different types of pipelines.

Table 3.1: Construction costs pipelines.

| **Product** | **Construction costs** (x €1000 per km) | **Exploitation costs** (x €1000 per km) | **Source** |
|---|---|---|---|
| **Natural gas** | 2500 | 75 | (Gasunie, 2009) |
| **Petrochemicals (8 inch)** | 500 | 15 | (Dönszelmann et al., 2008) |
| **Petrochemicals (20 inch)** | 1000 | 30 | (Arcadis, 2010) |
| **Propene** | 600 | 18 | (Dönszelmann et al., 2008) |
| **CO2** | 1000 | 18 | (Arcadis, 2010) |

To estimate investment costs an assumption in the configuration of pipelines is necessary. In section 2.3 a future demand for chemicals, natural gas, and possible renewable energy sources (such as CO2) was concluded. Furthermore, there is room for 6 to 8 pipelines in the proposed trajectories Dugernier et al., 2016. It is assumed there are three scenarios (attached to the volume growth scenarios, discussed in section 4.3). Where every scenario contains one natural gas pipeline, one pipeline destined for renewables (assumed costs of CO2) and the remaining pipelines are destined to chemical products. In the scenario 6 pipelines will be constructed, 7 in the medium scenario and 8 in the high scenario. Table 3.2 summarizes the configurations per scenario.

Table 3.2: Pipeline composition scenarios (own creation).

| **Scenario** | **Type** | **Composition** | **Avg. cost per km** |
|---|---|---|---|
| **Low** | | | €850.000 |
| | Natural gas | 1 | |
| | (Petro)chemicals | 4 | |
| | Renewables (CO2) | 1 | |
| **Medium** | | | €850.000 |
| | Natural gas | 1 | |
| | (Petro)chemicals | 5 | |
| | Renewables (CO2) | 1 | |
| **High** | | | €850.000 |
| | Natural gas | 1 | |
| | (Petro)chemicals | 6 | |
| | Renewables (CO2) | 1 | |

This research assumes an average costs of €850.000 per kilometre in the different scenarios.
In terms of maintenance and exploitation costs the sources state an average 3% per year of the construction costs based on the sources in table 3.1.

Then, the construction of the pipelines comes at the cost of land use. Most of the land in the trajectories in use for agriculture, landscape and forest (Departement Omgeving, 2020). A significant difference for the three trajectories is that the northern trajectory crosses more agricultural terrain, while the central and southern terrain will cross more nature reserve area and forests. Table 3.3 describes what the share of land use is that the trajectory will cross in terms of percentages of the trajectory length.

Table 3.3: Percentage of land use of the pipeline trajectory (Departement Omgeving, 2020) (Janssens & de Wael, 2014).

| | North | Central | South | Value (€/m²) |
|---|---|---|---|---|
| **Total hectares** | 1274 ha | 805 ha | 848 ha | - |
| **Estimated length** | 283 km | 179 km | 188 km | - |
| **Residential** | 1% | 2% | 2% | € 236.76 |
| **Recreational** | 0% | 2% | 4% | € 149.70 |
| **Nature reserve** | 17% | 22% | 25% | € 2.98 |
| **Forest** | 6% | 8% | 9% | € 2.98 |
| **Nature (other)** | 2% | 7% | 6% | € 2.98 |
| **Agriculture** | 66% | 44% | 49% | € 3.73 |
| **Industry** | 2% | 5% | 4% | € 98.08 |
| **Water extraction** | <1% | 0% | 0% | € 166.67 |
| **Other** | 7% | 11% | 2% | € 2.98 |

Every square metre of land has a certain value corresponding to the land use and purpose permit given to the land. The rightest column of table 3.3 displays the value per square metre. The value per square metre for nature, forests and agriculture is low, however the value for residential areas, water supply and extraction and recreational land use is high. Based on the table one can expect that the costs for land use of the North trajectory are lower, although it consumes the largest number of hectares, due to the fact the routing mainly goes through agricultural land.

### 3.3.2 Operation of a pipeline

In this section the functioning and operation of a pipeline is discussed. Pipeline transport works by using force to move a fluid or gas through a pipeline system. The force is mostly generated by a series of pumps. The number of pumps required for a pipeline trajectory is dependent on the geography of the area, a more hilly or mountainous area requires more pumps than a flat terrain. Departement omgeving (2020) has stated that every 80 kilometres a pump(station) or booster station should be installed. The pumps are powered by electricity, diesel/oil or gas, depending on the transported product.

Next to pumps to supply compression, another aspect in pipeline transportation are buffers or storage locations. A feed buffer can be applied to deal with fluctuations in demand, while a reception buffer at the customer side is necessary to store the product. This is visualized by figure 3.3:

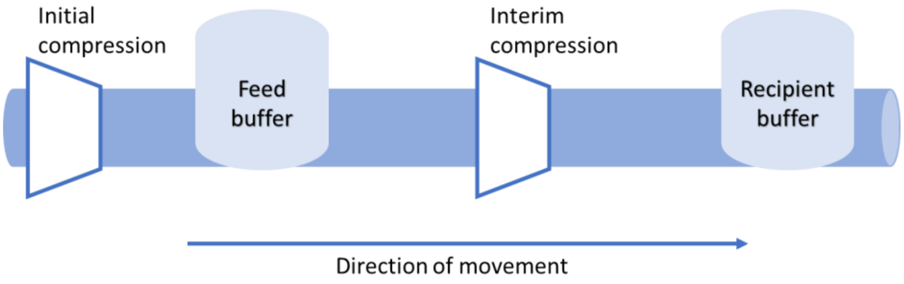

Figure 3.3: Visualization of pipeline operation (own creation).

The speed in which products move from the initial location to the recipient are dependent on multiple aspects. First, the product itself, the state of matter (required pressure to transport), weight and viscosity of the substance all play a role. Then, the number of pumps, plus the locations and distance between each pump and the pressure these pumps provide. And at last, the physical

characteristics of the pipeline play a role, especially the diameter of a pipeline (Smart Freight Centre & Cefic, 2021).
So, there is no straightforward answer to put an average speed on pipeline transport. Reports indicate that the speed of a product is somewhere between 5 and 13 kilometres per hour (Cheng et al., 2017)(Pienaar, 2008)(Trench, 2001)(Petroleum.co.uk, n.d.). This research assumes an average operating speed of 10 kilometres per hour. As the trajectories are not confirmed yet the design and booster stations are still to be determined.

### 3.3.3 Energy consumption and emissions of pipelines

In this section the energy consumption is discussed based on published research. First the emissions of pipeline transports, these come from three sources in operation (Worley Parsons, 2013), next to the emissions emitted during construction:

- Fugitive emissions
- Operation of compressors and turbines
- Blowdowns for compressors and pipelines

Fugitive emissions are emissions caused by leaks and unintentional releases of any products. Especially for natural gas pipelines fugitive emissions can be significant, as the unintended emissions contain methane which is a prominent greenhouse gas. An Australian study indicated that per kilometre of natural gas pipeline 8.72 tons of CO2 is emitted in terms of fugitive emissions (Mundia-Howe, 2015)(Worley Parsons, 2013). Other types of pipelines can also emit fugitive emissions, next to the fact that the construction and building quality have an influence of the eventual fugitive emission.

The second emission source is the operation and is probably (one of) the largest portions of emissions. There is little publicly available research about the emissions and energy consumption of the compression used for pipeline transport.
Pipeline transport emissions are dependent on two aspects, viscosity, and density of the product (Shing Yieng et al., 2016)(NEA & Haskoning, 1993). Viscosity of the transport product, higher viscosity will increase the loss of pressure thus higher energy consumption. And higher density will increase the energy consumption (NEA & Haskoning, 1993). Furthermore, diameter and used compression play an important role in energy consumption.
NEA & Haskonining (1993) report an energy consumption for pipeline transport for multiple products, the figures in this research contain the total energy required to transport, but also compress, break or even crush products before transporting in the pipelines.

Table 3.4: Energy consumption pipeline transport in MJ/ton-km (NEA & Haskoning, 1993).

| | **MJ/ton-km** |
|---|---|
| **Crude oil** | 0.25 |
| **Petrochemical products** | 0.11-0.18 |
| **Natural gas** | 0.56-0.84 |

In 2003 another study reports the figures given by the pipeline industry for petrochemical products and a theoretical approach. The figures in this research are within the range of the earlier study by NEA and Haskoning from 1993 (van Essen, Croezen, et al., 2003).

Table 3.5: Energy consumption petrochemical transport (van Essen, Croezen, et al., 2003).

| | **MJ/ton-km** |
|---|---|
| **Industry provided information** | 0.12 |
| **Theoretical approach** | |
| Ethylene | 0.13 |
| Propene | 0.12 |

When these mega Joules of energy per ton kilometre are expressed in specific emissions and in €cent per ton-km the distribution is applied to an electrically powered petrochemical pipeline on the trajectory Antwerp – Cologne. The emissions are based on the EU average (van Essen, Bello, et al., 2003).

Table 3.6: External costs of pipeline transport (van Essen, Croezen, et al., 2003).

| | **Shadow prices[2] (€ct/ton-km)** | | | | | |
|---|---|---|---|---|---|---|
| | **CO2** | **NOx** | **PM10** | **SO2** | **VOC** | **Total** |
| **Average** | 0.04 | 0.01 | 0.02 | 0.016 | 0.000 | 0.086 |
| **Best** | 0.03 | 0.01 | 0.01 | 0.013 | 0.000 | 0.063 |
| **Worst** | 0.05 | 0.01 | 0.02 | 0.021 | 0.001 | 0.111 |

The third aspect of emissions are blowdowns of compressors. These circumstances occur rarely. However, the amount of emission from this aspect is dependent on the number of compressors, valves, length of pipeline and quality of the used materials.

### 3.3.4 Operational expenditures

The operational expenditures consist of energy costs, labour/personnel, cost of service and maintenance (already covered in 3.4.2). Typically, in gas distribution, the allocation of these costs is 28% energy, 31% personnel, 29% costs of service and 12% of the operational costs are maintenance (Molnar, 2022). A Canadian study on operational expenditures in the oil pipeline sector concluded an allocation of costs energy 22%, wages 20%, materials (maintenance) 10%, services 12%, taxes 15% and other expenses 21% (Karangwa, 2008). This example and research indicate the breakdown of these costs are dependent on the products and configuration of the pipelines. Smaller diameter pipelines tend to be more expensive in transport costs per unit than large diameter pipelines, due to lower friction loss (Molnar, 2022). Furthermore, environment and weather conditions may affect the breakdown of operational costs, ageing pipelines required more maintenance and weather conditions can affect the ageing process.

The operational costs in this research will be subject to assumptions as well. The maintenance costs are assumed at 3% of the construction costs. Then, the energy costs will be calculated based on the estimated ton-kms from the mode choice model and the costs of energy. For the costs of personnel and service, an assumption must be made, where the breakdown from Karangwa (2008) and Molnar (2022) form a benchmark.

## 3.4 Project effects

Project effects are the changes or differences that occur when a project alternative is carried out compared to the situation when the project alternative was not carried out (Eijgenraam et al., 2000). To identify the expected project effects the information from the previous sections about the base case and the project alternative I used in combination with a causal relation diagram (CRD). The

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[2] Shadow prices: CO2 €0,05 per kg, NOx €7-12 per kg, PM10 €70-300 per kg, SO2 €4-10 per kg, VOC €3-6 per kg (van Essen, Croezen et al., 2003).

causal relationship diagram is a tool used for dealing with complex problems as the CRD exposes the mechanisms between factors (Vermaak, 2016). At the top of the CRD five blue boxes indicate external factors. The external factors are factors that cannot be influenced by the problem owner (geographic characteristics, economic growth) or are without of scope of this research (technological development).

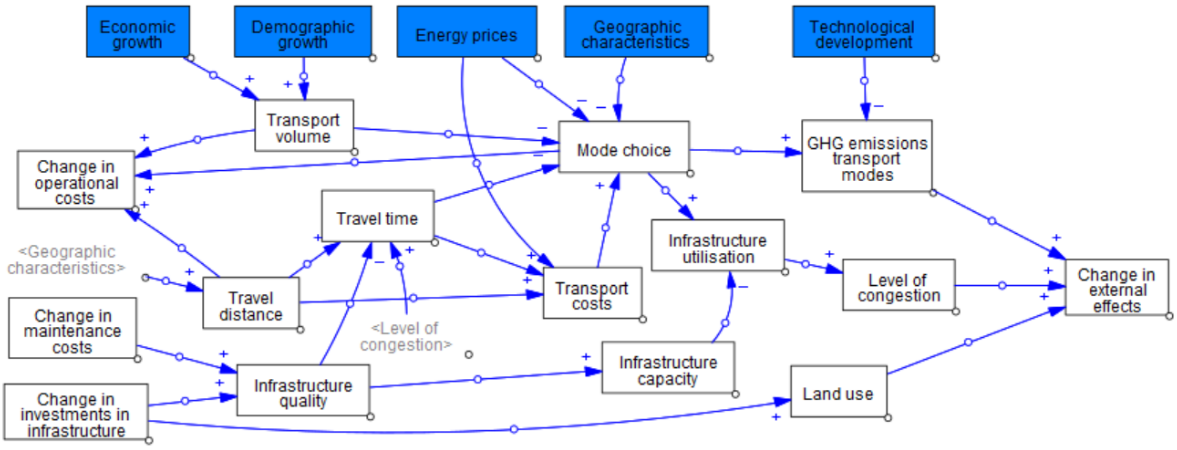


Figure 3.4: CRD effect identification (own creation).

The most important relations in the CRD with relation to identifying the effects are discussed in this section. The methodology already discussed the position of the CBAs to the mode choice model. This is visible in the CRD by the relations to and from transport volume, mode choice and transport costs. The mode choice model will be based on the transport costs, by a fixed costs and variable costs in travel time and travel distance. The estimated distribution of mode choice times the value of emissions will determine the change in external effects in the different alternatives. Based on Van Essen et al. (2019) the external costs of transport are: air pollution, climate change, noise, habitat loss, safety costs and congestion costs (also included in the CRD).

Furthermore, the mode choice will affect the change in toll and taxation revenues and the infrastructure utilisation, meaning that changes in transit time might occur.

Both travel time and travel distance are influenced by the infrastructure quality, which is affect by the change in investments and maintenance costs. The change in these costs will be costs induced by the project alternative as the made investments in base case alternative can be offset against each other in the project alternative. Furthermore, an investment in infrastructure is expected to come at the cost of land use.

The change in operational costs will be affected by the assigned transport volume to the pipeline mode in the project alternative. Next to volume, distance and energy prices will affect the operational costs.

Table 3.7 forms an overview of the identified effects and connects the effect to the affected party. The division in the affected parties marks whether the effect will be included in the FCBA or SCBA.

Table 3.7: Identified project effects SCBA (own creation).

| **Project effect** | **Definition** | **Direct or indirect effect?** | **Affected parties** |
|---|---|---|---|
| **Change in investments** | The variation in investment costs between base case alternative and project alternative. | Direct | Private parties/Government |
| **Change in maintenance costs** | The variation in maintenance costs induced by the project variant pipeline. | Direct | Private parties |
| **Loss of space costs** | The loss of space in terms of a loss of land use after the land has been used by another purpose. | Direct | Private parties/Society |
| **Change in operating costs** | The required costs of operating the project alternative.<br>Assuming the operating costs in the base case and project alternative remain the same. | Direct | Private parties |
| **Change in operating revenues** | The variation in the total amount of operating revenues. | Direct | Private parties |
| **Change in toll and taxation revenues** | Revenue generated from tolls and taxations of transport modes. | Direct | Government/Private parties |
| **Change in travel time benefits** | The variation in the wins or losses in transit times for society. | Direct/Indirect | Society/Users of a transport system |
| **Change in external effects of transport** | The change in external effects costs of transport. Considering climate change, air pollution, congestion, noise effects, loss of habitat costs and safety effects. | Direct/Indirect | Society |

Next to the effects mentioned in the table above, there are more effects that occur. This research carries out a partial SCBA and FCBA as there many aspects unclear about the project alternative (which is still in a reconnaissance phase). Effects might not be included in the SCBA due to a lack of data, information, or no previous research. And in other cases, the effect can be recognized, but it is not possible to value this as it is unknown in what magnitude this effect will occur and if it will occur.

One of those effects is the effect on spatial behaviour and spatial transport behaviour, this term is quite broad and can imply multiple effects. Such as a new pipeline will change the location of production facilities or changing logistical chains from one place to another as the new pipeline offers benefits due to the increased quality of transport. In general, these processes of moving logistical chains from one place to another happen consistently (Kindt et al., 2020). Though it is difficult to predict these effects, and this does not fit in the time and information constraints of this research. Therefore, it is important to recognize and mention these effects.

## 3.5 Effects and Valuation

In this section the effects are valued, this means that the effects will be connected to a certain costs factor to monetize them in a CBA. The value for an effect is derived from literature, previous research and publications related to effect.

### 3.5.1 Investment costs & Construction costs

As a CBA only considers the additional investment to the project alternative, the planned investments are not included in the SCBA as the investments are already in the base case variant. In the project variant a new investment is made, namely the construction of pipeline. The costs for construction will be included in the FCBA, as these costs are assigned to the private companies who will construct and use the pipelines.

The project variant has three scenarios, where three pipeline configurations are assumed. As the pipeline trajectory has place for 6 to 8 pipelines Dugernier et al., 2016. In the table below three scenarios are shown, where the low scenario has 6 pipelines, medium scenario 7 and the high scenario 8 pipelines.

Table 3.8: Pipeline composition scenarios (own creation).

| Scenario | Type | Composition | Avg. cost per km |
|---|---|---|---|
| **Low** | | | €850.000 |
| | Natural gas | 1 | |
| | (Petro)chemicals | 4 | |
| | Renewables (CO2) | 1 | |
| **Medium** | | | €850.000 |
| | Natural gas | 1 | |
| | (Petro)chemicals | 5 | |
| | Renewables (CO2) | 1 | |
| **High** | | | €850.000 |
| | Natural gas | 1 | |
| | (Petro)chemicals | 6 | |
| | Renewables (CO2) | 1 | |

Based on the prices per kilometre from different studies in table 3.1 the assumed average costs per kilometre is estimated at €850.000. As there are three trajectories considered in the GRUP the route varies. This has the effect that the length will vary and investments costs in terms of construction will differ as well.

Table 3.9: Trajectory length (own creation)(based on (Departement Omgeving, 2020)).

| Trajectory | Space used (ha) | Approximate trajectory length (km) |
|---|---|---|
| **North** | 1274 | 283 |
| **Central** | 805 | 179 |
| **South** | 848 | 188 |

The North trajectory consumes more space and has a significantly longer route than the trajectories Central and South. It can be expected that the construction costs at an assumed €850.000 per kilometre are therefore higher for the North trajectory opposed to the other two trajectories.

### 3.5.2 Maintenance costs

In terms of maintenance costs there is maintenance applied to the transport infrastructure and for the project variant the pipelines need maintenance as well.

The maintenance costs for pipelines were already shortly mentioned upon in section 3.3, the maintenance costs are assumed to be an annual 3% of the construction costs (Dönszelmann et al., 2008).

The maintenance costs must be borne by the private companies who use and operate the pipeline. These costs will be part of the operation costs and associated tariffs, thus this will be covered in the FCBA.

### 3.5.3 Loss of space costs

The loss of space costs, due to the construction of the new pipeline in the project variant, can be calculated by multiplying the value of the land and corresponding land use in combination with the total amount of land required to build the pipeline for the three trajectories. The North trajectory requires the most amount hectares (1274 ha), compared to the Central trajectory (805 ha) and South (848 ha) (see table 3.3). Table 3.10 displays the associated loss of space costs. Although the North trajectory requires the most land, it is the least expensive trajectory. Mainly because most of the trajectory flows through agricultural land and none of the trajectory goes through recreational land.

Table 3.10: Loss of space costs (own creation).

| | **North** | **Central** | **South** |
|---|---|---|---|
| **Residential** | € 30,165,592 | € 38,096,105 | € 40,147,867 |
| **Recreational** | € - | € 24,087,628 | € 50,769,857 |
| **Nature reserve** | € 6,454,591 | € 5,274,499 | € 6,316,557 |
| **Forest** | € 2,278,091 | € 1,918,000 | € 2,273,961 |
| **Nature (other)** | € 759,364 | € 1,678,250 | € 1,515,974 |
| **Agriculture** | € 31,365,794 | € 13,203,946 | € 15,496,337 |
| **Industry** | € 24,992,746 | € 39,454,151 | € 33,263,244 |
| **water** | € 9,716,861 | € - | € - |
| **Other** | € 2,657,773 | € 2,637,249 | € 505,325 |
| **Total** | € 108,390,810 | € 126,349,827 | € 150,289,120 |

Based on the current available information the north trajectory is most favourable in terms of costs for the loss of land use. However, the current trajectories are not definite in terms of a granted permit. So, loss of space costs may vary over time.

The loss of space costs is mainly perceived by society, especially farmers or inhabitants who will live or operate in the vicinity of the pipeline trajectory. The costs of the loss of space will be assigned to the private companies, thus this cost is part of the FCBA.

### 3.5.4 Loss of habitat costs

Transport has effects on nature, landscape, and natural habitats. The loss of habitat is expressed in three effects:

- Loss of habitat: transport leads to a loss of ecosystems, which are the habitats of flora and fauna. Transport has a negative effect on biodiversity.
- Habitat fragmentation: transport infrastructure can fragmentate and separate nature, especially animals.
- Habitat degradation: the loss of biodiversity due to emissions, toxic substances, and other substances. This is part of the air pollution costs and should not be counted double.

The costs on loss of habitat are different than the loss of space costs, as the loss of space costs are associated with the value of the land, while the loss of habitat is the consequence of transport.

Loss of habitat costs will be calculated using the estimated ton kilometres times the cost per ton kilometre of the transport mode. The ton kilometres are a result of the modal split model. The handbook on external costs from CE Delft reports the cost of habitat loss in €cent per ton kilometre for road, rail, and inland water transport on an EU average (van Essen et al., 2019). Despite the impacts of pipelines during construction, operation and maintenance there is no figure stated for pipeline transport on habitat loss. Pipelines can fragment habitats although large parts of the pipeline will or can be substrate, vegetation needs to be cleared and can spread invasive species, next to effects of spills are some of the potential effects (van Essen et al., 2019) (Sahley et al., 2017).

Table 3.11: Loss of habitat costs expressed in eurocent/ton-km (van Essen et al., 2019)

| **Transport mode** | **€ct/ton-km (EU average)** |
|---|---|
| **Road** | 0.19 |
| **Rail – Electric freight train** | 0.24 |
| **Rail – Diesel freight train** | 0.25 |
| **Inland water vessels** | 0.2 |
| **Pipeline** | 0.15 |

For pipeline transport the following figured is assumed to be lower than road transport. Road transport infrastructure is mainly above ground, opposed to the pipeline project which will be largely underground. However, the strip of land above the pipeline needs to be free and cannot be used for all purposes. Some sort of recreation, farming and restoration of natural habits and plants species can be applied aboveground the pipeline strip (Sahley et al., 2017). However, it is likely that the strip of land will fragmentate habitats, affect plants and eventually affect the food chain (Richardson et al., 2017). Therefore, this research assumes a €ct/ton-km of 0.15 for pipeline transport which is 25% than the value for road transport.
The minimization, restoration and avoidance of natural habitats and plants species should be a goal, as research shows that if restoration and avoidance of natural habitats contribute to reduce the impact of nature (Sahley et al., 2017).

The loss of space costs is perceived by 'society', as this is mainly a matter of nature and wildlife this belongs to society and is therefore included in the SCBA. The loss of space costs remains a cost, but when this cost is reduced by switching to a transport mode with lower costs this reduction is 'beneficial' to society, which is ultimately the goal.

### 3.5.5 Operating costs and revenues of the project alternative

In this section the operating costs and revenues are covered together. This effect is mainly the change in operating costs from the situation in the base case to the project alternative. This research only estimates this change in operating costs and assumes other operating costs for current infrastructure stay the same.
The operating costs for pipeline transport come from energy, labour, service and (Molnar, 2022). In this research it is assumed that the costs and revenues from tariffs demanded from customers of the pipeline transport are equal. In reality this is likely not the case as an operator of the pipeline wants to make profit and will set a margin on the tariffs.

First, the energy costs will be estimated using the results of the modal split model from chapter 4. The resulting ton-km assigned to the pipeline transport mode will be the input for the required energy (see 3.4.3). And the product of this will estimate the total costs of energy usage using a price for either electricity or natural gas. Prices for electricity and natural gas are subject to macro-economic and external factors, therefore prices of energy can affect the operating costs. In 2022 a conflict in Europe caused prices for energy to rise significantly and this can affect the business model of a potential pipeline operator considerably. This research will assume a multi-year average to come up with a representative energy tariff. The tariff is derived from European Union statistics database on the energy tariffs for non-household users between 2017 and the first semester of 2022 (Eurostat, n.d. -a)(Eurostat, n.d. -b).

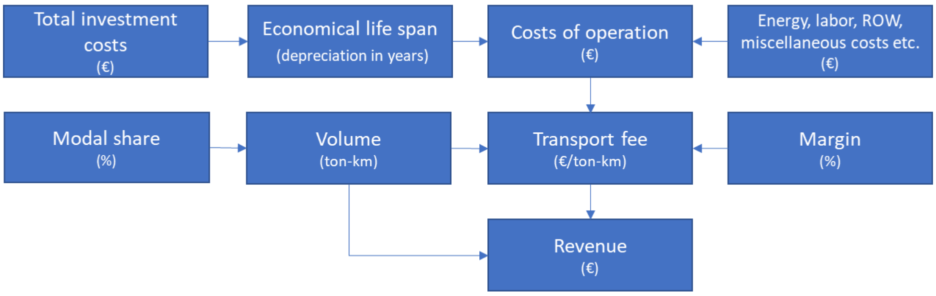
Table 3.12: Energy usage and costs (NEA & Haskoning, 1993)(van Essen, Croezen, et al., 2003)(Eurostat, n.d.-a)(Eurostat, n.d.-b)

| **Pipeline type** | **Energy type** | **MJ/ton-km** | **kWh/Ton-km** | **€ per kWh** |
|---|---|---|---|---|
| **(Petro)chemicals** | Electricity | 0.11-0.18 | 0.04 | 0.09 |
| **Natural gas** | Natural gas | 0.56-0.84 | 0.19 | 0.03 |

Second and third, the costs of personnel and costs of service, both these costs are difficult to estimate. Sources argue these costs take a large portion of the operating costs (Karangwa, 2008)(Molnar, 2022). This research assumes the combined share of these two cost components come down to €10 million per year each.
At last, maintenance costs Dönszelmann et al. (2008) estimates that the costs of maintenance are a yearly 3% of the initial construction costs.

These operating costs largely influence the tariffs for transporting via the pipeline and therefore the revenues for operating the pipeline. Tariff structures in pipeline transport are regularly structured to recover for capital costs, operating costs and an expected return (Molnar, 2022) (Bawono & Kusrini, 2018). The costs of the total investment will be held against the economical lifespan, which is 30 years for a pipeline (Capiau, 2010). The depreciation of the total investment costs will be included in the cost of operation. Then, operating costs consists off all the costs in this section (e.g., energy usage, costs of service, personnel etc.). Furthermore, the cost of capital and the cost of equity and debt should be included. However, as the pipeline project alternative is still in its reconnaissance stage, there is no information about debt and equity of a potential investment party. So, this is excluded from the tariff calculation. At last, an investor or operator is likely to make a margin on the tariffs, however this is excluded as well in this research (Bawono & Kusrini, 2018).
See the figure below for a schematical overview of what factors influence the cost of operation and transport fee.

Figure 3.5: Expenditures and tariff estimation.



The agreement on transport tariffs can be on different terms, either a periodical tariff agreement for several years or capacity, quantity, and tariff commitments (Molnar, 2022). In this research a yearly flat rate for tariffs will be estimated. Figure 3.5 describes the approach of estimating the transport fee. Once the total costs of operation and the modal share, including estimated volume of the transport modes, are estimated the transport fee in €/ton-km and €/ton is calculated. The revenues of operating the pipeline are calculated with the tariff times the volume.

### 3.5.6 Revenue on toll and taxation

Many governments in the EU have a taxation on energy, vehicle ownership and apply toll for freight transport on the road network (Schroten & ’t Hoen, 2016). Project alternatives can affect the revenue a government is receiving on tolls and taxations.

As a project alternative may affect the modal choice, the revenue on fuel duties, infrastructure charges and other fees may be reduced. Lower tax revenues can be seen as a welfare loss (van Meerkerk & Hilbers, 2015). However, the question should be if this loss is tax revenues outweighs the reduction in external effects, such as less pollution, noise, casualties etc.

In Belgium, Germany and the Netherlands, several taxes and tolls are applied to transport. Road transport has fuel duties, while in Belgium and Germany distance-based road charges are applied to trucks. Furthermore, rail transport and IWT have no taxes on energy but there are some infrastructural charges (Schroten & 't Hoen, 2016). So, a fluctuation in revenues from taxes and tolls can be expected, as the project alternative in this research is expected to create a shift in mode choice.
However, the transaction of toll and taxation is between two parties, the transport company or entity who wants to ship a product and the government who receives the taxes on transport. In this SCBA the decrease (or increase) in toll and taxation is included qualitatively. The first reason is that the toll and taxations are received by multiple governments. Second, tolls and taxations are subject to policy administration. And at last, the data gathered on OD relations is yearly information on transport flows, therefore calculating the tolls and taxations are deemed too difficult to calculate within the time span of this research.

### 3.5.7 Climate change costs

Climate change costs are external costs are an effect of transport. Climate change emissions include carbon dioxide, nitrogen oxide and methane, which are all greenhouse gases and contribute to climate change. The identification of these costs, and the wish to reduce these costs, are important. To estimate the climate change costs the modal split model (see chapter 4) estimate the amount of ton kilometres per transport mode. Corresponding to the transport mode a value in terms cost per ton kilometre is used (CE Delft, 2009). The figure or value of costs per ton kilometre is derived from the shadow price of emissions and general vehicle performance data per vehicle category.

Table 3.13: Climate change costs (van Essen et al., 2019) (van Essen, Croezen, et al., 2003).

| **Transport mode** | **€cent per ton-km (EU average)** |
|---|---|
| **Road** | 0.525 |
| **Rail (diesel freight train)** | 0.250 |
| **IWT** | 0.265 |
| **Pipeline** | 0.040 |

The climate change costs are caused by transport but borne by society. Therefore, a reduction of this external costs is desirable. The costs are based on the shadow price of CO2 of €100 per ton (Van Essen et al., 2019).

### 3.5.8 Air pollution costs

The emissions of air pollutants by transport are an external effect borne by society as well. Pollutants emitted by transport cause health effects to humans, but also crop loss, damage to materials and buildings and loss of biodiversity.
Like climate change costs the air pollution costs are estimated with the use of the estimations of the modal split model, the modal share in terms of ton kilometres are multiplied with transport performance metrics and the cost factors for health effects, crop losses etc.

Table 3.14: Air pollution costs (van Essen et al., 2019).

| Transport mode | €cent per ton-km (EU average)[3] |
|---|---|
| **Road** | 0.760 |
| **Rail (diesel freight train)** | 0.680 |
| **IWT** | 1.294 |
| **Pipeline** | 0.046 |

### 3.5.9 Congestion costs

Congestion is when vehicles are delayed in the travel process. Costs from congestion arise when other vehicles travel times are increased (van Essen et al., 2019). The costs for road congestion can be estimated using the figures derived from the handbook of external costs by CE Delft (van Essen et al., 2019). For other modes of transport these congestion costs cannot be estimated as rail transport is a sharply planned service, by the available capacity on the network.

For pipeline transport the same can be expected as for the rail network, as batches of products will be planned to transport through the available pipelines.

Congestion on the rivers and canals can occur, especially for locks and sluices. But another form of congestion can occur in ports when quays are occupied and (un)loading has a delay. However, no external cost factor is available by earlier research for congestion on the IWT network.

Table 3.15: Congestion cost (van Essen et al., 2019).

| Transport mode | €cent per ton-km (EU average) |
|---|---|
| **Road** | 0.797 |
| **Rail** | N/A |
| **IWT** | N/A |
| **Pipeline** | N/A |

### 3.5.10 Noise costs

Noise generated from traffic is also seen as a disutility. Noise costs are increasingly important, as urbanisation and increasing volumes of traffic more and more people are experiencing the disutility from noise (van Essen et al., 2019). The shadow price of noise costs is estimated at €25 per dB (Van Essen et al., 2019).

Noise is generated by most transport modes, however only the noise effects of rail and road transport are included in the EU handbook on external costs. Noise for inland waterways is considered negligible, as the transport usually takes place is sparsely populated areas.

For pipeline transport Departement Omgeving (2020) expects noise effects during construction and periodical controls of the pipeline. Typically, periodically controls of the pipelines will be executed on the ground by cars and by air using helicopters, planes or drones with measuring equipment. Next to construction, booster stations or pumps can generate noise during operation. The Flemish department has researched that also the generated noise during operation will not cause any disrupting sound effects (Departement Omgeving, 2020).

So, for road transport and rail transport a value can be put to the external effect of noise. For pipeline transport and IWT, there is no metric for noise effects, thus the metric is zero.

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[3] Shadow prices of the air pollutants are EU average, NOx €10.9 per kg, NMVOC €1.2 per kg, Sox €10.9 per kg, $PM_{2.5}$ €19.4 per kg, $PM_{10}$ €22.3 per kg (Van Essen et al., 2019).

Table 3.16: Noise costs (van Essen et al., 2019).

| Transport mode | €cent per ton-km (EU average) |
|---|---|
| **Road** | 0.4 |
| **Rail (diesel freight train)** | 0.65 |
| **Rail (electric freight train)** | 0.45 |
| **IWT** | 0.0 |
| **Pipeline** | 0.0 |

### 3.5.11 Safety effects

Transport has the tendency to cause accidents, therefore safety effects are included as well. As the costs of these accidents are borne by the transport users and society. In this research the change in the safety costs induced by the project alternative is included in the SCBA. The social costs of accidents consist of loss of life, medical costs, administrative costs, insurance costs, but also pain, grief and suffering caused by accidents (expressed in monetary terms) (van Essen et al., 2019). The Abbreviated Injury Scale is used by countries to estimate the safety or accidents costs. The level of injury or a fatality is based on this scale and contributes to the accident costs in a country[4]

This research will use the metric of €/ton-km to estimate safety costs, this metric differs per transport mode. A shift from one mode to another can reduce the total external accident costs. The external costs factors are shown in the table below, where road transport has a higher safety cost per ton-km compared to rail and IWT.

Table 3.17: Safety costs (van Essen et al., 2019).

| Transport mode | €cent per ton-km (EU average) |
|---|---|
| **Road** | 1.255 |
| **Rail (diesel freight train)** | 0.065 |
| **IWT** | 0.059 |

As one can see pipeline transport is not included in the table above. There is no safety cost figure derived from research. Next to the fact every product has a different safety and risk profile and that some products are hazardous goods and will not be transported via the road (van Essen, Croezen, et al., 2003). In general, pipeline transport is marked as a safer transport mode than IWT (Dönszelmann et al., 2008)(Goor & van Amstel, 2003). Furthermore, Janse & Rensma (2008) conclude based on previous research that pipeline transport is safer than the other transport modes (road, rail, IWT).

Table 3.18: transport mode safety ranking (Janse & Rensma, 2008).

| Transport mode | Safety ranking |
|---|---|
| Pipelines | 1 |
| Rail | 3-10 |
| Ship | 3-10 |
| Road | 300 |

Between rail and IWT the difference in the external cost factor is small (also suggested by table 3.17), but the difference towards road transport is significant.
Therefore, this research assumes a safety costs value of 0.02 €cent per ton-km, which is in line with the rankings defined in table 3.18 and the external costs factors in table 3.17.

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[4] Shadow prices accident costs: casualty €3.72 million, severe injury €498 thousand, slight injury €38 thousand (Van Essen et al., 2019).

### 3.5.12 Transit time benefits

A frequently named benefit of a project alternative is that it might induce a modal shift. Modal shift is practically speaking the process where transport is moved from a more polluting mode to a less polluting mode (Kemp, 2016). Furthermore, modal shift is thought to relief stress on current transport networks, especially the road network. This relief in stress can cause to lower travel times and the transit time benefits can be defined as the change in consumer surplus (UNECE, 2003).

The consumer surplus is the gain of transport users when a project alternative reduces travel times. Lower travel times attract more users on the specific part of the network where the project alternative had an impact. The gain in travel time and the attraction of users means an increase in the consumer surplus (UNECE, 2003). The transit time benefits are usually calculated by applying the 'rule of half', which means that every minute of gained transit time is divided by half. The theory behind this rule is that a new user on average gains half the time won with the new project alternative in comparison with a user who used the infrastructure before the project alternative was carried out (Mouter, n.d.-b) (Eijgenraam et al., 2000).

The consumer surplus or transit time benefits are difficult to measure and a theoretical effect, as rebound effects might take place. This effect may appear when an effort is performed to increase efficiency, but the effort made is quickly refilled by higher consumption (Kemp, 2016). Furthermore, effects such as a shift of logistical chains of flows for chemical products to Antwerp and the Ruhr area may occur when the project alternative is chosen. When this occurs the project alternative might reach capacity limits over time and some transport might shift to road transport.

Besides these possible effects, the OD data is not sufficient to calculate transit time benefits for other users. However, it is important to note the effect, as research has shown the gains of transit time benefits can be extensive. Therefore, this effect is included qualitatively in the SCBA.

### 3.5.13 Overview of effects and valuation

The valuation of the external effects leads to the following overview in table 3.19. The external effects have been discussed in this research, for more detailed information per external effects and sources or reasoning behind the applied costs, please refer to the corresponding section.

Table 3.19: Overview of monetized external effects.

| External effects €ct/tonkm | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| Climate change | 0.525 | 0.250 | 0.265 | 0.040 |
| Air pollution | 0.76 | 0.68 | 1.294 | 0.046 |
| Loss of habitat | 0.19 | 0.24-0.25 | 0.20 | 0.15 |
| Congestion | 0.797 | N/A | N/A | N/A |
| Noise | 0.4 | 0.45-0.65 | N/A | N/A |
| Safety | 1.255 | 0.065 | 0.059 | 0.02 |

Based on the table above, one can expect costs for climate change and air pollution will be a large cost experienced by society. Furthermore, the (relative) high costs per ton/km for congestion and safety in road transport can form a considerable cost.

# 4. Mode choice model

In this section the mode choice model is discussed. First, this chapter will go over the required input for the mode choice model in 4.1. Thereafter, the volume growth scenarios and corresponding growth factor model is discussed in 4.2. Then, section 4.3 discusses the deterrence function in depth, followed by the project cost development in the appraisal period. In sections 4.5 to 4.7 calibration and validation of the deterrence functions is discussed.

## 4.1 Input model

The mode choice model requires input, some of the input is already discussed in section 2.2. In 2.2 the observed zones were discussed and the acquired OD data from the Flemish government was structured and prepared. The other input required for this mode choice model are the skim matrix (with relation to the infrastructural analysis from section 2.4), and the input for travel distance and travel time per transport mode.
In Appendix B and C more information and visualizations of the input for the model are summarized.

### 4.1.1 Observed zones

The identification of the observed zones forms an important step in preparing the acquired data. The observed zones were identified in section 2.2 based on the location of large chemical and industrial clusters connected to existing pipeline infrastructure. The identified NUTS zones are marked in the figures below.

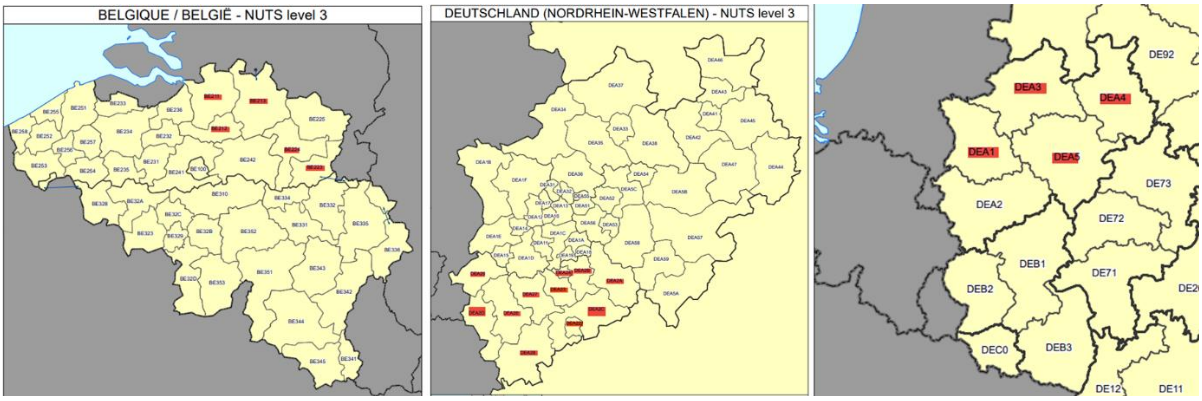

Figure 4.1: NUTS3 Belgium (Eurostat, 2020b). 4.2 NUTS3 Germany (Eurostat, 2020c). 4.3 NUTS2 Germany (Eurostat, 2020a) (Statistical Office of the European Communities. & European Commission., 2008).

The left picture displays Belgium with its NUTS3 zones, where seven NUTS3 zones are observed, these are the zones of Antwerp (this will also include the two zones of the port of Antwerp, who have separate zones from the rest of NUTS3 zone Antwerp), Mechelen, Turnhout, Hasselt and Tongeren. The Albertkanaal flows through these zones and the majority of the analysed GRUP trajectories for a potential pipeline flow through these zones.
A small part of some of the GRUP trajectories flows through the north-eastern part of the arrondissement of Leuven and a small part in the south of the arrondissement of Maaseik. However, the GRUP is not planning on adding antennas to clusters in one of these two NUTS zones. Therefore, the choice is made to exclude the NUTS zones of Leuven and Maaseik.
In the middle picture the detailed NUTS3 zones of North Rhine Westfalen are displayed, this detailed set of observed zones is part of the larger NUTS2 zone of Cologne (DEA2). The rest of the acquired data set is containing data of the NUTS2 zones Düsseldorf, Münster, Detmold and Arnsberg as displayed in the figure on the right.
In Appendix C the observed NUTS zones are summarized.

### 4.1.2 Skim matrix

The research includes four types of infrastructures: rail, road, inland waterways, and pipeline infrastructure. The infrastructure of the different transport modes determines whether an OD relation is possible. Therefore, the skim matrix is constructed for the mode choice model to identify which transport modes are available per OD pair. When reviewing the acquired data, it is noticeable that rail and inland water transport do have less interaction between OD pairs than road transport. An explanation for this occurrence could be that both trains and inland water vessels require particular infrastructure, the amount of railroad tracks, rivers and canals are limited, while the road network in north western Europe is dense and well developed.

An infrastructure analysis is carried out to conclude which mode is available per OD pair. For road transport the assumption is that the mode is always available per OD pair. This will also apply to the pipeline, the infrastructure plan in the current phase tells that all observed OD pairs should be connected to the new pipeline system.
For rail and inland water transport a skim must be made to determine possible OD pairs, as section 2.4 concluded that there might be limited origin and destination options for these two modes. The acquired data also signals that there are remarkably more OD pairs for these two modes without volume. In case there is no infrastructural relation possible for a transport mode this implies that the modal split model should be able to exclude the transport mode from the assignment of transport.

The approach for the skim matrix of rail and inland water transport is to use open sources and open street map tools for calculating time and distance between OD pairs for the transport modes.
The skim for OD relations in the rail network is analysed using an Open Street Map source called Signal (Beyssac, n.d.). Remarkably the train infrastructure between the observed pairs is quite well, there has been no indication of a missing link on an infrastructural basis between OD pairs.

In the case of inland water transport a similar approach is followed, the tool 'Blue roadmap' is an initiative from Bureau Voorlichting Binnenvaart (Bureau Voorlichting Binnenvaart, n.d.), an inland water transport branche organisation. For inland water transport there are multiple missing links, especially to observed NUTS zones in the North-Rhine Westfalen area. The river Rhine, the Ems canal and Wesel canal form the largest passable waterways in North-Rhine Westfalen, not every NUTS zone is connected to these waterways leading to missing links in this skim matrix.
The complete skim matrices of all four modes are displayed in Appendix D.

### 4.1.3 Impedance matrix

Following the skim made in the previous section an impedance matrix is constructed. The impedance matrix provides travel time and travel distance between OD pairs for the different transport modes.

First of all, distance and travel time are expected to be different for the different transport modes. As section 2.5 indicated the characteristic and logistic performance differ per transport mode. Furthermore, the skim matrix made clear that infrastructure is mode dependent.
Second, distance in transport modelling is dependent on assumptions. In transport modelling distance is modelled between two points, in this research the observed NUTS zones. Due to the aggregated data is not possible to track individual trips and simplicity wise centroids as a central point of attraction and production of trips in a NUTS zone is more convenient. The point of gravity in every NUTS zone will differ per transport mode as a railway hub or inland harbour terminal is bounded to a location, while the road network is denser.

The travel distance matrix for road transport is based on data files of the European Union for the distance between NUTS zones for road transport. The file contains the distance between all OD pairs, which are filtered to the observed NUTS zones (European Commission, n.d.). The distance between the NUTS zones is then divided by the average speed of 50 km/h, which will result in the travel time matrix for road transport. The average speed of 50 km/h is chosen as this forms a compromise to the different figures literature mentions (Macharis et al., 2018)(Desmet et al., 2008) (Jonkeren et al., 2020).

Rail transport and inland water transport use the same approach as for the Skim matrix. The same open-source tools are used ‘Signal’ (Beyssac, n.d.) and the ‘Blue roadmap’ (Bureau Voorlichting Binnenvaart, n.d.). Both tools display the travel distance by the transport mode and the travel time. Furthermore, the tool for IWT includes the amount of sluices a vessel must pass to reach a destination. As can be expected sluices can take upon a considerate amount of time and influence the travel time of inland water transport. As the tools report a travel time, there is no need to assume an average operating speed of the transport modes.

At last, the impedance matrix for the pipeline alternative is composed. This matrix will be based on the current trajectories of the GRUP. Where the North trajectory has a significant longer trajectory than the Central and South trajectory (see table 4.1). The impedance matrix is adjusted for the different trajectories according to the length.

Table 4.1: GRUP trajectories and approximate length (own creation).

| Trajectory | Space used (ha) | Approximate length (km) |
|---|---|---|
| **North** | 1274 | 283 |
| **Central** | 805 | 179 |
| **South** | 848 | 188 |

The operating speed of pipeline transport is assumed at 10 km/h, as operating speeds are between 5 and 13 km/h (Pienaar, 2008)(Cheng et al., 2017)(Petroleum.co.uk, n.d.). Operating speeds of pipelines are highly dependent on the configuration (compression, diameter, geographical conditions) and transported product (viscosity) (NEA & Haskoning, 1993).
An important note is that the impedance matrix is based on travel times without congestion over all transport modes.

The impedance matrices for all transport modes are displayed in Appendix D.

## 4.2 Growth factor modal and future OD matrices

Creating a mode choice model over the appraisal period, requires a growth factor model to estimate the transport volumes. Growth factor models are commonly applied in transport modelling, it is relatively simple and uses a verifiable base year matrix. In this research a network independent general factor will be used. As there is no identification of network dependent or specific OD relations that influence the model. For the growth factor three scenarios are applied, a low, medium and high growth scenario.

### 4.2.1 Prognosis and growth factors transport

The growth factors are based on prognosis and forecasts from different sources and will be split in the two periods, from the base year of the OD data 2010 to 2030. And from 2030 to 2055 the end of the appraisal period. The period from 2010 to 2030 a Belgian and German prognosis expect a growth of respectively 1.9% and 1.6% per year in terms of total transported tons until 2030 (Daubresse, 2015) (BMVI, 2016). For 2030 to 2050 an EU prognosis forecasts an annual 1.1% increase in transport EU wide (Capros et al., 2013). Next to these general expectations in transport growth, growth factors per product type can vary. Belgian and Dutch prognosis include forecasts per product type. The Belgian forecast suggest that oil, natural gas (NST2) and oil products (NST7) remain stable over the years. However, a decrease in import occurs for NST2 and NST7 products, respectively -3% and -1% between 2012 and 2030. Contrary, chemical products (NST8) will grow. Especially export of NST8 products is expected to increase 62% between 2012 and 2030 in Belgium, while national transport and import will increase to 39% and 20% (Daubresse, 2015). The Dutch forecast as a reference displays the same trends for the observed products, where NST2 and NST7 will stay stable and minorly decrease up to 2050 and chemical products will increase (Romijn et al., 2016).

From the figures in the forecast's growth factor are set per product type for the period 2010 to 2030 and from 2031 to 2055 to cover the appraisal period. There are three growth scenarios, low, medium and high.

Table 4.2: Growth factors until 2030.

| **Present – 2030** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **NST2** | -0.4% | -0.2% | +0.1% |
| **NST7** | -0.2% | -0.1% | +0.1% |
| **NST8** | +1.8% | +2.3% | +2.9% |

Between 2010 and 2030 there is an expected decrease of transport for NST2 and NST7 in the low and medium scenario. Only in the high scenario a small growth is expected for these two product groups. NST8 a growth is expected in all scenarios, ranging between 1.8% and 2.9%.
From 2031 to 2055 the growth factors display a similar trend. Both NST2 and NST7 display a decrease in expected transported tons for the low and medium scenario, while a small increase can be expected for the high scenario. For chemical products (NST8) still an overall increase is expected, however the growth has declined compared to the period of 2010 to 2030.

Table 4.3: Growth factors 2031-2055.

| **2031 – 2050** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **NST2** | -0.6% | -0.3% | +0.1% |
| **NST7** | -0.4% | -0.2% | +0.1% |
| **NST8** | +0.6% | +1.0% | +1.3% |

### 4.2.2 Matrix production and Balancing

Second step is applying the growth rates to the OD data. As the original OD matrix contains data from 2010 the first step is to calculate the transport volume for 2025. After the year 2025 the following matrix is applied with the growth rate from the tables in 4.3.1.
The next step is balancing the matrix, as growth rates are used differences can occur between the total of the rows and the total of the columns. The Fratar method is used for balancing the matrix. This method assumes that the increase in trips is proportional concerning the attraction factor of the destination zone and the production of the origin zone. This approach will initially cause an overestimation of trips from the production zone. To overcome this a factor is added, this factor is the ratio of the trip's origin zone times the growth factor divided by the sum of all trips from the destination zones (Dragu & Roman, n.d.).

## 4.3 Deterrence function

To determine the (dis)utility for a transport mode between origin and destination a deterrence function is drafted. The deterrence function should justify the characteristics of the transport mode. Thereafter, the estimated (dis)utility per OD pair for every transport mode is used in a MNL model as

discussed in section 1.3.
This paragraph builds on the deterrence function, the relation between the deterrence function and the characteristics of the transport modes.

Generalised cost is a concept used in transport economics, the generalised costs is a combination of monetary costs and non-monetary costs of a journey (Brümmerstedt et al., 2015). The generalized cost function, which is a (dis)utility or deterrence function, can be used to express the costs in order to decide between different transport mode options. Expressing the costs in a deterrence function is done by explanatory variables, this research will limit the number of explanatory variables to three, which are fixed costs (or alternative specific costs), travel distance and travel time.
As the acquired OD data is on an aggregate level, only limited explanatory variables are available (Jourquin, 2016). Furthermore, time and simplicity restrictions limit the number of explanatory variables.

The deterrence function used in this research is based on Jourquin (2016). Jourquin (2016) proposes a linear deterrence function containing a factor for fixed costs and variable costs in distance and travel time.

$$V_{m,p,r} = 2\alpha_{m,p,r} FC_{p.m} + \beta_{m,r} D_m + \gamma_{m,r} TT_m \qquad (4.1)$$

Where:
V = the (dis)utility of the total deterrence function
FC = fixed costs
D = distance
TT = travel time
m = transport mode
r = region
p = product type (NST product category)
α = parameter for fixed costs
β = parameter for distance
γ = parameter for travel time

The deterrence function of Jourquin (2016) captures the same essence as the aggregate modal split model mentioned in section 1.3.3[5]. It supposes that a transport mode has certain logistic characteristics, which is revealed by the fixed costs connected to transport mode. Where in this research the fixed costs are considered to be the alternative specific costs. Rodrigue (2020) issues that transport modes have a certain cost at distance zero, where one mode is more expensive over a short distance than other transport modes. See figure 4.4 below, the road transport mode has a steeper deterrence function than the other modes, this research will use this approach as well.

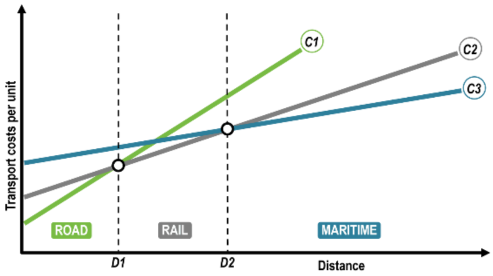

Figure 4.4: Transport cost per unit over distance (Rodrigue, 2020)

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[5] Formula 1.1 in section 1.3.3: $\log \frac{S_i}{S_j} = \beta_0 + \beta_1 (P_i - P_j) + \sum_W \beta_W (x_{iw} - x_{jw})$

The fixed costs will be based on the average tons transported per shipment, this figure differs per type of product. Borremans et al. (2016) describe in the Flemish freight transport model (Svrm) average transport volumes per product group. This research will assume the volume as the value for the fixed costs.

Table 4.4: average shipment size (Borremans et al., 2016).

| | **Average shipment size (in ton)** |
|---|---|
| **NST2** | 82.1 |
| **NST7** | 103.8 |
| **NST8** | 160.8 |

The parameter for fixed costs is assumed to capture the costs to eventually store products and load and unload. As loading and unloading will be of a certain cost, this research indicates in formula 4.1 also parameter α times two.

Next the distance and time in the model of Jourquin (2016) represent the to be estimated β parameters in the model of de Jong (2013) in formula 1.1. Both variables, time and distance, will have a parameter per transport mode, to achieve the approach from figure 4.4.
The impedance matrices composed in 4.1.3 indicate the different distance and travel times per OD pair for the different transport modes.

The parameters in the deterrence function will be calibrated to the acquired OD data, there are three parameters in the deterrence function and every parameter is mode dependent. As the average shipment size is also NST product type dependent, this is also included in the deterrence function. Furthermore, section 2.2 highlighted the differences between modal split ratios between regions. The use of train and inland water vessels is substantially higher between the international trade (Flanders to NRW or NRW to Flanders), than national transport within Flanders. Therefore, another division in the deterrence function is made between regions. There are three OD pair groups recognized, the first group is the national transport within Flanders, second region is the international transport between NRW and Flanders and the third group is the transport from or to the port of Antwerp. Appendix D containing the skim and OD matrix will include this division in groups as well. By including product type and region in the deterrence function a better fit to the acquired OD data can reached. The next section discusses the calibration of the parameters and the fit to the OD data.

## 4.4 Cost figure development

Next to volume growth factors in section 4.2, factors for transport costs are applied to the scenarios. The development of transport costs per transport can affect the mode choice over time and should therefore be included in the mode choice model.

According to Knutsson (2008) there are four factors that affect transport costs in the EU, those four factors are oil and energy prices, environmental taxations, infrastructure and personnel. Where fuel and taxations are connected, as fuels are regularly taxed. Next to fuel taxation, distance-based taxation for trucks is regularly applied in Europe.
As for the factor infrastructure Knutsson (2008) identifies burdens for rail infrastructure as international harmonization is lacking in Europe. Road transport must deal with congestion and also a lack of personnel is increasing costs in wages for this transport mode.

A Belgian forecast foresees a significant increase in IWT transport, and the German forecast expects increasing costs for road transport in general (Daubresse, 2015) (BMVI, 2016). The Dutch institute for

Mobility (KiM) published a report on cost figures for the transport modes road, rail and IWT between 2016 and 2018. In those years, an increase in costs was measured, the transport costs of trains remained fairly stable, while the costs of road and IWT transport increased over these years, with respectively 3.1-4.6% and 3.3% (Jonkeren et al., 2020).

Another report by the Dutch institute for Mobility on transport cost has indexed the transport cost for liquid bulk goods over a longer period. The report tells that both road and inland water transport costs have increased between 1980 and 2015 with respectively 2.7% and 2.4% on average. On the other hand, rail transport costs have decreased over the period 1996 to 2015 with an average 2.6%, but a comment should be placed with this figure as rail transport costs have increased between 2004 and 2015 at an average 3.1% (Rijkswaterstaat, 2016). In the period before 2004, some significant cost reductions are displayed by the cost indexations. Thereby creating a distorted image of the cost development over time. Therefore, this research will use the indexed cost development of (bulk) rail transport from 2004 to 2015.

Table 4.5: Average transport cost increase (Rijkswaterstaat, 2016).

| Transport mode | Time period | Average cost increase % |
|---|---|---|
| **Road** | 1980-2015 | +2.6% |
| **Rail** | 1996-2015 | -2.6% |
| **Rail** | 2004-2015 | +3.1% |
| **IWT** | 1980-2015 | +2.4% |

Although these are all Dutch cost figures, the figures are based on input from transport companies in the Netherlands and therefore the figures are considered to stand for the trend development of transport costs and are representative for the purpose of this research.

Based on the cost figures by the Dutch institute for Mobility (KiM) the following cost figures are assumed across the three scenarios:

Table 4.6: Transport costs growth (own creation).

| | Low | Medium | High |
|---|---|---|---|
| **Road** | +2.1% | +2.6% | +3.1% |
| **Rail** | +2.5% | +3.0% | +3.5% |
| **IWT** | +1.9% | +2.4% | +2.9% |

The figures in the table above are based on the cost figure development by the Dutch institute for Mobility (Rijkswaterstaat, 2016). In the medium scenario the average cost development is used between 1980 and 2015 for road and inland water transport and 1996 to 2015 for rail transport. For pipeline transport the cost figure development is assumed to be equal to IWT. As section 2.5 indicated the two transport modes are the most comparable among the ones considered in the research.

In the low scenario the cost figure is -0.5% compared to the medium scenario and in the high scenario the figure is +0.5%. The thought for this variation comes from demand and supply principle. In high demand for transport and a growing economy cost will rise compared to the supply. This includes the supply transport companies can offer, but also the greater stress there is on the transport network, higher wages and even higher demand for transport can increase energy prices.

## 4.5 Calibration deterrence functions

The calibration of the deterrence function and the modal split parameters are an essential step in the modal split model. The parameters will influence the mode choice and affect the outcome of project alternatives. The calibration of the parameters is carried out for the transport modes, road, rail and inland water transport. For pipeline transport no OD data was acquired, section 4.6 discusses the approach to the calibration of the deterrence function for pipeline transport.

Calibration is performed by using the observed modal split from the acquired OD matrices from the base year and based on the proposed deterrence function together with the composed transport costs from the impedance matrix.

In the calibration three models are tested and optimised using Microsoft Excel solver program. The first model is partially based on a basic model of Jourquin (2016), the model just includes distance (as a form of travel costs) and travel time (formula 4.2). This is rather simple and basic model, so it forms a start point for more complicated models hereafter.

$$V_m = \beta_m D_m + \gamma_m TT_m \qquad (4.2)$$

The second model (formula 4.3) is extended with fixed costs and a corresponding parameter. The previous paragraph explains why fixed costs seem to be a factor in freight transport, as warehousing, loading, and unloading are a significant factor in the logistics process.

$$V_{m.p} = 2\alpha_{m,p} FC_p + \beta_m D_m + \gamma_m TT_m \qquad (4.3)$$

The third and last model is extended to applying regions, as discussed in the previous paragraph the OD matrices do show differences between OD pairs for the Flemish NUTS zones, interaction between the port of Antwerp NUTS zones and the interaction between Flemish and German NUTS zones. This will result in separate utility functions per OD pair group. See formulas (2a-2c) below.

$$V_{m,p,r} = 2\alpha_{m,p,r} FC_{p.m} + \beta_{m,r} D_m + \gamma_{m,r} TT_m \qquad (4.4)$$

$$V_{m,p,1} = 2\alpha_1 * FC_{p.m} + \beta_{m,1} * D_1 + \gamma_{m,1} * TT_1 \qquad (4.4a)$$

$$V_{m,p,2} = 2\alpha_2 * FC_{p.m} + \beta_{m,2} * D_2 + \gamma_{m,2} * TT_2 \qquad (4.4b)$$

$$V_{m,p,0} = 2\alpha_0 * FC_{p.m} + \beta_{m,0,} * D_0 + \gamma_{m,0} * TT_0 \qquad (4.4c)$$

Where:
V = the (dis)utility of the total deterrence function
FC = fixed costs
D = distance
TT = travel time
m = transport mode
r = region
p = product type (NST product category)
α = parameter for fixed costs
β = parameter for distance
γ = parameter for travel time

Then the utility functions are put in a MNL model where exponentials are used to compute the share of a transport mode (%) per OD pair. The MNL function includes another parameter the dispersion factor ‘μ’, which can be seen in formula 4.5 below. The dispersion factor in a multinomial logit formula is always negative, however the value can be very close to zero. The rule of thumb is that the closer the dispersion factor is to zero, the less disutility is derived from the mode. And the more negative the dispersion factor, the more disutility and less attractive the mode is.

$$\Pr(m) = \frac{\exp\,(V_m^{\mu})}{\sum_{n=1}^{N} \exp\,(V_n^{\mu})} \qquad (4.5)$$

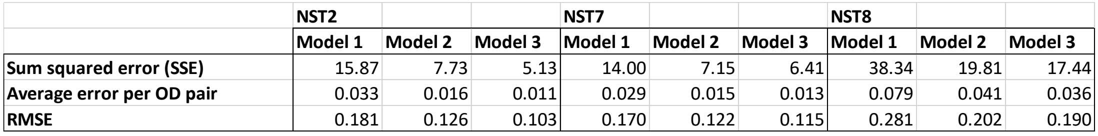
Where:
Pr = probability of mode m
$V_m$ = utility of mode m
$V_n$ = utility of mode n
μ = the dispersion factor per transport mode

So, in short, the first model has per transport mode three parameters to calibrate, the second model four parameters to estimate and the third mode has per transport mode ten parameters for estimation.
The models are constructed in Microsoft Excel, the metric to indicate the accuracy of the models used in this research are the Sum of Squared Errors (SSE) and the Root Mean Square Error (RMSE).

The Sum of Squared error is the difference between the observed value and the calculated value. The sum square is the total of all the difference between these values, so the part of variation which is not modelled. In general, the lower the value of the SSE, the better the model (Corporate Finance Institute, 2022).
Next to the SSE another metric will be used to describe the performance of the different models, the Root Mean Square Error (RMSE). The RMSE metric tells how far the predicted value of the model differs from the observed data set. In this case a lower difference indicates the model is better in predicting the observed value. The RMSE is calculated by the square of the difference between the observed and the predicted value, divided by the sample size. Then the square rout is taken of that number. The RMSE metric does provide a degree of accuracy in relation to the observed data, however the RMSE should be interpreted in a different way than a metric like R-squared.
The metric R-squared is another often seen metric used to indicate the accuracy of a model compared to the observed data. In this research the choice is made to use RMSE instead of R-squared as ‘perfect’ data in a linear regression will come up with a R-squared that fits in the assumption the sum of square totals is equal to the sum of square errors and the sum of square residuals. RMSE requires some interpretation, a RMSE of zero would indicate a perfect fit of the data to the model, however this is almost never achieved. Also, a higher RMSE in one data set would not mean that the model is ‘worse’ than another model with a lower RMSE and another data set (Hyndman & Koehler, 2006).

The modal split parameters are first estimated by an iterative procedure to find a suboptimum result. After iteratively reaching the suboptimum, a solver within the Microsoft Excel package is used to minimize the sum of squares (SSE) by adjusting the parameters of the models. Hereby reaching an optimal solution for the models. The results of the estimation are show in the table below:

Table 4.7: Calibration results.



| | **NST2** | | | **NST7** | | | **NST8** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Model 1** | **Model 2** | **Model 3** | **Model 1** | **Model 2** | **Model 3** | **Model 1** | **Model 2** | **Model 3** |
| **Sum squared error (SSE)** | 15.87 | 7.73 | 5.13 | 14.00 | 7.15 | 6.41 | 38.34 | 19.81 | 17.44 |
| **Average error per OD pair** | 0.033 | 0.016 | 0.011 | 0.029 | 0.015 | 0.013 | 0.079 | 0.041 | 0.036 |
| **RMSE** | 0.181 | 0.126 | 0.103 | 0.170 | 0.122 | 0.115 | 0.281 | 0.202 | 0.190 |

The models are estimated per product type, from the table we can conclude that the most extensive model, which is model 3, overall performs the best across all product types. Both in terms of the SSE and the RMSE. Therefore, model 3 will be used as modal split model for remainder of this research.

Please refer to Appendix E to see more results and information on the calibration of the different models.

The average error per observation, so per OD pair, indicates that model 3 is considerably accurate for the purpose of this study. Error in prediction can come from several aspects. The forecast of external factors, transport attributes and just model errors can cause errors in the prediction of transport demand forecasts (Make & Preston, 1998). Models are an approximation of reality, the models simplify many aspects of the reality, but the goal is to capture most of the real-world relations and elements. Therefore, perfect models most of the time do not exist and errors are a part of the modelling process, where the trade-off between time and optimizing models is a key component.

## 4.6 Calibration deterrence function: pipeline transport

In this research OD data of three transport modes, road, rail, and inland water transport, was acquired. However, no OD data could be obtained for pipeline transport. The Belgian and Flanders' government do not have OD data about current pipeline transport, also the Belgian (chemical) companies do not want to provide the OD data for pipeline transport. For (chemical) companies the unwillingness is reasonable, as this is sensitive business information.

The proposed approach is to use the current OD data of the three transport modes. Based on the calibrated parameters of these three modes, scenarios for the calibration of the parameters of pipeline transport are estimated. Eventually the research strives to point out scenarios which are (un)reasonable.

For pipeline transport the same deterrence function based on Jourquin (2016) is used as in section 4.4 was proposed:

$$V_{m,p,r} = 2\alpha_{m,p,r}FC_{p.m} + \beta_{m,r}D_m + \gamma_{m,r}TT_m \quad (4.7)$$

Where:
V = the (dis)utility of the total deterrence function
FC = fixed costs
D = distance
m = transport mode
r = region
p = product type (NST product category)
α = parameter for warehousing, loading, unloading per product type and transport mode
β = parameter for distance per transport mode
γ = parameter for travel time per transport mode

As explained in section 4.4, the deterrence function supposes a fixed costs component and two variable costs components for travel distance and travel time. Rodrigue (2020) has visually composed this in figure 4.4, where the fixed costs on the vertical axis are put to the variable costs on the horizontal axis. Based on the figure from Rodrigue (2020), the pipeline is added in figure 4.5. In the figure there are two marked points. On the vertical axis the fixed cost's location is marked with relation to the fixed costs component of the deterrence function and on the horizontal axis the slope of the line is marked with relation to the distance and travel time component of the deterrence function (to display the variable costs per kilometre).

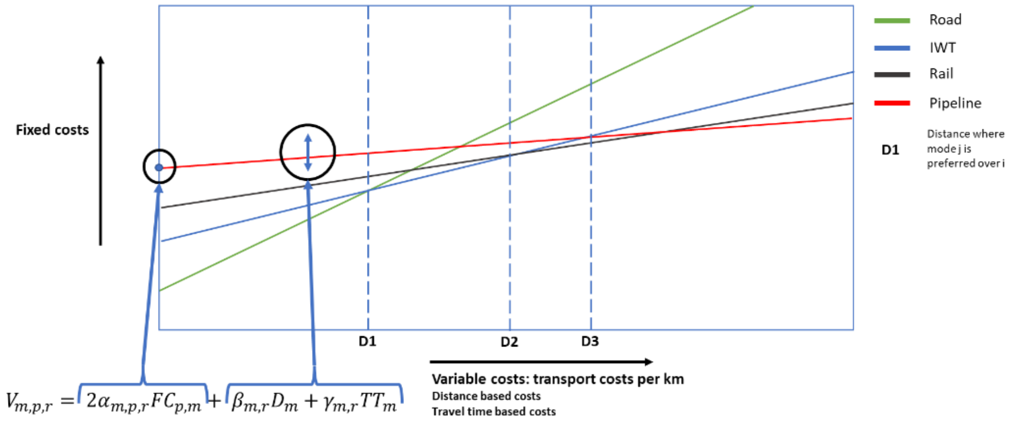


Figure 4.5: Conceptual deterrence function (based on Rodrique (2020)).

The hypothesis is that the mode pipeline has a higher fixed costs than IWT, rail and road transport. Therefore, the intersection with the vertical axis is placed higher than the other three modes. Pipeline transport is a mode that is capable of transporting high volumes of products over a medium to long distances between fixed origins and destinations based on the analysis in section 2.5. Pipeline transport is infrastructure bound and the infrastructural network is not dense, therefore the choice to use pipeline transport should be less attractive on short distances, resulting in an assumed higher fixed cost. For the slope of the variable costs function, section 2.5 has indicated that the variable costs per kilometre are lower than the other three modes. So, the deterrence function of the pipeline will intersect with deterrence functions of the other modes at a certain point which is dependent on distance and time (variable costs).
Based on the performance overview a conclusion was that due to the high capacity, relative low operating speeds and infrastructural dependency, pipelines mostly match the characteristics of inland water transport. Competition with road transport would be difficult based on the logistic indicators, as trucks are very efficient in small batch and just-in-time deliveries with a great deal of flexibility due to extended road networks.

The scenarios for estimating the parameters of pipeline transport are displayed in the table below. For parameter α, fixed costs, the highest value among parameter α for road, rail and IWT is used. The approach stated that is assumed that the initial fixed costs are highest for pipeline transport compared to the other modes.
For parameter β and γ, the transport time and distance parameters in the deterrence function, the values are multiplied with the corresponding β and γ of IWT. As section 2.5 concluded that pipeline and IWT are the most comparable based on their logistic indicators.

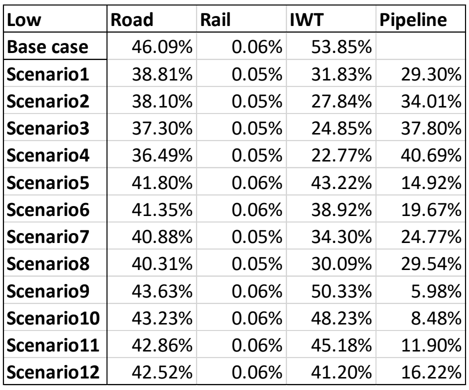
Table 4.8: Scenarios to estimate pipeline deterrence function parameters (own creation).

| Scenario | Fixed costs (α) | Variable costs (β,γ) |
|---|---|---|
| **1** | +10% | -10% |
| **2** | +10% | -20% |
| **3** | +10% | -30% |
| **4** | +10% | -40% |
| **5** | +20% | -10% |
| **6** | +20% | -20% |
| **7** | +20% | -30% |
| **8** | +20% | -40% |
| **9** | +30% | -10% |
| **10** | +30% | -20% |
| **11** | +30% | -30% |
| **12** | +30% | -40% |

Another parameter which needs to be assessed for pipeline transport is the dispersion factor ($\mu$) in the MNL model. The approach to determine the dispersion factor for pipeline transport will be to start with a value of $\mu = -0.090$, the results of the MNL model show expected behaviour using this value. The dispersion factor will be included in a sensitivity analysis, to see what changes to this variable will affect the result of the SCBA.

Table 4.9 below displays the estimated modal split in ton-kilometres with a dispersion factor of -0.90 in de the different scenarios for the Central trajectory of the project alternative. Scenarios 1 to 4 are the most favourable scenarios, as the fixed costs parameter α is only increased with 10%. The scenarios where the fixed costs parameters increase to 20% (scenarios 5 to 8) and 30% (scenarios 9 to 12), the share decreases swiftly.

Table 4.9: Estimated modal split growth scenario Low Central trajectory (in ton-km) (own creation).



| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 38.81% | 0.05% | 31.83% | 29.30% |
| **Scenario2** | 38.10% | 0.05% | 27.84% | 34.01% |
| **Scenario3** | 37.30% | 0.05% | 24.85% | 37.80% |
| **Scenario4** | 36.49% | 0.05% | 22.77% | 40.69% |
| **Scenario5** | 41.80% | 0.06% | 43.22% | 14.92% |
| **Scenario6** | 41.35% | 0.06% | 38.92% | 19.67% |
| **Scenario7** | 40.88% | 0.05% | 34.30% | 24.77% |
| **Scenario8** | 40.31% | 0.05% | 30.09% | 29.54% |
| **Scenario9** | 43.63% | 0.06% | 50.33% | 5.98% |
| **Scenario10** | 43.23% | 0.06% | 48.23% | 8.48% |
| **Scenario11** | 42.86% | 0.06% | 45.18% | 11.90% |
| **Scenario12** | 42.52% | 0.06% | 41.20% | 16.22% |

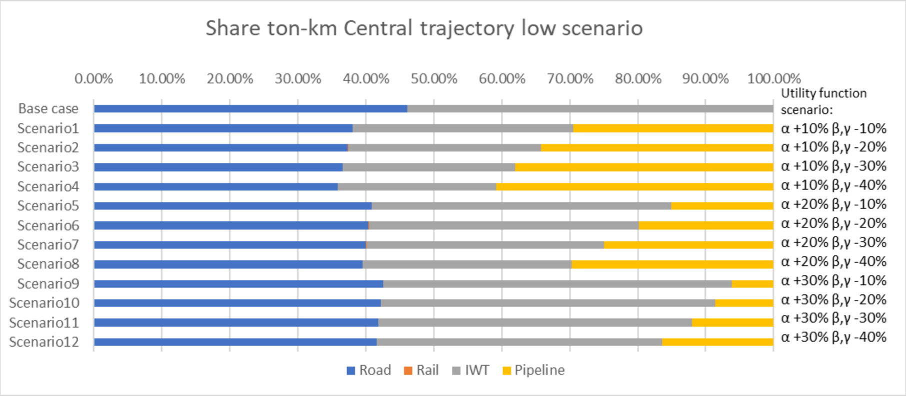


Figure 4.6: modal share (own creation).

What can be concluded from this table is that the share of IWT decreases the most in terms of ton-km when the pipeline is added to the modal split. Road transport also decreases considerably in scenarios 1 to 4, however the share in scenario 9 to 12 remains high and decreases only a few percentage points.

Furthermore can be concluded that, the modal share is sensitive to changes in the scenarios. A reason can be the dispersion factor, therefore a sensitivity analysis will be carried out. Another cause can be the proportion of the fixed costs, thus parameter α, of the estimated deterrence function. This explains why the share decreases rapidly when the scenarios apply a higher factor to the fixed costs parameter.

Appendix F contains the delta table for the modal split in ton-km, but also the tables for the modal split in terms of transported tons. Furthermore, the modal split for all other trajectories and growth scenarios, are also in Appendix F.

At last, should be mentioned this approach contains multiple assumptions and the hypothesis of pipeline transport has a higher fixed costs compared to other modes. Pipeline transport is a fundamental different transport mode with other characteristics compared to the other transport modes considered. Section 2.5 also indicates these differences. The proposed approach to estimate the parameters in the deterrence function for pipeline transport are an attempt to deal with the missing data in this research. Therefore, the results of the mode choice model and the results of the CBAs must be reviewed carefully.

## 4.7 Validation and Outliers

In paragraph 4.6 the results of the various models were presented. From the three models, the most extensive and complicated was the model that showed the least margin of errors.

For validation of the models an approach is followed for mode choice models with aggregate OD data (Zhang, 2013). Two perspectives will be used in this validation process, a disaggregate and aggregate perspective to research the errors of the model. In the disaggregate perspective the market share of the observed area is reviewed towards the market shares in the model. And in the aggregate perspective a more detailed position is taken towards the errors made on origin and destination relation, where outliers will be discussed as well.

### 4.7.1 Disaggregated perspective

The aggregated perspective will take position from a more global perspective, where the market shares among the observed OD relations are reviewed. For this validation perspective the observed market shares and the calculated market shares are used.

The table below describes the percentual error between the observed market shares and the calculated market shares for the observed OD relations.

Table 4.10: Percentual error between observed and calculated market shares (own creation).

| % Error | NST2 | NST7 | NST8 |
|---|---|---|---|
| **Road** | 13.24% | 4.37% | 11.03% |
| **Rail** | -0.03% | -0.87% | -1.80% |
| **IWT** | -13.22% | -3.49% | -9.23% |

The figures tell that road transport is overestimated in the calculated model (namely model 3). This is to a greater extent at the expense of inland water transport, and to a lesser extent, at the expense over railway transport. An explanation for the error in market share can be largely attributed to the explanatory power of the model's attributes.

### 4.7.2 Aggregated perspective

Next, the aggregated perspective will dive more into detail and highlight the error between OD relations and considers the outliers from the calculated market shares compared to the observed values. Outliers can be the result of modelling, as the model tries to capture important aspects from the way modal choice is determined. Capturing all aspects and include dozens of explanatory variables is not realistic in terms of effort and time constraints. Next to modelling, outliers can also be result of other effects. There can be rules and regulations that do not allow truck transport near city centers for example. This research will preliminarily focus on the modelling part of explaining outliers, however it is important to note and highlight outliers and include that in the results.

The table below describes the percentual error between observed and calculated market shares between the transport regions in the model. To repeat these regions, there is a distinction made between national transport within Flanders (region 1), transport from or to the port of Antwerp (region 2) and international transport between Flanders and NRW (region 0).

Table 4.11: Percentual error between observed and calculated market shares, split on regions (own creation)

| | **NST2** | | | **NST7** | | | **NST8** | | |
|---|---|---|---|---|---|---|---|---|---|
| **Error** | **Region 1** | **Region 2** | **Region 0** | **Region 1** | **Region 2** | **Region 0** | **Region 1** | **Region 2** | **Region 0** |
| **Road** | 0.45% | 17.55% | -1.22% | 1.14% | 6.43% | -16.24% | 4.49% | 15.63% | 17.10% |
| **Rail** | -0.01% | -0.03% | -0.01% | -0.18% | -1.10% | -0.07% | -0.02% | -2.10% | -7.57% |
| **IWT** | -0.44% | -17.52% | 1.23% | -0.96% | -5.32% | 16.31% | -4.47% | -13.53% | -9.52% |

Again, the figures indicate that the road transport is overestimated at the expense of IWT and rail transport. This applies predominantly to region 2 for all three product groups, this tells us that the model has difficulty to calculate the market shares for OD relations from or to the port of Antwerp. Furthermore, region 0 shows larger errors for NST7 and NST8.

In the following part of this paragraph the errors for regions become clearer as the outliers of our model are discussed. For this paragraph, it is determined that at an outlier has a standard error of 0.2 (20%) or higher.
The identification that road transport is overestimated, and that goes at the expense of inland water transport, is confirmed by reviewing some of the outliers in the table below. Together with the note that transport for region 2 and region 0 contain larger errors.

Table 4.12: Considered outliers (own creation).

| | Transport mode | SE | Origin | Destination | Calc | Observed |
|---|---|---|---|---|---|---|
| **NST2** | | | | | | |
| 1 | Road | 0.364 | 23. Haven ANT_RO | 4. HASSELT | 66.06% | 5.75% |
| 2 | IWT | 0.364 | 23. Haven ANT_RO | 4. HASSELT | 33.94% | 94.25% |
| 3 | Road | 0.278 | 24. Haven ANT_LO | 40. DEA1 | 77.87% | 25.16% |
| 4 | IWT | 0.278 | 24. Haven ANT_LO | 40. DEA1 | 22.13% | 74.84% |
| **NST7** | | | | | | |
| 5 | Road | 0.211 | 23. Haven ANT_RO | 41. DEA3 | 30.66% | 76.57% |
| 6 | IWT | 0.211 | 23. Haven ANT_RO | 41. DEA3 | 69.34% | 23.43% |
| 7 | Road | 0.600 | 24. Haven ANT_LO | 42. DEA4 | 100.00% | 22.56% |
| 8 | Rail | 0.600 | 24. Haven ANT_LO | 42. DEA4 | 0.00% | 77.44% |
| **NST8** | | | | | | |
| 9 | road | 0.90 | 30. DEA23 | 1. ANTWERPEN | 100.00% | 5.29% |
| 10 | rail | 0.90 | 30. DEA23 | 1. ANTWERPEN | 0.00% | 94.71% |
| 11 | road | 0.71 | 24. Haven ANT_LO | 34. DEA27 | 9.28% | 93.26% |
| 12 | rail | 0.71 | 24. Haven ANT_LO | 34. DEA27 | 9.28% | 93.26% |

For the different product groups some large outliers are selected. What can be concluded is that road transport is deemed more favourable in the mode choice model. Based on the logistic characteristics the mode choice model overestimates the share of road transport.
Opposite can be applied to rail and inland water transport, their logistic characteristics step in advantage in case of higher distances and higher travel time. In the mode choice model these characteristics are less noticeable and therefore the rail in inland water transport is underestimated by the model. This also emerges from the outliers, for example the first and second outlier in table 5.8. This is the OD relation between port of Antwerp right shore (Rechteroever) and Hasselt. On This trajectory the observed share of IWT is over 94%, however the modal split model estimated close to 34% for IWT between this OD pair. The modal split model estimates a lower share, therefore underestimating IWT.
Another trajectory with outliers that caught attention is 9 and 10 from table 4.12. Again, road transport is overestimated, opposite to rail transport which is underestimated. The OD trajectory between DEA23 (Cologne) and Antwerp is highly favorable to train transport as there are two railroad connections between the two regions, however the model estimates a significantly lower share for rail transport, as the dispersion factor is more negative for rail transport and higher parameter values for fixed costs and distance.

Outliers have shown that the model overestimates road transport, at the expense of rail and inland water transport. The model and its parameters are calibrated to capture reality, where literature has shown that rail and inland water transport benefit from longer distances and less time constraining transport. The mode choice model has a degree of error, where OD pairs and the share of transport modes are under- or overestimated. This error is deemed acceptable for the resources available in this research. But the degree of error should be noted when reviewing the results of this research.

# 5. Monetary evaluation: SCBA & FCBA

In this chapter the results of the SCBA and FCBA for the base case alternative and project alternative are presented. First, this chapter will show which effect is considered under which evaluation method. Then the considered effects of the FCBA are monetized and thereafter the SCBA. The results of both FCBA and SCBA are combined in an overview where the results are discussed.

## 5.1 Effects and evaluation method

This research considers a FCBA and SCBA, as section 3.4 and 3.5 pointed out that the costs for investors and companies on one side and society and the government at the other side are clearly split. The project alternative requires investments from companies who want to transport their liquid bulk product through a pipeline instead of the currently available transport modes. The upside for society/government is that the pipeline transport is reducing external effects of transport. The table below describes the effects which are included in either the FCBA or the SCBA.

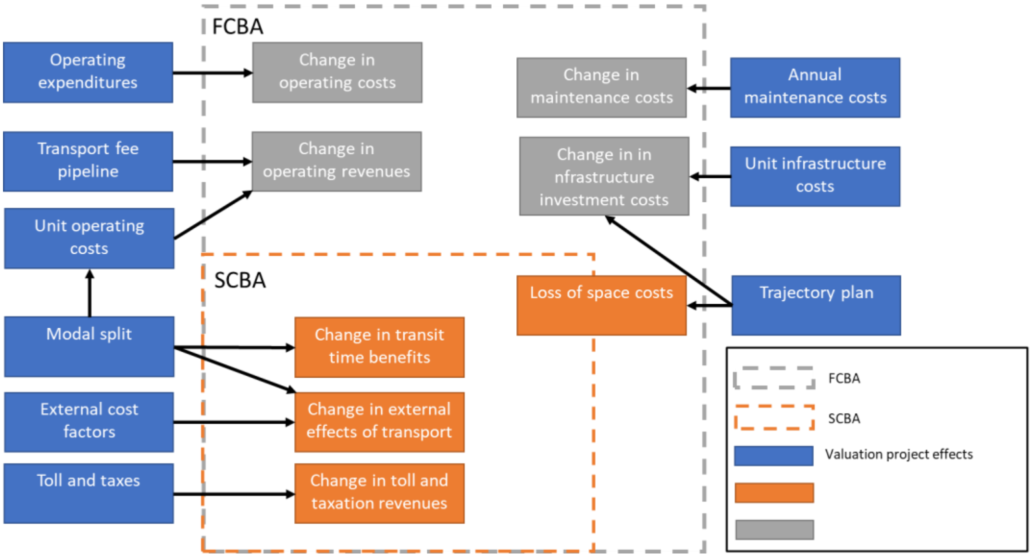


Figure 5.1: Effects and evaluation method (own creation).

As one can see in figure 5.1 the SCBA comprises all effects that affect society, where the change in external effects can be estimated via the estimated modal split from the modal split model in chapter 4. Furthermore, this SCBA includes the change in transit time benefits and changes in toll and tax revenues in a qualitative score. At last, the loss of space costs due to the project alternative is included, the loss of space is endured by society as the space cannot be used for all purposes. However, the costs are borne by the investors of the pipeline.

The FCBA is consisting of investment costs (different trajectories as of this moment), maintenance costs, loss of space costs, operating costs and a prominent issue is the revenue generated from operating the pipelines.

## 5.2 FCBA

The FCBA includes construction costs, maintenance costs, loss of space costs, operating costs and revenues. The costs and revenues have been estimated using (literature) sources and project files of the current GRUP plans.

More details on the calculations of this section can be found in Appendix G or see Appendix J for the corresponding Excel files.

### 5.2.1 Construction costs

The construction for the pipeline is dependent on three factors discussed in section 3.5: the construction costs per kilometre, the length of the trajectory and the number of pipelines in the configuration.

The construction of the pipeline is fictively planned to start in 2025, this is year 0 in the SCBA. The construction is estimated to take place in 5 years. Over the five years the total construction cost is paid. The Net Present Value (NPV) of the total construction costs (*TCC*) is calculated using the following formula:

$$TCC = \sum_{t=0}^{4} CC * TL * N * \frac{1}{(1+DR)^t} \qquad (5.1)$$

Where:
TCC= total construction costs
CC = Construction costs per kilometer (€850.000)
TL = Trajectory length (North, South or Central)
N = Number of pipelines (dependent on scenario low, medium, high)
DR = discount rate (4.5%)
t = year of appraisal period

In table 5.1 the present value of the construction costs is displayed containing the information on the different factors. Due to the longer trajectory of North, the costs are significantly higher than the other two trajectories.

Table 5.1: Construction costs (own calculations).

| Trajectory | Space used (ha) | Approximate trajectory length (km) | Construction costs (€million) | | |
|---|---|---|---|---|---|
| | | | Low | Medium | High |
| **North** | 1274 | 283 | € 1,324 | € 1,545 | € 1,766 |
| **Central** | 805 | 179 | € 838 | € 977 | € 1,117 |
| **South** | 848 | 188 | € 880 | € 1,026 | € 1,173 |

### 5.2.2 Maintenance costs

Maintenance costs are assumed to be 3% of the investment costs for pipeline construction (Dönszelmann et al., 2008). The maintenance costs are calculated from year 5 to the end of the appraisal period (year 30). As the maintenance will take place from the moment the pipelines are in use.

The following formula is used to calculate the total maintenance costs (*TMC*):

$$TMC = \sum_{t=5}^{30} MCF * TCC * \frac{1}{(1+DR)^t} \qquad (5.2)$$

Where:
MCF = maintenance cost factor (3% of TCC)
TCC = Total construction costs
DR = discount rate (4.5%)
t = year of appraisal period

For the three trajectories and their corresponding construction costs (see table 5.1), this would come down to the present value of maintenance costs in the table below.

Table 5.2: maintenance costs for pipeline (own creation).

| **Maintenance costs (€million)** | | | |
|---|---|---|---|
| **Trajectory** | **Low** | **Medium** | **high** |
| **North** | € 549.9 | € 641.6 | € 733.3 |
| **Central** | € 347.8 | € 405.8 | € 463.8 |
| **South** | € 365.3 | € 426.2 | € 487.1 |

### 5.2.3 Loss of space costs

The loss of space is the last source of investment costs. The loss of space costs is again spread over the construction years, so year 0 to year 4. In section 3.5.3 (and table 3.10) the loss of space costs was already calculated, this was the lumpsum and not the present value over the construction period of 5 years. The loss of space costs (LoSC) is calculated using the following formula:

$$TLoSC = \sum_{t=0}^{4} Ha * VoL * \frac{1}{(1+DR)^t} \qquad (5.3)$$

Where:
Ha = hectare of land (derived from table 3.3)
VoL = value of land-use (derived from table 3.3)
DR = discount rate (4.5%)
t = year of appraisal period

With the use of the formula the following present value can be calculated for the three trajectories:

Table 5.3: Loss of space costs per trajectory (own creation).

| **Trajectory** | **Loss of space costs (in €million)** |
|---|---|
| **North** | € 99.4 |
| **Central** | € 115.9 |
| **South** | € 137.9 |

Although the trajectory of North is the longest and consumes the most space, the present value of the loss of space is the lowest. The primary reason is that the trajectory flows through uninhabited areas and mostly agricultural land, unlike the Central and South trajectory.

### 5.2.4 Overview investment costs

In this section the investment costs are put together for the three scenarios and the three different trajectories that are considered in Flanders.
As discussed, there is a significant difference in terms of the trajectories, this difference affects the total costs for a large part. The longer North trajectory is over 50% more expensive compared to the Central trajectory and even over 90% more expensive compared to the South trajectory, considering all investment costs.

Table 5.4: Investment costs North trajectory (own creation).

| **Trajectory North** (in €million) | **Low** | **Medium** | **high** |
|---|---:|---:|---:|
| Construction costs | € 1,324 | € 1,545 | € 1,766 |
| Maintenance costs | € 549.90 | € 641.60 | € 733.30 |
| Loss of space costs | € 99.40 | € 99.40 | € 99.40 |
| **Total** | € 1,973.54 | € 2,285.94 | € 2,598.35 |

Table 5.5: Investment costs Central trajectory (own creation).

| **Trajectory Central** (in €million) | **Low** | **Medium** | **high** |
|---|---|---|---|
| Construction costs | € 838 | € 977 | € 1,117 |
| Maintenance costs | € 347.80 | € 405.80 | € 463.80 |
| Loss of space costs | € 115.93 | € 115.93 | € 115.93 |
| **Total** | € 1,301.32 | € 1,498.92 | € 1,696.51 |

Table 5.6: Investment costs South trajectory (own creation).

| **Trajectory South** (in €million) | **Low** | **Medium** | **high** |
|---|---|---|---|
| Construction costs | € 880 | € 1,026 | € 1,173 |
| Maintenance costs | € 365.30 | € 426.20 | € 487.10 |
| Loss of space costs | € 137.89 | € 137.89 | € 137.89 |
| **Total** | € 1,382.90 | € 1,590.41 | € 1,797.93 |

The Central trajectory is the least expensive but has the higher loss of space costs compared to the North trajectory. However, on the total construction costs, the loss of space costs is marginal. Therefore, the Central trajectory is the most favourable trajectory from a cost perspective.

### 5.2.5 Operating costs & Revenues

The aspects that define the operating costs are discussed in 3.5.5. These aspects in combination with the most important assumptions are shortly discussed with relation to estimating the operating costs.
At first depreciation of the investment, according to Capiau (2010) pipelines have an economical life span of 30 years. Therefore, it is assumed the depreciation of construction costs in the previous section takes 30 years.
Furthermore, the pipeline needs energy to power the pumps and booster stations. The energy used will form a significant part of the costs made. The research takes into account that transport per pipeline and the energy required will vary for various products. Therefore, different energy consumption and energy costs as presented in section 3.3.4 are taken in to account.
Next to energy, costs will be salaries of operators at the pipeline, permits, periodical checks of the pipeline, maintenance etc. The maintenance costs were discussed in section 5.2.2, the costs for service and personnel are assumed to be €10 million per year for both aspects.
In case the pipeline is operated by a third-party (some sort of public private partnership) or another company, these companies are likely to make a profit margin on the transport. However, this research presumes that the operating costs are equal to the transport fees.

The following formulas are based on Bawono & Kusrini (2018) to estimate the revenue and the associated costs of operation and tariffs.

$$Revenue = tariff * volume \qquad (5.4)$$

$$Tariff_t = \frac{Cost\ of\ operation_t}{Volume_t} * \frac{(1+DR)^t}{1} \qquad (5.5)$$

Where:
Tariff = yearly cost of transporting one ton of product in €/ton.
Cost of operation = yearly total cost of operating and transporting in €.
Volume = yearly estimated volume in ton.

DR = discount rate (4.5%)
t = year of FCBA.

$$Cost\ of\ operation_t = Depreciation + Maintenance_t + Labour_t + Service_t + Energy_t \quad (5.6)$$

$$Volume_t = V_{NST2,t} + V_{NST7,t} + V_{NST8,t} \quad (5.7)$$

The tariff is calculated by dividing the yearly total costs of operation by the yearly total volume transported via pipeline of all the considered product groups.
In the rest of this section first the facets of costs of operation are discussed, followed by the yearly volume and at last the tariffs are discussed.

### Depreciation

The depreciation is the combined sum of the total construction costs and total loss of space costs, divided by the economical lifespan of the pipeline (30 years). The results of the *TCC* and *TLoSC* can be found in 5.2.1 and 5.2.3.

$$Depreciation = \frac{TCC+TLoSC}{Ls} \quad (5.8)$$

Where:
*Depreciation = depreciation per year*
*TCC = Total construction costs*
*LoSC = Loss of Space costs*
*Ls = economical lifespan (30 years)*
*DR = discount rate (at 4.5%)*
*t = year of FCBA*

The results of the yearly depreciation are displayed in the table below. The central trajectory is the most favorable in terms of costs (5.2.1) and therefore also has the lowest depreciation per year. The depreciation is fixed cost every year.

Table 5.7: Yearly depreciation of project alternative.

| In €million | **Low** | **Medium** | **High** |
|---|---|---|---|
| **North** | € -47.46 | € -54.81 | € -62.17 |
| **Central** | € -31.78 | € -36.44 | € -41.09 |
| **South** | € -29.32 | € -38.81 | € -43.69 |

### Maintenance

Next, maintenance costs were calculated in section 5.2.2, the yearly maintenance costs are calculated using the maintenance cost factor times the total cost of construction. This will be multiplied with the discount rate.

$$Maintenance_t = MCF * TCC * \frac{1}{(1+DR)^t} \quad (5.9)$$

Where:
MCF = Maintenance cost factor (3%)
TCC = total construction costs
DR = Discount rate (4.5%)
t = year of the FCBA, where in this formula t = 4…30.

### Labour and Costs of Service

The following two costs for labour and costs of service are consisting of an assumed constant, the constant is multiplied with the discount rate.

$$Labour_t = L * \frac{1}{(1+DR)^t} \qquad (5.10)$$

Where:
L = Labour costs assumed at €10 million per year.
DR = Discount rate (4.5%)
t = year of FCBA. In this formula t = 4 … 30.

$$Service_t = S * \frac{1}{(1+DR)^t} \qquad (5.11)$$

Where:
S = costs of service, assumed at €10 million per year.
DR = discount rate (4.5%)
t = year of FCBA. In this formula t = 4 … 30.

### *Energy costs*

At last, the costs for energy, the costs for energy are calculated using the estimated ton-km volumes of transport of the modal split model. The volumes are multiplied with the energy consumption per ton-km derived from NEA & Haskoning (1993) and van Essen, Croezen, et al. (2003). This will provide the total energy used in kilowatt hours, which is multiplied by the energy tariffs based on the EU average between 2017 and 2022 (Eurostat, n.d.-a)(Eurostat, n.d.-b).
As described the NST2 products are transported using natural gas and the NST7 and NST8 products are transported using electricity as energy carriers.

$$Energy_t = (V_{NST2,t} * E_{Gas} * T_{Gas}) + ((V_{NST7,t} + V_{NST8,t}) * E_{Electricity} * T_{Electricity}) \qquad (5.12)$$

Where:
V = volume in ton-km
E = energy consumption in kWh/ton-km
T = energy tariffs in €/kWh
t = year of FCBA

The results of calculating the energy costs are extensive as these costs are dependent on the growth scenario (either low, medium or high). In a low growth scenario, the general total volume of transport is lower than in the high scenario. Furthermore, the modal split model also shows different behaviour in the different growth scenarios combined with the different scenarios for the utility function (cost function) of the pipeline. Here, a growth scenario of medium or high does not imply the percentage of transport volume via pipeline is higher than in the low growth scenario.

### *Volume*

The volume transported in tons is derived from the modal split model estimations. As described under energy costs the volumes transported differ per year as the modal split considers a growth scenario, cost figure development of the transport modes and there are different scenarios for the utility function of the pipeline.
The share of pipeline transport in the different scenarios can be found in Appendix F. The yearly volumes can be found in the Excel file ‘SCBA Project Alternative’.

### *Tariffs and Revenue*

The tariffs for pipeline transport can be calculated using the formula below and is based on Bawono & Kusrini (2018).

$$Tariff_t = \frac{Cost\ of\ operation_t}{Volume_t} * \frac{(1+DR)^t}{1} \qquad (5.13)$$

The revenues are calculated using the tariffs times the assigned volume. The assigned volume is subject to the estimations in the mode choice model and the utility function scenarios from chapter 4.

The tariffs for pipeline transport should be representative to attract a shift in mode choice. In the figure below an overview is given for the tariff in €/ton-km for the Central trajectory with the growth scenarios and utility function scenarios for the pipeline cost function. The overview of tariffs for the other two trajectories are displayed in Appendix F.

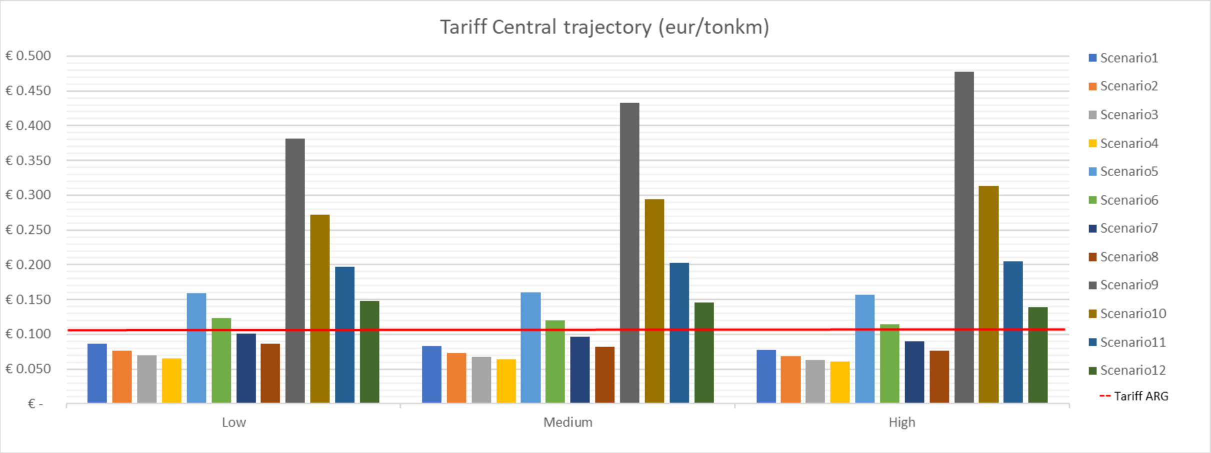


Figure 5.2: Tariffs Central trajectory in €/ton-km (own creation).

The figure displays that the tariffs vary widely across the different scenarios. Especially for scenarios 9 to 12 the tariffs are remarkably high, compared to scenario 1 to 4. The question arises which tariffs can be seen as representative due to this large spread caused by the different scenarios.

This is shown by research from ARG (1999) for a potential propylene pipeline between the Benelux and Cologne/Gelsenkirchen. In the feasibility study a tariff of €0.109 per ton-km was considered for the transport of the chemical propylene. The transport tariffs in figure 5.2 are in multiple scenarios close to the tariffs calculated by the feasibility study of ARG, especially scenario 5 to 8 balance well around the proposed tariff in the feasibility study. Therefore, this study assumes scenario 5 to 8 to be the most reasonable utility function scenarios. However, the tariff figure dates from 1999, inflation and overall rise in costs of transport are likely to have an effect on this figure, assuming that the tariffs have risen as well.

The tariffs for the South trajectory are close to the Central trajectory. However, this is not the case for the North trajectory. Higher construction costs and maintenance costs due to the longer trajectory affect the estimated costs of operation. Furthermore, the longer transport times make this route less attractive for a modal shift meaning less volume resulting in higher tariffs.

Appendix G contains all tables and figures for all trajectories and scenarios.

### 5.2.6 Results FCBA

In this section all calculated and estimated costs and revenues of the project alternative are combined form the investors’ or pipeline operator’s perspective. The results of the FCBA contain the Net Present Value (NPV), Benefit-Cost Ratio (BCR) and pipeline transport tariff estimation.

First the NPV, the result is negative for all trajectories and scenarios. There are two reasons for the negative NPVs embedded in the assumptions of this research. First, this research has calculated that the pipeline infrastructure over an economical life span for 30 years. In the FCBA the pipeline infrastructure is in use for 26 years as construction was assumed to take 5 years. This leaves a residual life span of 4 years, thus 4 years of depreciation left. Second, this research estimated pipeline transport tariffs and revenue that matched the costs of operation for the estimated volumes of transport. The transport tariffs were only cost-covering. Therefore, the result of the NPV is the remaining depreciation. As can be expected, the Benefit-Cost ratio all below 1.0 as the NPVs are negative.

Table 5.8: FCBA Central trajectory low growth scenario (own creation).

| **NPV (in million euro)** | | | | |
|---|---|---|---|---|
| **Project effects** | **Scenario 5** | **Scenario 6** | **Scenario 7** | **Scenario 8** |
| **Change in investment costs** | | | | |
| Construction costs | € -837.6 | € -837.6 | € -837.6 | € -837.6 |
| Loss of space costs | € -115.9 | € -115.9 | € -115.9 | € -115.9 |
| **Change in operational costs** | | | | |
| Energy | € -37.5 | € -48.3 | € -59.7 | € -70.4 |
| Personnel | € -127.0 | € -127.0 | € -127.0 | € -127.0 |
| Maintenance costs | € -347.9 | € -347.9 | € -347.9 | € -347.9 |
| Costs of service | € -127.0 | € -127.0 | € -127.0 | € -127.0 |
| Tonkm (million tonkm) | 19,969,864,057 | 25,829,793,380 | 31,906,419,621 | 37,443,128,612 |
| Volume (tons) | 126,090,643 | 154,148,254 | 183,009,466 | 209,691,900 |
| **Change in revenues** | € 1,465.8 | € 1,476.6 | € 1,487.9 | € 1,498.7 |
| **NPV FCBA** | € -127.1 | € -127.1 | € -127.1 | € -127.1 |

Nevertheless, the NPVs in the different volume growth scenarios and for the different trajectories do indicate the Central trajectory is the most favourable trajectory from the FCBA perspective. The table below shows the NPV of the trajectories and growth scenarios.

Table 5.9: FCBA NPV results.

| **NPV** (in € million) | **Low** | **Medium** | **High** |
|---|---|---|---|
| **North** | € - 189.8 | € - 219.3 | € - 248.7 |
| **Central** | € - 127.1 | € - 145.7 | € - 164.4 |
| **South** | € - 135.7 | € - 155.2 | € - 174.8 |

The most important findings are on the tariff estimation for the pipeline project. The transport tariffs are a result of the assigned volume from the mode choice model and the estimated operational costs in the FCBA. The estimated transport tariffs for the project alternative compared to a feasibility study by ARG (1999) indicate that multiple utility function scenarios (scenario 5 to 8) in the Central and South trajectory approach the figures from the feasibility study from 1999 and these scenarios can be considered more realistic. However, the feasibility study was calculating on a margin and was conducted in 1999, so it is expected transport costs have risen over time.

In short, from a financial and investors perspective the Central trajectory offers the most attractive opportunities. Due to the shorter trajectory it has the lowest investment costs and potentially offers the lowest transport tariffs. Contrary, the North trajectory is least favourable due to the longest trajectory the most costs are accompanied with this trajectory. However, the pro of this trajectory is the least costs in terms of loss of space. Which could be argued that the North trajectory is the least disturbing to society. This will form an interesting point of discussion in combination with the results of the SCBA in the next section, as from a policy perspective there could be a tradeoff between the trajectories at the expense of a reduction in external effects.

## 5.3 SCBA

The SCBA comprises all societal effects, so this includes all external effects caused by transport and two other effects change in transit time effects and change in toll and tax revenues are scored on a

qualitative scale.
Please refer to Appendix H contains all the detailed results of the calculations.

### 5.3.1 External effects

The external costs that are included in this research in a quantitative way are: loss of habitat costs, climate change costs, air pollution costs, congestion costs, noise effects and safety effects.
For these external effects a cost factor an overview is displayed in 3.5.13, the external cost factors are derived from van Essen et al. (2019) or other sources discussed in section 3.5. The cost factor is multiplied with the estimated ton-kilometer per transport mode from the mode choice model.
The following formula is used to calculate the costs for external effects.

$$External\ effect = \sum_{t=0}^{30} ECF_m * TonKm_{m.t} * \frac{1}{(1+DR)^t} \qquad (5.14)$$

Where:

*ECF* = external costs factor for transport mode *m* (in €/tonkm)
*Tonkm* = the ton-kilometers per transport mode *m* in year *t*
*DR* = discount rate (4.5%)
*t* = year appraisal period
*m* = transport mode *m* to *n*

### 5.3.2 Results monetized effects SCBA

In this section the change in external effects costs of transport are calculated. As mentioned in 5.3.1 the external effects of transport are included in the monetized effects of the SCBA.
Table 5.10 displays the change in the external effects of transport for the Central trajectory in the low volume growth scenario and the utility function scenarios 5 to 8 (the same utility function scenarios as in the FCBA).

Table 5.10: SCBA results Central trajectory, low scenario.

| | | | | |
|---|---|---|---|---|
| **Central trajectory** | | | | |
| **Growth volume scenario: low** | | | | |
| **Discount rate: 4.5%** | | | | |
| **NPV (in million euro)** | | | | |
| **Change in external effects** | **Scenario 5** | **Scenario 6** | **Scenario 7** | **Scenario 8** |
| Air pollution | € 111.0 | € 148.9 | € 188.1 | € 223.7 |
| Climate change costs | € 34.4 | € 43.5 | € 52.8 | € 61.5 |
| Congestion costs | € 37.5 | € 42.9 | € 48.5 | € 54.0 |
| Noise costs | € 19.1 | € 21.9 | € 24.7 | € 27.6 |
| Safety | € 61.5 | € 71.3 | € 81.4 | € 91.3 |
| Loss of habitat costs | € 9.1 | € 12.4 | € 15.7 | € 18.8 |
| **NPV SCBA** | € 272.6 | € 340.8 | € 411.2 | € 477.0 |

The SCBA and corresponding positive NPVs indicate that there are gains for society with the project alternative. Across all the utility function scenarios reductions in air pollution costs and climate change costs stand out. The mode choice model in chapter 4 indicated that IWT covers more than half the ton-km in the base case, the shift to pipeline transport primarily comes from IWT. Where IWT has higher air pollution costs than pipeline transport.
Furthermore safety costs stand out. The cost factor for accidents in road transport are high compared to the other two modes, which is also reflected in the results. The shift to pipeline transport from road transport leads to significant reductions in safety costs.
When utility function scenario 5 is taken a closer look at, the positive values in table 5.11 make clear that large portions of the gains in the project alternative are from reductions in climate change and

air pollution costs. Furthermore, the change in safety costs and congestions due to a shift from road transport to pipeline transport form gains for society.

For congestion costs and noise costs there were no external costs factors found in the handbook on external costs of transport for IWT (for rail no congestion costs factors were included) (van Essen et al., 2019). Hence, no congestion costs are estimated for these two transport modes, and no noise costs are included for IWT. This is explained in section 3.5.

Table 5.11: SCBA results scenario 5 Central trajectory, low scenario.

| **NPV (in € million)** | | | | |
|---|---|---|---|---|
| **Scenario 5** | **Road** | **Rail** | **IWT** | **Pipeline** |
| **Air pollution** | € 30.09 | € 0.00 | € 85.35 | € -4.42 |
| **Climate change costs** | € 20.78 | € 0.00 | € 17.50 | € -3.84 |
| **Congestion costs** | € 37.47 | € - | € - | € - |
| **Noise costs** | € 19.05 | € 0.04 | € - | € - |
| **Safety** | € 59.03 | € 0.00 | € 4.41 | € -1.92 |
| **Loss of habitat costs** | € 7.59 | € 0.01 | € 15.47 | € -14.00 |

In appendix H the results of NPV of the base case on itself and the project alternative, including the different trajectories and scenarios are shown. The results of the South trajectory are fairly equal compared to the Central trajectory. But, the North trajectory does show significant lower NPVs.

Table 5.12 (left) SCBA results North trajectory, low scenario.

Table 5.13 (right): SCBA results South trajectory, low scenario.

| **NPV** (in €million) | | | | |
|---|---|---|---|---|
| **Low** | **Scenario 5** | **Scenario 6** | **Scenario 7** | **Scenario 8** |
| **Air pollution** | € 11.8 | € 26.5 | € 52.4 | € 94.6 |
| **Climate change costs** | € 8.3 | € 12.7 | € 19.9 | € 30.5 |
| **Congestion costs** | € 16.5 | € 21.3 | € 27.5 | € 35.1 |
| **Noise costs** | € 8.4 | € 10.8 | € 14.0 | € 17.9 |
| **Safety** | € 25.5 | € 33.4 | € 44.0 | € 57.3 |
| **Loss of habitat costs** | € 0.3 | € 1.6 | € 3.9 | € 7.6 |
| **Total** | € 70.7 | € 106.3 | € 161.8 | € 243.1 |

| **NPV** (in €million) | | | | |
|---|---|---|---|---|
| **Low** | **Scenario 5** | **Scenario 6** | **Scenario 7** | **Scenario 8** |
| **Air pollution** | € 95.6 | € 133.2 | € 174.5 | € 213.6 |
| **Climate change costs** | € 30.7 | € 39.8 | € 49.6 | € 59.0 |
| **Congestion costs** | € 35.1 | € 40.7 | € 46.5 | € 52.4 |
| **Noise costs** | € 17.9 | € 20.8 | € 23.7 | € 26.7 |
| **Safety** | € 57.3 | € 67.4 | € 77.9 | € 88.4 |
| **Loss of habitat costs** | € 7.7 | € 11.0 | € 14.6 | € 17.9 |
| **Total** | € 244.3 | € 312.8 | € 386.7 | € 458.0 |

### 5.3.4 Results non-monetized effects

In section 3.5 the recognized effects where valued if that was deemed possible. Two recognized effects, toll and taxation revenues and transit time effects, were regarded to be estimated on a qualitative scale instead of monetizing these effects.

The qualitative score will be based on a Likert scale, ranging from very negative (- -) to very positive (++). The different scenarios will be scored using this 5-point Likert scale. This scale is often used in questionnaires or willingness to pay research, but provides a clear insight and is therefore useful for the qualitative effects in the CBA (Mouter, 2014) (European Union, 2016).

#### *Toll and taxation revenues*

The toll and taxation revenues are mainly derived from duties on fuels for road transport and infrastructural charges as discussed in section 3.5. When a shift would occur from road transport to pipeline transport and the pipelines are owned by a private company, it is unknown if a infrastructural taxation is applied for the pipeline. In general, a loss in toll and taxations revenues can be seen as a loss in welfare, as the revenues of toll and taxation are expected to be put back in society by the government (van Meerkerk & Hilbers, 2015).

The effect on toll and tax revenues is heavily dependent on the modal shift that would occur. In the table below the shift in ton-km is displayed for the medium scenario for the most favourable trajectory Central. What can be concluded from the modal split modal and the estimated modal split in ton-km is that the shift to pipeline transport mainly comes from inland water transport and to a lesser extent from road transport (scenario 1 to 8). In fact the percentage of modal shift from road transport is relatively more constant, in contrast to the shift from inland water transport where the modal shift is more sensitive to the scenarios.

Table 5.14: Delta modal split in ton-km for medium scenario Central trajectory

| Medium | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base** | 77.41% | 0.02% | 22.56% | |
| **Scenario1** | -10.44% | -0.01% | -20.88% | 31.33% |
| **Scenario2** | -11.10% | -0.01% | -25.28% | 36.39% |
| **Scenario3** | -11.87% | -0.01% | -28.25% | 40.13% |
| **Scenario4** | -12.65% | -0.01% | -30.07% | 42.73% |
| **Scenario5** | -7.75% | -0.01% | -7.34% | 15.10% |
| **Scenario6** | -8.04% | -0.01% | -12.55% | 20.59% |
| **Scenario7** | -8.34% | -0.01% | -18.13% | 26.48% |
| **Scenario8** | -8.81% | -0.01% | -22.91% | 31.73% |
| **Scenario9** | -6.19% | -0.01% | 0.80% | 5.40% |
| **Scenario10** | -6.55% | -0.01% | -1.42% | 7.98% |
| **Scenario11** | -6.83% | -0.01% | -4.90% | 11.74% |
| **Scenario12** | -7.01% | -0.01% | -9.74% | 16.77% |

The total amount of revenue made from the three transport modes are displayed in the table below (for the year 2016) (Schroten & ’t Hoen, 2016). The table includes the revenues made from passenger transport/vehicles and transport for other product groups (which are not considered in this research).

Table 5.15: Tax revenues in Belgium (Schroten & ‘t Hoen, 2016).

| Transport mode | Tax | Revenue (in €million) |
|---|---|---|
| **Road** | | |
| | Fuel tax | 4730 |
| | Vehicle ownership tax | 1478 |
| | Insurance tax | 894 |
| | Time based road charges (replaced in 2016) | 593 |
| | Toll specific parts (lieskenshoektunnel) | 26 |
| **Rail** | | |
| | Network statement | 643 |
| **IWT** | | |
| | Port charges | 13.14 |
| | Fairway dues | 4.9 |
| | Dues for locks and bridges | 0.89 |
| | Water pollution charges | 1.47 |

A large decrease in transport via IWT will have an impact on the amount of revenue made from IWT. However, the sum of revenue is low in comparison to road transport. Therefore, the decrease in revenue from IWT is noted, however a potential decrease in tax revenue from road transport can be significantly higher due to the taxes on vehicle ownership, fuel duties and time-based road charges.

In short, the qualitative score for toll and taxation revenues from a government and societal perspective, a reduction in market share for the transport modes road, rail and IWT is worse for the amount of revenue collected. The higher the market share for these three transport modes, the more revenue is expected.
The base case has been scored neutral (0). The score for the scenarios must be put in perspective.

The transport volume of NST2, 7 and 8 products between the observed zones is only partial to the total sum of transport in Flanders (and Belgium). Furthermore, the data does not contain transito transport (transport that has no origin or destination in Flanders). Therefore, the share of transport observed in the scope in this research is only a margin of the total sum of transport that is subject to toll and taxes. This can be demonstrated by the total volume of transport in 2010, which is 271.4 million tons for all product categories between the observed OD pairs. And the fraction of the product groups 2, 7 and 8 was 53.8 million tons in 2010.

Although the share of observed transport products is a segment of the total transport volume, reductions are expected to affect the revenue of tolls and taxes slightly. Therefore, the scenarios with a share in ton-kms for pipeline transport over 25% will be scored negative (-), while other shares below 25% will be scored neutral.

Table 5.16: Qualitative scores tolls and tax revenue Central trajectory.

| **Qualitative score** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Base case** | 0 | 0 | 0 |
| **Scenario1** | - | - | - |
| **Scenario2** | - | - | - |
| **Scenario3** | - | - | - |
| **Scenario4** | - | - | - |
| **Scenario5** | 0 | 0 | 0 |
| **Scenario6** | 0 | 0 | 0 |
| **Scenario7** | 0 | 0 | - |
| **Scenario8** | - | - | - |
| **Scenario9** | 0 | 0 | 0 |
| **Scenario10** | 0 | 0 | 0 |
| **Scenario11** | 0 | 0 | 0 |
| **Scenario12** | 0 | 0 | 0 |

#### *Transit time benefits*

The transit time benefits can be a factor in infrastructure appraisals, as the gained time by transit users can be expressed in monetary values. In this research the transit time benefits are expressed in a qualitative score, where again as in the effect of tolls and taxations revenue the modal split plays an important role. Transit times for all transport modes could decrease in case a modal shift towards the project alternative takes place. However, as this research' scope includes three specific product groups, this is only a portion of the total amount transport that is taking place in the observed region of this research. This can be demonstrated by the total volume of transport in 2010, which is 271.4 million tons for all product categories. And the fraction of the product groups 2, 7 and 8 was 53.8 million tons in 2010. Furthermore, the data acquired only has data on freight transport of the observed zones, meaning transito freight transport is not included as well as passenger transport. So, a shift in ton-kms from road transport to pipeline transport has a smaller impact than the number shows. Therefore, the qualitative score for every scenario will be neutral.

### 5.3.5 Results SCBA

The SCBA included the external effects of transport and monetized these effects. Apart for the external effects, the changes in revenues of toll and tax and transit time benefits were included in a qualitative way.

The project alternative indicates that reductions in external effects can be achieved and therefore positive NPVs are the results in the SCBA. Large reductions in external effects from transport are the

reductions of air pollution, safety costs, climate change costs and congestion costs.
The mode choice model from chapter 4 assigns the transport shares per OD pair to the available transport modes. When significant shares are assigned to transport modes with more favourable external cost factors per ton-km, reductions in costs for society can be achieved resulting in positive NPVs. Pipeline transport features more favourable external cost factors compared to the other transport modes in this research, contributing to the reduced external costs of transport. Next to the modelled autonomous sustainable development of existing transport modes.

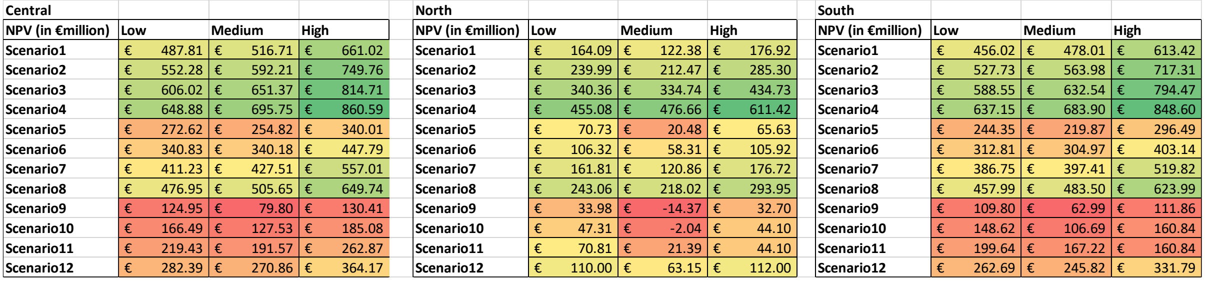
Table 5.17: SCBA results Central trajectory.

| | | | | |
|---|---|---|---|---|
| **Central trajectory** | | | | |
| **Growth volume scenario: low** | | | | |
| **Discount rate: 4.5%** | | | | |
| **NPV (in million euro)** | | | | |
| **Change in external effects** | **Scenario 5** | **Scenario 6** | **Scenario 7** | **Scenario 8** |
| Air pollution | € 111.0 | € 148.9 | € 188.1 | € 223.7 |
| Climate change costs | € 34.4 | € 43.5 | € 52.8 | € 61.5 |
| Congestion costs | € 37.5 | € 42.9 | € 48.5 | € 54.0 |
| Noise costs | € 19.1 | € 21.9 | € 24.7 | € 27.6 |
| Safety | € 61.5 | € 71.3 | € 81.4 | € 91.3 |
| Loss of habitat costs | € 9.1 | € 12.4 | € 15.7 | € 18.8 |
| **NPV SCBA** | € 272.6 | € 340.8 | € 411.2 | € 477.0 |
| Change in transit time bene | 0 | 0 | 0 | 0 |
| Change in toll and tax rever | 0 | 0 | 0 | - |

Table 5.17 shows the SCBA results in the utility function scenario 5 to 8, which were concluded to be the most realistic based on the conclusions from section 5.2. For these utility functions the variation in the NPVs is noticeable. This can be explained by the assigned share of pipeline transport, in scenario 5 the share is little over 15% of the total ton-km, while in scenario 8 the share of the pipeline is over 29% of the total ton-km. Accompanied with more favourable external cost factors this leads to more considerable higher NPVs.

The tables below provide a NPV overview of all the three considered trajectories, volume growth scenarios and utility function scenarios. From these NPVs can be concluded that the Central trajectory (table on the left) has the highest NPVs across all scenarios and trajectories. The South trajectory (right table) is close to the Central trajectory, while the North trajectory has considerably lower NPVs.

Table 5.18: NPVs of all trajectories and scenarios.



| **Central** | | | |
|---|---|---|---|
| **NPV (in €million)** | **Low** | **Medium** | **High** |
| **Scenario1** | € 487.81 | € 516.71 | € 661.02 |
| **Scenario2** | € 552.28 | € 592.21 | € 749.76 |
| **Scenario3** | € 606.02 | € 651.37 | € 814.71 |
| **Scenario4** | € 648.88 | € 695.75 | € 860.59 |
| **Scenario5** | € 272.62 | € 254.82 | € 340.01 |
| **Scenario6** | € 340.83 | € 340.18 | € 447.79 |
| **Scenario7** | € 411.23 | € 427.51 | € 557.01 |
| **Scenario8** | € 476.95 | € 505.65 | € 649.74 |
| **Scenario9** | € 124.95 | € 79.80 | € 130.41 |
| **Scenario10** | € 166.49 | € 127.53 | € 185.08 |
| **Scenario11** | € 219.43 | € 191.57 | € 262.87 |
| **Scenario12** | € 282.39 | € 270.86 | € 364.17 |

| **North** | | | |
|---|---|---|---|
| **NPV (in €million)** | **Low** | **Medium** | **High** |
| **Scenario1** | € 164.09 | € 122.38 | € 176.92 |
| **Scenario2** | € 239.99 | € 212.47 | € 285.30 |
| **Scenario3** | € 340.36 | € 334.74 | € 434.73 |
| **Scenario4** | € 455.08 | € 476.66 | € 611.42 |
| **Scenario5** | € 70.73 | € 20.48 | € 65.63 |
| **Scenario6** | € 106.32 | € 58.31 | € 105.92 |
| **Scenario7** | € 161.81 | € 120.86 | € 176.72 |
| **Scenario8** | € 243.06 | € 218.02 | € 293.95 |
| **Scenario9** | € 33.98 | € -14.37 | € 32.70 |
| **Scenario10** | € 47.31 | € -2.04 | € 44.10 |
| **Scenario11** | € 70.81 | € 21.39 | € 44.10 |
| **Scenario12** | € 110.00 | € 63.15 | € 112.00 |

| **South** | | | |
|---|---|---|---|
| **NPV (in €million)** | **Low** | **Medium** | **High** |
| **Scenario1** | € 456.02 | € 478.01 | € 613.42 |
| **Scenario2** | € 527.73 | € 563.98 | € 717.31 |
| **Scenario3** | € 588.55 | € 632.54 | € 794.47 |
| **Scenario4** | € 637.15 | € 683.90 | € 848.60 |
| **Scenario5** | € 244.35 | € 219.87 | € 296.49 |
| **Scenario6** | € 312.81 | € 304.97 | € 403.14 |
| **Scenario7** | € 386.75 | € 397.41 | € 519.82 |
| **Scenario8** | € 457.99 | € 483.50 | € 623.99 |
| **Scenario9** | € 109.80 | € 62.99 | € 111.86 |
| **Scenario10** | € 148.62 | € 106.69 | € 160.84 |
| **Scenario11** | € 199.64 | € 167.22 | € 160.84 |
| **Scenario12** | € 262.69 | € 245.82 | € 331.79 |

At last, the construction of pipeline infrastructure will have a considerable impact on various social aspects. The effects are monetized, but it should be noted that the construction of pipeline infrastructure affects nature, agricultural land, can lead to dispossession of properties to get right of way, the change of risk contours for local residents etc. This highlights the trade-off between lowering externalities for society and the effects of the constructed infrastructure on local residents and stakeholders.

## 5.4 Sensitivity analysis

Sensitivity analyses are conducted to investigate the (robustness of the) results and what effects the sensitivity scenarios have on the outcome of the evaluation methods. The sensitivity analyses that will be conducted are:

- Change in the dispersion factor of pipeline transport in the modal split model.
- Change in the discount rate.
- Completion date of the project alternative

These sensitivity analyses will be conducted, and the results are discussed in the following section. Please refer to Appendix I for all tables and calculations.

### 5.4.1 Dispersion factor

The dispersion factor 'µ' is part of the multinomial logit formula (see formula (5.15)) and the modal split model. The dispersion factor is calibrated for the three transport modes with OD data, for pipeline transport the dispersion could not be calibrated, but was assumed at the value -0.090.

$$\Pr(m) = \frac{\exp\,(V_m^{\mu})}{\sum_{n=1}^{N} \exp\,(V_n^{\mu})} \qquad (5.15)$$

The dispersion factor is calibrated for the three transport modes with OD data, for pipeline transport the dispersion could not be calibrated, but was assumed at the value -0.090. Therefore, a sensitivity analysis is conducted. In this sensitivity analysis the value will be increased with and decreased with 25% to see what effects this has on the outcome of both the SCBA and FCBA. The dispersion factor will be adjusted to -0.113 and -0.068.

Table 5.19: Share in ton-km% with µ +25% Central trajectory.

| **Low** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 44.12% | 0.07% | 54.48% | 1.34% |
| **Scenario2** | 43.83% | 0.06% | 54.09% | 2.01% |
| **Scenario3** | 43.45% | 0.06% | 53.35% | 3.13% |
| **Scenario4** | 43.04% | 0.06% | 51.96% | 4.94% |
| **Scenario5** | 44.54% | 0.07% | 54.83% | 0.56% |
| **Scenario6** | 44.44% | 0.07% | 54.76% | 0.73% |
| **Scenario7** | 44.30% | 0.07% | 54.62% | 1.01% |
| **Scenario8** | 44.11% | 0.07% | 54.35% | 1.47% |
| **Scenario9** | 44.67% | 0.07% | 54.90% | 0.36% |
| **Scenario10** | 44.63% | 0.07% | 54.89% | 0.42% |
| **Scenario11** | 44.57% | 0.07% | 54.86% | 0.51% |
| **Scenario12** | 44.48% | 0.07% | 54.81% | 0.64% |

| **Medium** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 43.96% | 0.04% | 54.96% | 1.04% |
| **Scenario2** | 43.69% | 0.04% | 54.68% | 1.59% |
| **Scenario3** | 43.31% | 0.04% | 54.09% | 2.57% |
| **Scenario4** | 42.87% | 0.04% | 52.84% | 4.24% |
| **Scenario5** | 44.30% | 0.04% | 55.18% | 0.48% |
| **Scenario6** | 44.21% | 0.04% | 55.14% | 0.60% |
| **Scenario7** | 44.09% | 0.04% | 55.06% | 0.81% |
| **Scenario8** | 43.92% | 0.04% | 54.88% | 1.17% |
| **Scenario9** | 44.41% | 0.04% | 55.22% | 0.33% |
| **Scenario10** | 44.37% | 0.04% | 55.21% | 0.38% |
| **Scenario11** | 44.31% | 0.04% | 55.20% | 0.45% |
| **Scenario12** | 44.23% | 0.04% | 55.17% | 0.56% |

| **High** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 43.72% | 0.02% | 55.42% | 0.83% |
| **Scenario2** | 43.47% | 0.02% | 55.23% | 1.28% |
| **Scenario3** | 43.08% | 0.02% | 54.79% | 2.11% |
| **Scenario4** | 42.62% | 0.02% | 53.73% | 3.62% |
| **Scenario5** | 43.99% | 0.03% | 55.55% | 0.43% |
| **Scenario6** | 43.92% | 0.03% | 55.53% | 0.53% |
| **Scenario7** | 43.81% | 0.03% | 55.48% | 0.68% |
| **Scenario8** | 43.65% | 0.02% | 55.37% | 0.95% |
| **Scenario9** | 44.08% | 0.03% | 55.57% | 0.32% |
| **Scenario10** | 44.05% | 0.03% | 55.57% | 0.36% |
| **Scenario11** | 44.00% | 0.03% | 55.56% | 0.41% |
| **Scenario12** | 43.92% | 0.03% | 55.55% | 0.51% |

The table above describes the ton-km% per mode for the Central trajectory when the dispersion factor is increased with 25% (µ=-0.113). The share of the pipeline diminishes compared to the assumed value of -0.090. Table 5.20 describes the ton-km% when the dispersion factor is reduced with 25% (µ=-0.068). With this adjustment the share of pipeline transport doubles or even triples in some scenarios.

Table 5.20: Share in ton-km% with µ -25% Central trajectory.

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 22.35% | 0.05% | 12.74% | 64.85% |
| **Scenario2** | 21.61% | 0.05% | 11.87% | 66.46% |
| **Scenario3** | 20.96% | 0.05% | 11.24% | 67.74% |
| **Scenario4** | 20.37% | 0.05% | 10.79% | 68.79% |
| **Scenario5** | 26.67% | 0.05% | 16.60% | 56.68% |
| **Scenario6** | 25.80% | 0.05% | 15.32% | 58.83% |
| **Scenario7** | 24.91% | 0.05% | 14.11% | 60.93% |
| **Scenario8** | 24.06% | 0.05% | 13.11% | 62.78% |
| **Scenario9** | 30.70% | 0.05% | 19.73% | 49.52% |
| **Scenario10** | 30.06% | 0.05% | 18.86% | 51.02% |
| **Scenario11** | 29.35% | 0.05% | 17.84% | 52.75% |
| **Scenario12** | 28.56% | 0.05% | 16.68% | 54.71% |

| Medium | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 21.77% | 0.03% | 11.59% | 66.60% |
| **Scenario2** | 21.06% | 0.03% | 10.81% | 68.09% |
| **Scenario3** | 20.45% | 0.03% | 10.29% | 69.22% |
| **Scenario4** | 19.90% | 0.03% | 9.93% | 70.14% |
| **Scenario5** | 26.28% | 0.03% | 15.56% | 58.13% |
| **Scenario6** | 25.33% | 0.03% | 14.21% | 60.43% |
| **Scenario7** | 24.39% | 0.03% | 12.96% | 62.62% |
| **Scenario8** | 23.52% | 0.03% | 12.00% | 64.45% |
| **Scenario9** | 30.51% | 0.03% | 18.54% | 50.91% |
| **Scenario10** | 29.88% | 0.03% | 17.82% | 52.26% |
| **Scenario11** | 29.17% | 0.03% | 16.86% | 53.94% |
| **Scenario12** | 28.34% | 0.03% | 15.67% | 55.95% |

| High | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 21.19% | 0.02% | 10.58% | 68.21% |
| **Scenario2** | 20.51% | 0.02% | 9.91% | 69.55% |
| **Scenario3** | 19.95% | 0.02% | 9.49% | 70.54% |
| **Scenario4** | 19.45% | 0.02% | 9.20% | 71.33% |
| **Scenario5** | 25.89% | 0.02% | 14.68% | 59.40% |
| **Scenario6** | 24.86% | 0.02% | 13.22% | 61.90% |
| **Scenario7** | 23.84% | 0.02% | 11.93% | 64.21% |
| **Scenario8** | 22.94% | 0.02% | 11.02% | 66.01% |
| **Scenario9** | 30.30% | 0.02% | 17.59% | 52.08% |
| **Scenario10** | 29.69% | 0.02% | 17.00% | 53.29% |
| **Scenario11** | 28.97% | 0.02% | 16.07% | 54.94% |
| **Scenario12** | 28.09% | 0.02% | 14.83% | 57.05% |

The share in terms of ton-km determines the results of the SCBA and FCBA for the majority. The large variations in ton-km cause that the results to be far apart.

In the SCBA, the +25% analysis indicates only some significant reduction in external effects in scenario 4. While in the -25% the external effects are reduced by large figures, as can be expected based on the share of ton-km and the lower external costs factor of pipeline transport.

Table 5.21 (left): NPV external effects µ +25% Central trajectory.
Table 5.22 (right): NPV external effects µ -25% Central trajectory.

| NPV (in €million) | Low | Medium | High |
|---|---|---|---|
| **Scenario1** | € 35.77 | € -13.25 | € 32.99 |
| **Scenario2** | € 49.30 | € -0.45 | € 45.07 |
| **Scenario3** | € 70.42 | € 20.77 | € 66.43 |
| **Scenario4** | € 102.56 | € 54.92 | € 102.59 |
| **Scenario5** | € 19.17 | € -27.25 | € 21.13 |
| **Scenario6** | € 22.86 | € -24.09 | € 23.96 |
| **Scenario7** | € 28.75 | € -18.95 | € 28.54 |
| **Scenario8** | € 38.05 | € -10.58 | € 36.09 |
| **Scenario9** | € 14.50 | € -31.07 | € 17.77 |
| **Scenario10** | € 15.83 | € -29.89 | € 18.91 |
| **Scenario11** | € 17.82 | € -28.14 | € 20.54 |
| **Scenario12** | € 20.88 | € -25.39 | € 23.23 |

| NPV (in €million) | Low | Medium | High |
|---|---|---|---|
| **Scenario1** | € 1,045 | € 1,136 | € 1,361 |
| **Scenario2** | € 1,069 | € 1,162 | € 1,388 |
| **Scenario3** | € 1,090 | € 1,182 | € 1,409 |
| **Scenario4** | € 1,107 | € 1,199 | € 1,427 |
| **Scenario5** | € 916 | € 989 | € 1,189 |
| **Scenario6** | € 948 | € 1,025 | € 1,233 |
| **Scenario7** | € 978 | € 1,061 | € 1,275 |
| **Scenario8** | € 1,006 | € 1,092 | € 1,310 |
| **Scenario9** | € 799 | € 858 | € 1,039 |
| **Scenario10** | € 823 | € 882 | € 1,063 |
| **Scenario11** | € 849 | € 910 | € 1,094 |
| **Scenario12** | € 878 | € 942 | € 1,132 |

The FCBA will have the same NPV figures, as the operational costs and tariffs (revenue) are set equal. Therefore, only the difference in tariffs will be highlighted in the sensitivity analysis.

Table 5.23 (left): Tariffs µ +25% Central trajectory.
Table 5.24 (right): Tariffs µ -25% Central trajectory.

| Central | Low | Medium | High |
|---|---|---|---|
| **Scenario1** | € 1.765 | € 2.288 | € 2.755 |
| **Scenario2** | € 1.164 | € 1.485 | € 1.799 |
| **Scenario3** | € 0.745 | € 0.916 | € 1.084 |
| **Scenario4** | € 0.472 | € 0.552 | € 0.630 |
| **Scenario5** | € 4.172 | € 4.877 | € 5.196 |
| **Scenario6** | € 3.219 | € 3.887 | € 4.257 |
| **Scenario7** | € 2.341 | € 2.918 | € 3.319 |
| **Scenario8** | € 1.607 | € 2.042 | € 2.406 |
| **Scenario9** | € 6.360 | € 6.836 | € 6.888 |
| **Scenario10** | € 5.499 | € 6.033 | € 6.157 |
| **Scenario11** | € 4.567 | € 5.139 | € 5.343 |
| **Scenario12** | € 3.602 | € 4.145 | € 4.366 |

| Central | Low | Medium | High |
|---|---|---|---|
| **Scenario1** | € 0.044 | € 0.044 | € 0.042 |
| **Scenario2** | € 0.044 | € 0.043 | € 0.041 |
| **Scenario3** | € 0.043 | € 0.042 | € 0.041 |
| **Scenario4** | € 0.042 | € 0.042 | € 0.040 |
| **Scenario5** | € 0.050 | € 0.049 | € 0.047 |
| **Scenario6** | € 0.048 | € 0.047 | € 0.045 |
| **Scenario7** | € 0.047 | € 0.046 | € 0.044 |
| **Scenario8** | € 0.046 | € 0.045 | € 0.043 |
| **Scenario9** | € 0.056 | € 0.055 | € 0.052 |
| **Scenario10** | € 0.054 | € 0.054 | € 0.051 |
| **Scenario11** | € 0.053 | € 0.052 | € 0.050 |
| **Scenario12** | € 0.051 | € 0.051 | € 0.049 |

The tariffs for transport rise greatly in table 5.23, due to the dispersion factor increase there is very little transport assigned to the pipeline compared to the regular scenario (or reduced dispersion factor in table 5.24). Therefore, the operational costs have to divided by a smaller volume and that is responsible for the rise in tariffs. In table 5.24 the tariffs for the reduced dispersion factor are shown.

Here the tariffs are decreased much below the tariff mentioned in the feasibility study from ARG (1999) of €0.109 per ton-km.

The modal split model is sensitive to the dispersion factor, as adjustments of 25% in the dispersion factor influence the mode choice considerably and therefore the outcomes of the SCBA and FCBA (or pipeline transport tariffs). In the case of the increased dispersion factor, the reduction on external effects is low or even negative (so an increase in external effects).
When the dispersion factor is decreased, the pipeline is made more attractive as a transport mode, this is clearly visible in the tables in this section. The tariffs for pipeline transport drop significantly below the transport tariff found in a feasibility study. This is expected behaviour of the results as the mode choice and outcomes of the evaluation methods move in the same direction.

### 5.4.2 Discount rate

In this sensitivity analysis the discount rate is reduced. In section 3.1.2 the discount rate was determined to be 4.5%, where 3% is consisting of the expected return on investments for a diversified portfolio of investments. And 1.5% consists of a risk-premium for the investment in an infrastructural project.
In this sensitivity analysis the discount rate is reduced to 3%. The results of this action will be reviewed for the SCBA and FCBA.

The NPV of FCBA becomes a bit more negative. The reason for this behavior is that the investment costs in the first 5 years of the FCBA are against higher present values due to the lower discount rate.

Table 5.25: NPV FCBA discount rate 3%.

| **NPV** | **Low** | **Med** | **High** |
|---|---|---|---|
| **North** | € -195.19 | € -225.44 | € -255.70 |
| **Central** | € -130.73 | € -149.87 | € -169.00 |
| **South** | € -139.51 | € -159.61 | € -179.71 |

Table 5.26: NPV FCBA discount rate 4.5%.

| **NPV** | **Low** | **Med** | **High** |
|---|---|---|---|
| **North** | € -189.8 | € -219.3 | € -248.7 |
| **Central** | € -127.1 | € -145.7 | € -164.4 |
| **South** | € -135.7 | € -155.2 | € -174.8 |

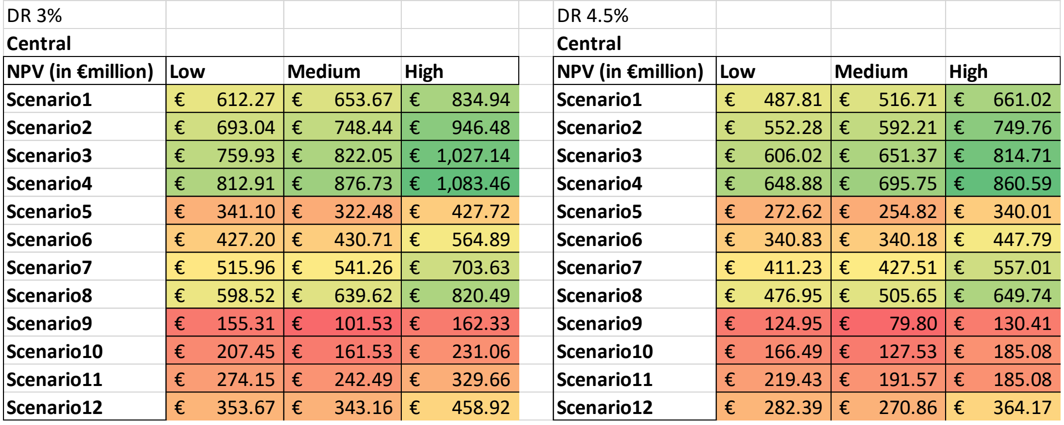
Furthermore, tariffs for pipeline transport reduce when the discount rate is lowered to 3%. This can be explained as a lower discount rate increases the projected revenue streams.

Table 5.27: Delta tariffs for pipeline transport Central trajectory with discount rate at 3% with 4.5%.

| Central | Low | Medium | High |
|---|---|---|---|
| **Scenario1** | € -0.01 | € -0.01 | € -0.01 |
| **Scenario2** | € -0.01 | € -0.01 | € -0.01 |
| **Scenario3** | € -0.01 | € -0.01 | € -0.01 |
| **Scenario4** | € -0.01 | € -0.01 | € -0.01 |
| **Scenario5** | € -0.02 | € -0.02 | € -0.02 |
| **Scenario6** | € -0.02 | € -0.02 | € -0.01 |
| **Scenario7** | € -0.01 | € -0.01 | € -0.01 |
| **Scenario8** | € -0.01 | € -0.01 | € -0.01 |
| **Scenario9** | € -0.05 | € -0.06 | € -0.07 |
| **Scenario10** | € -0.04 | € -0.04 | € -0.04 |
| **Scenario11** | € -0.03 | € -0.03 | € -0.03 |
| **Scenario12** | € -0.07 | € -0.07 | € -0.07 |

In the case of the SCBA, the reduction in external effects become larger due to the lower discount rate. This lower discount rate makes this project alternative more socially beneficial.

Table 5.28: NPV in external effects base case and project alternative Central trajectory (discount rate 3% and 4.5%).



| DR 3% | | | |
|---|---|---|---|
| **Central** | | | |
| **NPV (in €million)** | **Low** | **Medium** | **High** |
| **Scenario1** | € 612.27 | € 653.67 | € 834.94 |
| **Scenario2** | € 693.04 | € 748.44 | € 946.48 |
| **Scenario3** | € 759.93 | € 822.05 | € 1,027.14 |
| **Scenario4** | € 812.91 | € 876.73 | € 1,083.46 |
| **Scenario5** | € 341.10 | € 322.48 | € 427.72 |
| **Scenario6** | € 427.20 | € 430.71 | € 564.89 |
| **Scenario7** | € 515.96 | € 541.26 | € 703.63 |
| **Scenario8** | € 598.52 | € 639.62 | € 820.49 |
| **Scenario9** | € 155.31 | € 101.53 | € 162.33 |
| **Scenario10** | € 207.45 | € 161.53 | € 231.06 |
| **Scenario11** | € 274.15 | € 242.49 | € 329.66 |
| **Scenario12** | € 353.67 | € 343.16 | € 458.92 |

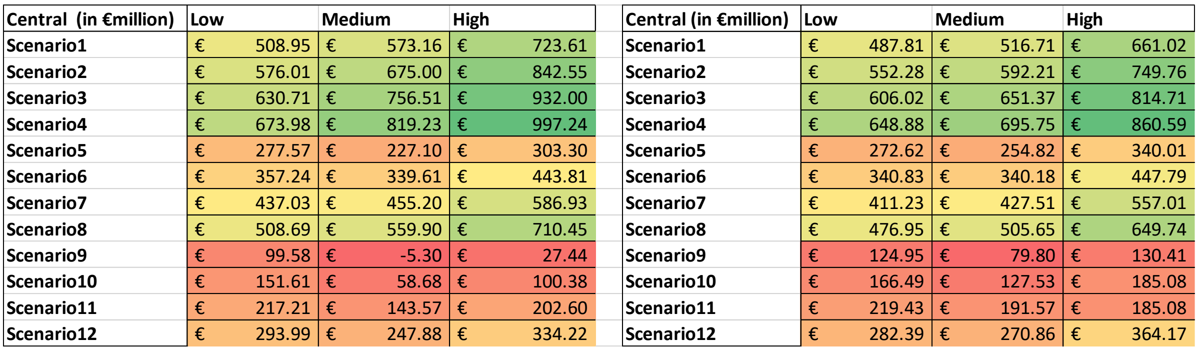
| DR 4.5% | | | |
|---|---|---|---|
| **Central** | | | |
| **NPV (in €million)** | **Low** | **Medium** | **High** |
| **Scenario1** | € 487.81 | € 516.71 | € 661.02 |
| **Scenario2** | € 552.28 | € 592.21 | € 749.76 |
| **Scenario3** | € 606.02 | € 651.37 | € 814.71 |
| **Scenario4** | € 648.88 | € 695.75 | € 860.59 |
| **Scenario5** | € 272.62 | € 254.82 | € 340.01 |
| **Scenario6** | € 340.83 | € 340.18 | € 447.79 |
| **Scenario7** | € 411.23 | € 427.51 | € 557.01 |
| **Scenario8** | € 476.95 | € 505.65 | € 649.74 |
| **Scenario9** | € 124.95 | € 79.80 | € 130.41 |
| **Scenario10** | € 166.49 | € 127.53 | € 185.08 |
| **Scenario11** | € 219.43 | € 191.57 | € 185.08 |
| **Scenario12** | € 282.39 | € 270.86 | € 364.17 |

### 5.4.3 Completion date of project alternative

In this sensitivity analysis the completion of the project alternative is reduced to one year. It is possible to construct over a kilometer of pipeline per day in certain circumstances.

By decreasing the completion date of the project alternative a positive effect for the SCBA is achieved. In the SCBA the reductions of external effects are increased, thus the NPV has become more positive.

Table 5.29: The NPV in external effects, left for completion period 1 year and right completion period 5 years for the Central trajectory.



| **Central (in €million)** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Scenario1** | € 508.95 | € 573.16 | € 723.61 |
| **Scenario2** | € 576.01 | € 675.00 | € 842.55 |
| **Scenario3** | € 630.71 | € 756.51 | € 932.00 |
| **Scenario4** | € 673.98 | € 819.23 | € 997.24 |
| **Scenario5** | € 277.57 | € 227.10 | € 303.30 |
| **Scenario6** | € 357.24 | € 339.61 | € 443.81 |
| **Scenario7** | € 437.03 | € 455.20 | € 586.93 |
| **Scenario8** | € 508.69 | € 559.90 | € 710.45 |
| **Scenario9** | € 99.58 | € -5.30 | € 27.44 |
| **Scenario10** | € 151.61 | € 58.68 | € 100.38 |
| **Scenario11** | € 217.21 | € 143.57 | € 202.60 |
| **Scenario12** | € 293.99 | € 247.88 | € 334.22 |

| **Central (in €million)** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Scenario1** | € 487.81 | € 516.71 | € 661.02 |
| **Scenario2** | € 552.28 | € 592.21 | € 749.76 |
| **Scenario3** | € 606.02 | € 651.37 | € 814.71 |
| **Scenario4** | € 648.88 | € 695.75 | € 860.59 |
| **Scenario5** | € 272.62 | € 254.82 | € 340.01 |
| **Scenario6** | € 340.83 | € 340.18 | € 447.79 |
| **Scenario7** | € 411.23 | € 427.51 | € 557.01 |
| **Scenario8** | € 476.95 | € 505.65 | € 649.74 |
| **Scenario9** | € 124.95 | € 79.80 | € 130.41 |
| **Scenario10** | € 166.49 | € 127.53 | € 185.08 |
| **Scenario11** | € 219.43 | € 191.57 | € 185.08 |
| **Scenario12** | € 282.39 | € 270.86 | € 364.17 |

In the FCBA the NPV of the different scenarios is moved to zero, as the economic life cycle of the pipeline is set at 30 years and by adjusting the completion date to 1 year the full depreciation is achieved over the period 2026 to 2055.

The effects on the estimated transport tariffs are affected by increases for the low and medium growth scenarios. For the North and South trajectory, a minor decrease in tariffs is seen in the high growth scenario. The Central trajectory estimates increases in tariffs for all growth scenarios, except for a single utility function scenario in the high growth scenario.

From a societal perspective a reduction in completion date of the transport alternative would offer more societal value, as the time period where external effect reductions can be achieved with modal shift are increased. From the financial perspective the NPV will be zero for all trajectories and growth scenarios as the complete economical life span is covered (30 years). This implies the BCR ratio is also 1 for all trajectories and scenarios. For the tariffs increases are seen, the reason for this is that investment costs are compressed in one year, while with the construction period of 5 years the NPV of the investments costs was lower due to the discount rate. The reduction of the construction date to one year is challenging, however a reduction of sometime will offer more societal benefit.

# 6. Conclusions

In this concluding chapter the main findings and conclusions are discussed. Section 6.1 discusses the main conclusion and answers the research questions. Section 6.2 discusses the recommendations for further research. At last, section 6.3 contains a reflection on the research process.

## 6.1 Conclusions

The aim of this research was to perform an identification and evaluation of potential pipeline transport for liquid bulk transport in the Antwerp – Ruhr trajectory. From a societal and financial perspective, therefore including socio-economic and transport related effects.

The main research question this thesis addressed was: *"To what extent will a new pipeline system for liquid bulk transport be socially and financially beneficial in the Antwerp - Ruhr trajectory?*

Based on the results of the SCBA can be concluded that pipeline transport can offer considerable reductions in terms of external effects of transport, which is beneficial for society. The foremost reductions appear when the shift from IWT to pipeline transport takes place, this causes considerable reductions in climate change and air pollution costs. Furthermore, the shift from road transport to the pipeline comes with considerable reductions in estimated congestion costs and safety costs. Still, there is an important social trade-off between the gains in terms of the reductions in external effects of transport and the effect of the pipeline infrastructure on nature and people. New pipeline infrastructure can disrupt nature, affect the use of agricultural land and lead to dispossession of properties for acquiring right of way of the pipeline infrastructure. Furthermore, the FCBA shows multiple scenarios in which a competitive transport tariff can be offered to persuade a shift towards to pipeline transport.
However, there is uncertainty to what extent a modal shift to pipeline transport will take place. The followed approach to estimate a mode choice model with limited aggregate data and even missing data can be suitable for exploratory research, still the required assumptions and missing data make the results of the mode choice model prone to under or overestimation of the modal shift. This is illustrated by conducted sensitivity analysis, which indicates that changes to the uncalibrated dispersion factor for pipeline transport affects the outcome of the evaluation methods significantly. Therefore, the main conclusion is that pipeline transport is a potential alternative, however more information and data is required to conclude that the pipeline infrastructure is a cost-efficient option, which is also the foremost recommendation.

Hereafter the sub-questions for this thesis will be answered as well and build upon the conclusion of the research question.

- *SQ1: What transport alternatives and (i.e., technical) configurations are relevant in the geographical scope of the research?*

This research has identified that four modes of transport are capable of transporting liquid bulk transport in the geographical scope. These four modes are also currently operating in the geographical area. The hinterland of the Port of Antwerp offers favourable connections with the available infrastructure. Furthermore, demand and supply seem to be well situated along the available infrastructure.
In terms of transport alternatives to the current, a new set of pipelines is considered. The reconnaissance project has identified three trajectories, North, Central and South. The North trajectory can be deemed as the most advantageous in terms of land use, although this trajectory consumes the largest amount of space. The loss of space or right of way costs are the lowest for this trajectory as the trajectory runs mostly through agricultural land which has a lower land use value than inhabited areas, protected natural areas or water extraction areas.

The other two configurations of this project alternative are the Central and South trajectory, both these trajectories are similar in terms of loss of space.

- *SQ2: What are characteristics of the transport mode configurations and how can these be modelled?*

The characteristics of the relevant transport modes are determined by comparing the transport modes over logistic indicators. From literature research logistic performance indicators were qualitatively scored.

Table 6.1: Performance transport modes over logistic indicators.

| Mode | Range of product options | Capacity | Distance covered | Time | Service | Reliability | Accessibility | Transport cost per unit |
|---|---|---|---|---|---|---|---|---|
| **Truck** | Extensive | Low | Short to moderate | High | High | Moderate | High | High |
| **Pipeline** | Limited | (very) high | Long | Low | Medium | High | Low | Very low |
| **IWT** | Moderate | High | Moderate to long | Low | Low | Moderate | Moderate | Low |
| **Rail** | Extensive | Moderate | Moderate to long | Moderate | Low | High | Moderate | Low |

The analysis concludes that road transport is a transport mode with low fixed costs, as this transport can transport a versatile number of products, in relative low quantities, is flexible due to its infrastructure and can offer quick service due to its high operational speeds. This comes at the expense of high transport costs per unit.
For pipeline, inland water vessels and trains the logistic character is different. These modes require more specific and especially less densely constructed infrastructure as rails and rivers or canals. Furthermore, the operating speeds of these modes are lower, where inland water vessels and pipelines have a comparable operational speed. These three transport modes often operate over longer distances. The competitive advantage of these modes lies in the lower transport cost per unit (variable costs) together with the higher capacities of the modes. Where pipeline can offer the largest capacities and potentially around the clock service.

These logistic characteristics are modelled in a mode choice model by selecting a model that is capable of including the fixed costs and variable costs of transport modes.

$$V_{m,p,r} = 2\alpha_{m,p,r} FC_{p.m} + \beta_{m,r} D_m + \gamma_{m,r} TT_m \quad (6.1)$$

V = the (dis)utility of the total deterrence function
FC = fixed costs
D = distance
m = transport mode
r = region
p = product type (NST product category)
α = parameter for warehousing, loading, unloading per product type and transport mode
β = parameter for distance per transport mode
γ = parameter for travel time per transport mode

The model assumes fixed costs which are costs before any distance is covered, so these costs exist out of loading, unloading, warehousing etc. These fixed costs were based on the average shipment size applied of the NST product type. The variable costs are costs made when covering distance and travel time. This research has calibrated the mode choice model based on historic OD data from the

Flemish government for road, rail and inland water transport in the base case alternative. The calibration confirmed what the logistic indicator also implied, road transport is overall dominant on shorter distance origin and destination relations. On the longer distances the share of rail transport and inland water transport increased.

Next to the logistic characteristics of the transport modes, the mode choice model requires input for the distance and travel time between OD pairs, the expected growth of transport volume in the future and the development of costs for transport over the appraisal period.

The mode choice model calibrated the parameters of the historic OD data with the use of Microsoft Excel, and this resulted in the following metrics concerning accuracy in table 6.2.
Three models were tested where formula 6.1 corresponds to model 3 and was found the most extensive and most accurate model.

Table 6.2: Calibration results.

| | **NST2** | | | **NST7** | | | **NST8** | | |
|---|---|---|---|---|---|---|---|---|---|
| | **Model 1** | **Model 2** | **Model 3** | **Model 1** | **Model 2** | **Model 3** | **Model 1** | **Model 2** | **Model 3** |
| **Sum squared error (SSE)** | 15.87 | 7.65 | 5.13 | 14.00 | 7.15 | 6.39 | 38.34 | 19.82 | 17.43 |
| **Average error per OD pair** | 0.033 | 0.016 | 0.011 | 0.029 | 0.015 | 0.013 | 0.079 | 0.041 | 0.036 |
| **RMSE** | 0.181 | 0.126 | 0.103 | 0.170 | 0.122 | 0.115 | 0.281 | 0.202 | 0.190 |

- *SQ3: What is the current share per transport mode in the geographical scope?*

The current modal share is calculated based on the acquired data from the Flemish department of Mobility. The data was first prepared by removing all no-observed NUTS zones from the data.
The modal share between the observed OD pairs is dominated by road transport.

Table 6.3: Modal share in ton%.

| **Modal split observed data** | **NST2** | **NST7** | **NST8** |
|---|---|---|---|
| **Road** | 65.94% | 74.11% | 66.90% |
| **Rail** | 0.03% | 0.87% | 4.20% |
| **IWT** | 34.04% | 25.01% | 28.90% |

In terms of percentual errors, the mode choice model overestimates the share in transported tonnes for road transport across all product groups. Especially IWT is underestimated at the expense of road transport. This important to notice as in reality the share of IWT is larger than the model estimates.

Table 6.4: Percentual error of mode choice model.

| **% Error** | **NST2** | **NST7** | **NST8** |
|---|---|---|---|
| **Road** | 13.24% | 4.37% | 11.03% |
| **Rail** | -0.03% | -0.87% | -1.80% |
| **IWT** | -13.22% | -3.49% | -9.23% |

- *SQ4: What will be the effect on the share per transport mode after introducing pipeline as a transport alternative?*

For pipeline transport no historic OD data was acquired. Therefore, this research created multiple utility function scenarios based on the parameters of the three transport modes that could be calibrated using the historic OD data of the Flemish department of Mobility.
The scenarios for pipeline transport are based on the hypothesis that the fixed costs are higher compared to road, rail and inland water transport. As the pipeline is a transport mode that requires larger shipments, thus more costs are associated to storing, loading and unloading. The variable costs of pipeline transport, so the transport cost per unit is lower than the other modes according to the literature research in *SQ2*. So, based on these logistic indicators the deterrence functions of the

transport modes are visualized in figure 6.1, the vertical axis represents the fixed costs of a transport mode which include loading, unloading, warehousing, possible compression of products etc. And on the horizontal axis the function of the variable costs, costs made when transport is moving in time and distance costs.

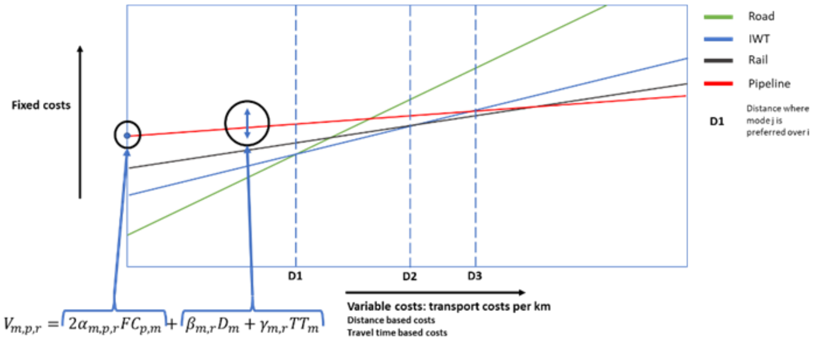


Figure 6.1: Conceptual deterrence function approach (based on (Rodrique, 2020)).

The approach is conducted with 12 utility function scenarios. The fixed costs parameter for pipeline transport is increased compared to the highest parameter of the calibrated transport modes. The variable costs are decreased compared to inland water transport, this results in the following scenarios in table 6.5

Table 6.5: Deterrence function approach pipeline transport.

| **Scenario** | **Fixed costs (α)** | **Variable costs (β,γ)** |
|---|---|---|
| **1** | +10% | -10% |
| **2** | +10% | -20% |
| **3** | +10% | -30% |
| **4** | +10% | -40% |
| **5** | +20% | -10% |
| **6** | +20% | -20% |
| **7** | +20% | -30% |
| **8** | +20% | -40% |
| **9** | +30% | -10% |
| **10** | +30% | -20% |
| **11** | +30% | -30% |
| **12** | +30% | -40% |

Applying the scenarios in the mode choice model resulted in the following modal shares for the different configurations of the project alternative.

Table 6.6: Estimated modal split North trajectory (in ton-km) (own creation).

| **Low** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 41.10% | 0.06% | 50.95% | 7.88% |
| **Scenario2** | 40.11% | 0.06% | 47.44% | 12.39% |
| **Scenario3** | 39.13% | 0.06% | 41.86% | 18.95% |
| **Scenario4** | 38.22% | 0.06% | 34.63% | 27.09% |
| **Scenario5** | 43.13% | 0.06% | 53.81% | 2.99% |
| **Scenario6** | 42.46% | 0.06% | 52.62% | 4.86% |
| **Scenario7** | 41.71% | 0.06% | 50.20% | 8.02% |
| **Scenario8** | 41.00% | 0.06% | 45.81% | 13.13% |
| **Scenario9** | 44.08% | 0.07% | 54.63% | 1.22% |
| **Scenario10** | 43.76% | 0.07% | 54.31% | 1.87% |
| **Scenario11** | 43.27% | 0.06% | 53.60% | 3.07% |
| **Scenario12** | 42.67% | 0.06% | 52.05% | 5.22% |

| **Medium** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 41.13% | 0.04% | 51.64% | 7.19% |
| **Scenario2** | 40.12% | 0.04% | 47.84% | 11.99% |
| **Scenario3** | 39.18% | 0.04% | 41.55% | 19.23% |
| **Scenario4** | 38.35% | 0.04% | 33.05% | 28.57% |
| **Scenario5** | 43.09% | 0.04% | 54.43% | 2.44% |
| **Scenario6** | 42.40% | 0.04% | 53.37% | 4.18% |
| **Scenario7** | 41.66% | 0.04% | 50.96% | 7.34% |
| **Scenario8** | 40.99% | 0.04% | 46.13% | 12.84% |
| **Scenario9** | 43.92% | 0.04% | 55.06% | 0.98% |
| **Scenario10** | 43.63% | 0.04% | 54.83% | 1.50% |
| **Scenario11** | 43.15% | 0.04% | 54.28% | 2.53% |
| **Scenario12** | 42.54% | 0.04% | 52.89% | 4.53% |

| **High** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 41.10% | 0.02% | 52.36% | 6.51% |
| **Scenario2** | 40.12% | 0.02% | 48.24% | 11.61% |
| **Scenario3** | 39.23% | 0.02% | 41.28% | 19.46% |
| **Scenario4** | 38.50% | 0.02% | 31.46% | 30.01% |
| **Scenario5** | 42.95% | 0.02% | 55.03% | 2.00% |
| **Scenario6** | 42.25% | 0.02% | 54.13% | 3.59% |
| **Scenario7** | 41.52% | 0.02% | 51.77% | 6.69% |
| **Scenario8** | 40.91% | 0.02% | 46.53% | 12.53% |
| **Scenario9** | 43.67% | 0.03% | 55.48% | 0.82% |
| **Scenario10** | 43.42% | 0.02% | 55.33% | 1.23% |
| **Scenario11** | 42.94% | 0.02% | 54.92% | 2.11% |
| **Scenario12** | 42.30% | 0.02% | 53.75% | 3.93% |

Table 6.7: Estimated modal split Central trajectory (in ton-km) (own creation).

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 38.00% | 0.06% | 32.42% | 29.52% |
| **Scenario2** | 37.34% | 0.05% | 28.41% | 34.20% |
| **Scenario3** | 36.59% | 0.05% | 25.39% | 37.97% |
| **Scenario4** | 35.83% | 0.05% | 23.30% | 40.82% |
| **Scenario5** | 40.83% | 0.06% | 43.98% | 15.12% |
| **Scenario6** | 40.44% | 0.06% | 39.62% | 19.88% |
| **Scenario7** | 40.02% | 0.06% | 34.96% | 24.97% |
| **Scenario8** | 39.50% | 0.05% | 30.72% | 29.73% |
| **Scenario9** | 42.54% | 0.06% | 51.29% | 6.11% |
| **Scenario10** | 42.17% | 0.06% | 49.14% | 8.63% |
| **Scenario11** | 41.84% | 0.06% | 46.03% | 12.07% |
| **Scenario12** | 41.55% | 0.06% | 41.99% | 16.40% |

| Medium | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 38.15% | 0.04% | 30.48% | 31.33% |
| **Scenario2** | 37.50% | 0.04% | 26.08% | 36.39% |
| **Scenario3** | 36.72% | 0.04% | 23.11% | 40.13% |
| **Scenario4** | 35.95% | 0.03% | 21.29% | 42.73% |
| **Scenario5** | 40.85% | 0.04% | 44.02% | 15.10% |
| **Scenario6** | 40.55% | 0.04% | 38.81% | 20.59% |
| **Scenario7** | 40.25% | 0.04% | 33.23% | 26.48% |
| **Scenario8** | 39.79% | 0.04% | 28.45% | 31.73% |
| **Scenario9** | 42.40% | 0.04% | 52.16% | 5.40% |
| **Scenario10** | 42.04% | 0.04% | 49.94% | 7.98% |
| **Scenario11** | 41.76% | 0.04% | 46.46% | 11.74% |
| **Scenario12** | 41.58% | 0.04% | 41.62% | 16.77% |

| High | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 38.32% | 0.02% | 28.52% | 33.14% |
| **Scenario2** | 37.64% | 0.02% | 23.85% | 38.48% |
| **Scenario3** | 36.82% | 0.02% | 21.09% | 42.06% |
| **Scenario4** | 36.03% | 0.02% | 19.59% | 44.35% |
| **Scenario5** | 40.80% | 0.02% | 44.13% | 15.05% |
| **Scenario6** | 40.63% | 0.02% | 38.01% | 21.33% |
| **Scenario7** | 40.48% | 0.02% | 31.44% | 28.06% |
| **Scenario8** | 40.06% | 0.02% | 26.22% | 33.70% |
| **Scenario9** | 42.16% | 0.02% | 53.06% | 4.75% |
| **Scenario10** | 41.82% | 0.02% | 50.85% | 7.30% |
| **Scenario11** | 41.60% | 0.02% | 47.06% | 11.32% |
| **Scenario12** | 41.54% | 0.02% | 41.32% | 17.12% |

Table 6.8: Estimated modal split South trajectory (in ton-km) (own creation).

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 38.27% | 0.06% | 34.48% | 27.19% |
| **Scenario2** | 37.61% | 0.05% | 29.91% | 32.42% |
| **Scenario3** | 36.85% | 0.05% | 26.34% | 36.76% |
| **Scenario4** | 36.05% | 0.05% | 23.85% | 40.05% |
| **Scenario5** | 41.02% | 0.06% | 45.69% | 13.23% |
| **Scenario6** | 40.59% | 0.06% | 41.46% | 17.89% |
| **Scenario7** | 40.17% | 0.06% | 36.59% | 23.18% |
| **Scenario8** | 39.67% | 0.06% | 31.91% | 28.36% |
| **Scenario9** | 42.71% | 0.06% | 52.00% | 5.23% |
| **Scenario10** | 42.31% | 0.06% | 50.11% | 7.52% |
| **Scenario11** | 41.95% | 0.06% | 47.24% | 10.75% |
| **Scenario12** | 41.63% | 0.06% | 43.29% | 15.02% |

| Medium | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 38.40% | 0.04% | 32.86% | 28.70% |
| **Scenario2** | 37.77% | 0.04% | 27.68% | 34.52% |
| **Scenario3** | 36.99% | 0.04% | 24.00% | 38.97% |
| **Scenario4** | 36.17% | 0.03% | 21.75% | 42.05% |
| **Scenario5** | 41.00% | 0.04% | 46.00% | 12.96% |
| **Scenario6** | 40.66% | 0.04% | 41.02% | 18.28% |
| **Scenario7** | 40.37% | 0.04% | 35.16% | 24.44% |
| **Scenario8** | 39.95% | 0.04% | 29.76% | 30.25% |
| **Scenario9** | 42.57% | 0.04% | 52.85% | 4.54% |
| **Scenario10** | 42.17% | 0.04% | 50.96% | 6.83% |
| **Scenario11** | 41.85% | 0.04% | 47.85% | 10.27% |
| **Scenario12** | 41.62% | 0.04% | 43.20% | 15.14% |

| High | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 38.55% | 0.02% | 31.25% | 30.18% |
| **Scenario2** | 37.93% | 0.02% | 25.48% | 36.56% |
| **Scenario3** | 37.11% | 0.02% | 21.88% | 40.98% |
| **Scenario4** | 36.25% | 0.02% | 19.95% | 43.77% |
| **Scenario5** | 40.92% | 0.02% | 46.38% | 12.68% |
| **Scenario6** | 40.69% | 0.02% | 40.63% | 18.66% |
| **Scenario7** | 40.55% | 0.02% | 33.68% | 25.75% |
| **Scenario8** | 40.23% | 0.02% | 27.59% | 32.16% |
| **Scenario9** | 42.33% | 0.02% | 53.71% | 3.94% |
| **Scenario10** | 41.94% | 0.02% | 51.90% | 6.14% |
| **Scenario11** | 41.65% | 0.02% | 48.61% | 9.71% |
| **Scenario12** | 41.54% | 0.02% | 43.23% | 15.21% |

What can be concluded is that the North trajectory is less attractive from the transport perspective to assign volume to the pipeline. The Central and South trajectory, which are considerably shorter are assigned with significantly larger shares.

So, the mode choice is affected by the project alternative in two ways. First, the deterrence function scenarios for the pipeline demonstrate large variability in terms of assigned shares. Especially in scenario 1 to 4 the shares can be considered as high. The shares reduce as the fixed costs increase through scenario 5 to 12.
Second, the configuration of the project alternative largely affects the share of pipeline transport. The Central and South trajectory attract more transport volume as they are more attractive due to the shorter trajectory.
At last, the conclusion on the research question already mentioned that due to the lack of OD data for pipeline transport also the dispersion factor of the multinomial logit function had to be assumed. A sensitivity analysis indicated that variations in the dispersion factor have a large influence on the mode choice and therefore the results of both SCBA and FCBA (mainly transport tariffs). Again, the lack of OD data has caused to make an assumption on the dispersion factor. The confirmation of sensitivity to the dispersion factor is an important mark that is noted and indicates that the results of SCBA and FCBA should be interpreted with considering this uncertainty.

- *SQ5: What are the estimated social and financial effects of the project alternative?*

The SCBA and FCBA as evaluation methods were conducted to estimate the social and financial effects of the project alternative. In the SCBA the external effects of transport included: air pollution, climate change, congestion, noise, safety and loss of space costs. Furthermore, two effects the change in transit time benefits and the change in toll and taxation revenues were included qualitatively.
In the FCBA the project alternatives' investments costs are included, the construction costs and loss of space costs. And the operational costs, this includes maintenance, labour, services and energy/fuels.

The external effects were estimated with a cost factor for external effect and the estimated ton-km per transport mode derived from the mode choice model. Also, the required energy in the FCBA project alternative is calculated using the assigned ton-kms to pipeline transport.

The table below displays the results of the FCBA and SCBA for four utility function scenarios, which are deemed to be most realistic. To come to that conclusion this research estimated the transport tariffs for pipeline transport and compared the tariffs to a feasibility study from 1999 that is representative for the geographical scope and product groups. The four utility function scenarios 5 to 8 were balanced around the (competitive) transport tariff in the feasibility study. Furthermore, the table displays the Central trajectory in a low volume growth scenario.

Table 6.9: CBA results Central trajectory low growth scenario.

| **Central trajectory** | | | | |
|---|---|---|---|---|
| **Growth volume scenario: low** | | | | |
| **Discount rate: 4.5%** | | | | |
| **NPV (in million euro)** | | | | |
| **Project effects** | **Scenario 5** | **Scenario 6** | **Scenario 7** | **Scenario 8** |
| **Change in investment costs** | | | | |
| Construction costs | € -837.6 | € -837.6 | € -837.6 | € -837.6 |
| Loss of space costs | € -115.9 | € -115.9 | € -115.9 | € -115.9 |
| **Change in operational costs** | | | | |
| Energy | € -37.5 | € -48.3 | € -59.7 | € -70.4 |
| Personnel | € -127.0 | € -127.0 | € -127.0 | € -127.0 |
| Maintenance costs | € -347.9 | € -347.9 | € -347.9 | € -347.9 |
| Costs of service | € -127.0 | € -127.0 | € -127.0 | € -127.0 |
| Tonkm (million tonkm) | 19,969,864,057 | 25,829,793,380 | 31,906,419,621 | 37,443,128,612 |
| Volume (tons) | 126,090,643 | 154,148,254 | 183,009,466 | 209,691,900 |
| **Change in revenues** | € 1,465.8 | € 1,476.6 | € 1,487.9 | € 1,498.7 |
| **NPV FCBA** | € -127.1 | € -127.1 | € -127.1 | € -127.1 |
| **Change in external effects** | | | | |
| Air pollution | € 111.0 | € 148.9 | € 188.1 | € 223.7 |
| Climate change costs | € 34.4 | € 43.5 | € 52.8 | € 61.5 |
| Congestion costs | € 37.5 | € 42.9 | € 48.5 | € 54.0 |
| Noise costs | € 19.1 | € 21.9 | € 24.7 | € 27.6 |
| Safety | € 61.5 | € 71.3 | € 81.4 | € 91.3 |
| Loss of habitat costs | € 9.1 | € 12.4 | € 15.7 | € 18.8 |
| **NPV SCBA** | € 272.6 | € 340.8 | € 411.2 | € 477.0 |
| Change in transit time benefits | 0 | 0 | 0 | 0 |
| Change in toll and tax revenues | 0 | 0 | 0 | - |

The NPVs for the FCBA are all negative and equal. The reason for this is that due to a lack of information, the operational revenues are calculated to level the operational costs. So that the revenues are calculated based on a transport tariff without margins for the operator. This results in a negative NPV, where the negative NPV is the sum of the remaining depreciation of the pipeline infrastructure. Therefore, the NPV of the project alternative is always negative across all scenarios. See table 6.10 below.

Table 6.10: FCBA NPV for all trajectories and volume growth scenarios.

| **NPV** | **Low** | **Med** | **High** |
|---|---|---|---|
| **North** | € -189.8 | € -219.3 | € -248.7 |
| **Central** | € -127.1 | € -145.7 | € -164.4 |
| **South** | € -135.7 | € -155.2 | € -174.8 |

Contrary to the negative NPVs in the FCBA, the NPVs of the SCBA are positive in table 6.9. The SCBA displays that significant gains come from the reductions of air pollution, climate change and safety costs. A shift to pipeline transport, which emits less pollutants and GHGs, benefits society. Furthermore, the external costs factor attached to safety in road transport and a modal shift to pipeline transport provides considerable gains for society. It should be noted that these monetized gains come at the cost of land, dispossessions due to right of way rights and effects for local residents that will live nearby the pipeline infrastructure. The NPVs display a monetized figure, but the trade-off between these monetized gains and effects for local residents should be included in the eventual decision process of the Flemish government.

Overall, the variation in the NPVs of the SCBA are also large. The modal share of the transport modes declares this variation. Table 6.7 displays the modal share, where in scenario 5 of the low scenario little more than 15% of the modal share is for pipeline transport, where in scenario 8 close to 30% is for pipeline transport. So, this indicates that the larger the modal shift, the higher the gains for society. Aside from the autonomous sustainability trends per transport mode incorporated in the calculations of the external effects.

Table 6.9 displays the low volume growth scenario for the central trajectory. Overall, in the other volume growth scenarios (medium and high), the NPV increases as the mode choice model assigns more ton-kms to the pipeline transport resulting in higher NPVs. See table 6.11 below.

Table 6.11: NPV SCBA Central trajectory.

| **NPV (in €million)** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Scenario1** | € 487.81 | € 516.71 | € 661.02 |
| **Scenario2** | € 552.28 | € 592.21 | € 749.76 |
| **Scenario3** | € 606.02 | € 651.37 | € 814.71 |
| **Scenario4** | € 648.88 | € 695.75 | € 860.59 |
| **Scenario5** | € 272.62 | € 254.82 | € 340.01 |
| **Scenario6** | € 340.83 | € 340.18 | € 447.79 |
| **Scenario7** | € 411.23 | € 427.51 | € 557.01 |
| **Scenario8** | € 476.95 | € 505.65 | € 649.74 |
| **Scenario9** | € 124.95 | € 79.80 | € 130.41 |
| **Scenario10** | € 166.49 | € 127.53 | € 185.08 |
| **Scenario11** | € 219.43 | € 191.57 | € 262.87 |
| **Scenario12** | € 282.39 | € 270.86 | € 364.17 |

For the other two trajectories, North and South, the NPVs of the SCBA are significantly lower. Table 6.12 displays the NPV of the North and South trajectory. Compared to table 6.11 overall the Central trajectory offers higher NPVs across all scenarios. Therefore, the North trajectory is the most favourable trajectory from a SCBA and FCBA perspective.

Table 6.12: NPV SCBA North and South trajectory.

| **North** | | | | | **South** | | | |
|---|---|---|---|---|---|---|---|---|
| **NPV (in €million)** | **Low** | **Medium** | **High** | | **NPV (in €million)** | **Low** | **Medium** | **High** |
| **Scenario1** | € 164.09 | € 122.38 | € 176.92 | | **Scenario1** | € 456.02 | € 478.01 | € 613.42 |
| **Scenario2** | € 239.99 | € 212.47 | € 285.30 | | **Scenario2** | € 527.73 | € 563.98 | € 717.31 |
| **Scenario3** | € 340.36 | € 334.74 | € 434.73 | | **Scenario3** | € 588.55 | € 632.54 | € 794.47 |
| **Scenario4** | € 455.08 | € 476.66 | € 611.42 | | **Scenario4** | € 637.15 | € 683.90 | € 848.60 |
| **Scenario5** | € 70.73 | € 20.48 | € 65.63 | | **Scenario5** | € 244.35 | € 219.87 | € 296.49 |
| **Scenario6** | € 106.32 | € 58.31 | € 105.92 | | **Scenario6** | € 312.81 | € 304.97 | € 403.14 |
| **Scenario7** | € 161.81 | € 120.86 | € 176.72 | | **Scenario7** | € 386.75 | € 397.41 | € 519.82 |
| **Scenario8** | € 243.06 | € 218.02 | € 293.95 | | **Scenario8** | € 457.99 | € 483.50 | € 623.99 |
| **Scenario9** | € 33.98 | € -14.37 | € 32.70 | | **Scenario9** | € 109.80 | € 62.99 | € 111.86 |
| **Scenario10** | € 47.31 | € -2.04 | € 44.10 | | **Scenario10** | € 148.62 | € 106.69 | € 160.84 |
| **Scenario11** | € 70.81 | € 21.39 | € 44.10 | | **Scenario11** | € 199.64 | € 167.22 | € 160.84 |
| **Scenario12** | € 110.00 | € 63.15 | € 112.00 | | **Scenario12** | € 262.69 | € 245.82 | € 331.79 |

## 6.2 Recommendations

Based on the conclusions and assumptions made in this research, the following recommendations for further research are suggested.

- Insist on pipeline transport information.

From a government perspective, the Flemish government should insist on quantitative data of pipeline transport. The decision to construct pipelines in a densely populated country as Belgium should be taken with care. The conclusion on the research question was that there is uncertainty towards the results of the evaluation methods due to this lack of information. Therefore, insisting on more details and cooperation from the companies who are interested in this project would provide lots on insights.

- Mode choice model: acquire data on other explanatory variables to increase the explanatory power of the mode choice model.

This research has used a relatively simple model, which was a linear model consisting of fixed costs and variable costs in distance and travel time. By adding more explanatory variables the model can be calibrated more precise to the historic data. Therefore, the results will become more trustworthy, which can be useful as this thesis had to deal with multiple scenarios and uncertainty.

- Mode choice model: the modal does not incorporate the effect of weather of water levels and water current for IWT.

The current mode choice model is limited to the distance and time matrix estimated by using a navigation tool from Bureau Voorlichting Binnenvaart (n.d.). This navigation tool estimated the time and distance of inland water vessels between origins and destinations.
However, the water levels of canals and rivers is dependent on the amount of rain and meltwater, especially on the Rhine water levels can vary over the year. In the past years, the summer has been often dry causing lower water levels. The effect for inland water vessels is that the ships cannot be loaded to their full capacity. A mode choice model could incorporate this if there is data on monthly or weekly basis, or a mode choice model could apply a dynamic capacity for inland water vessels, where the drought in the summer is modelled by lower capacities of the vessels.

- Mode choice model: Include a minimum volume or batch size for pipeline transport.

The current mode choice model does not include a minimum volume of required batch size for pipeline transport. A pipeline is only likely to be used when a certain volume is transported on a day to day or periodical basis. When the quantities are low, a pipeline will not be necessary and probably less attractive to transport. Therefore, incorporating a minimum volume or required batch size for pipeline transport would be a good addition to the mode choice model.

- OD data: acquire OD data that splits the NST product groups more specific.

In section 2.1 the observed market segment was discussed, including the NST product groups. These groups are combined of subgroups of different kind of products. The acquired OD data only contained data on the NST group level, while having more detailed product group information could be very worthful. As the current data now also contains products that actually cannot be transported via pipelines considered in this research. Think of solid materials as coal and lignite in NST2.
So, a more detailed OD data split on specific products would benefit this kind of research.

- Research other project alternatives.

This research has mainly focused on the base case alternative, so the current situation. And respond to a current issue if the pipeline is a suitable alternative from a societal and financial perspective. Technological development is continuous and there might be very promising alternatives that are not covered in this research. In inland water transport the technological developments occur with electric batteries, hydrogen engines and so on. This is also the case for road transport where technology adapts to what is asked by society.
Researching other project alternatives can put this thesis into perspective to gain more insights in what would be cost effective and efficient from the perspective of society (and from the perspective of business/transport companies).

Furthermore, a recommendation would be to keep on track with the updates on the state of GRUP. And especially follow the lay-out and configuration of the trajectories. This includes changes of direction/trajectory, materials used, diameters of pipelines planned etc. as this can affect the financial viability of the project.

- Research on the safety/risk contours between the different trajectories.

The GRUP considers three trajectories, the North trajectory flows through less dense inhabited areas, while the Central and South trajectory cover more densely populated zones. From a societal perspective this asks for a more detailed approach into the possible risk contour zones and the requirements to guarantee safety for the different trajectories. This research has assumed that the proposed trajectories meet the standards and regulations.

- Further research on non-monetized effects and spatial transport/logistic chains.

The SCBA and FCBA both consisted mainly of effects that could be valued and monetized. However, there are various interesting effects that can occur when transport alternatives are added. Especially in the case of this pipeline alternative. When the pipelines are constructed for example, what effects will this have on global or regional transport streams. Will the pipelines cause more companies to settle in Flanders of the Ruhr region as the pipelines offer advantages to the logistical chains of these companies?

It can be expected that one who researches this will stumble upon the same problems regarding the lack of information. However, to study this aspect for a single chemical company or chemical plant would be very insightful.

## 6.3 Reflection

In this study performing an evaluation of multiple transport modes has challenged me in many ways. Firstly, pipeline transport has been a blind spot to me, I knew that pipeline transport was a major transport mode however during my study this transport mode was not covered in many cases. That made me curious to research the transport mode and the infrastructure required for this transport mode. Particularly in combination with the GRUP initiated in Flanders.

Secondly, the reason that pipeline transport had been a blind spot became clear to me. Covering and acquiring data has been a difficult job, eventually it became clear acquiring data that fitted to my thesis would not be possible within a near future. That challenged me to deal with scenarios to estimate the parameters of the deterrence function and my mode choice model.

Third, during my study period at the TU Delft, on multiple occasions the CBA and SCBA were covered in courses during the bachelors and masters. I enjoyed those courses and therefore this thesis and subject fitted to my likings. However, constructing a evaluating a SCBA and FCBA and acquiring all the necessary information is totally different to the well-structured assignments I would see during the courses in my study.

The last challenge I want to highlight is dealing with the uncertainty, due to the lack of data of pipeline transport that I could not obtain. But also, the uncertainty of that accompanies the evaluation methods. In a CBA and in models we try to capture processes and factors that seem to replicate reality, but the reality is that uncertainty limits the reliability. Technological developments, social norms, politics and economic events and go so on change the course of the future. It is not possible to model and incorporate everything in a CBA. During the research you must accept that uncertainty is part of this ex-ante transport appraisals, but that makes it challenging.

If I were able to start this study all over again, I would have put more attention to the different trajectories as this became more and more important at the end of the research, because these trajectories actually form the project alternatives within the project alternative itself. Next to that, I think a software program that allowed to draw links and nodes to visualize and could calculate with my modal choice model would be more appropriate to my needs than Microsoft Excel. Furthermore, I would have acted more swiftly when it became clear no data could be acquired for the pipeline transport mode. Therefore, I should have come to my supervisors sooner, as they are there to help you when you get stuck in the process. Personally, that is one of the biggest lessons I learned during this study.

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# Appendix A: CBA methodology

## *Major steps in CBA*

CBA consists of eight documented steps (Romijn & Renes, 2013):

1. Problem analysis.
2. Baseline alternative (zero alternative).
3. Define project alternatives.
4. Determine effects and benefits.
    i. Based on a willingness to pay/accept.
    ii. More extensive methods such as hedonic pricing and stated preference.
5. Determine costs and benefits.
6. Analyse variants and risks.
7. Overview of costs and benefits.
8. Results.

**Step 1: Problem analysis**
In the first step the analyst described the problem for which a solution is being sought. The problem analysis stresses the reason why a stakeholder should act. The problem analysis should describe the parameters within the problem should be solved, this could be certain goals or constraints.

**Step 2: Baseline alternative**
The baseline alternative is a scenario in which there are no policy instruments or project alternatives introduced. This baseline alternative is important as it serves as a reference point for project alternatives (Damart & Roy, 2009).

**Step 3: Project alternatives**
Project alternatives are measures or instruments which are expected to solve the problem derived from the problem analysis. Alternatives should exactly and clearly describe the actions to be taken, the resources needed and the expected effects of the alternative. For every scenario or alternative, the CBA tries to figure out if the value of the output would be greater than the value without the project (Eijgenraam et al., 2000).

**Step 4: Determine effects and benefits**
Determination of effects and benefits will be essential step in the (S)CBA. In this step the effects are identified, quantified, and valued.
Before any quantification can happen, the effects should be identified. Identifying the effects can be done by start with who is directly affected by the project (alternatives) and then secondary effects (indirect effects). According to (Boardman et al., 2018) , some sort of causal relation between alternative and effect is necessary to treat it as an impact.
When identifying effects, it is wise to add some sort of measurement indicators (e.g. monetized terms, tons emitted pollutants, numbers of lives saved per year) and describe which stakeholders are likely to be affected (Boardman et al., 2018)(Romijn & Renes, 2013).

After identifying, the effects must be quantified. This done by comparing changes between the alternative and the baseline alternative. Various methods can quantify the different effects.
The more effects can be quantified, the more weight it gives to the results of the CBA (Romijn & Renes, 2013). Effects that cannot be quantified should be scored qualitative.

The valuation of effects is necessary to compare costs versus benefits, but also compare the different alternatives. Valuing the effects can be done by a willingness to pay for certain effects, but also

existing markets exist with market prices. These are also called tangible elements.
Effects without existing markets can be established via valuation indices, but also questionnaires (Romijn & Renes, 2013). These are called intangible elements and often more difficult to monetize.

**Step 5: Determine costs**
Costs are determined to acknowledge the number of resources are spent on implementing an alternative by the stakeholders. Costs may one-off, recurring, fixed or increasing over time. It is important to acknowledge and always compare the costs to the baseline alternative.
Furthermore costs can be a ‘grey area’, as negative benefits may look like costs but should be classified as benefits.

**Step 6: Analyse variants and risks**
CBA is (partly) based on assumptions, therefore applying and incorporate risks to the CBA is necessary.

**Step 7: Overview of costs and benefits**
In this step the costs and benefits of all effects are stated. Often indicators are used to show the welfare effect. One is the (net) present value (NPV). As earlier explained the costs and benefits are considered over a time-period. The impacts are subject to a discount rate to consider inflation and risks. A positive NPV indicates a return on investment, however that does not mean the project should be executed. Other projects may have a higher NPV or a slight positive NPV might not be worth the risk.

Other indicators which are used often are Benefit-Cost ratio (BCR or B/C ratio) and the internal rate of return (IRR).
BCR divides all the benefits by the costs. This results in rather a value higher than 1, which means there are more benefits than costs. Or lower than 1, which indicates more costs than benefits. Again, a BCR higher than 1, does not indicate the project should be executed, differences in defining an impact as a cost instead of a benefit can have big influence. As BCR cannot identify costs and benefits separately (Romijn & Renes, 2013).

The IRR is a metric related to the discount rate in the NPV. If the IRR is larger than the discount rate, this indicates a gain in total welfare. A higher IRR means a more profitable project.

It is important to note that these indicators say something about the project, but not everything. It is likely that some effects may not be monetized. Which will exclude them from these ratios or indicators. It is up to the decision makers to conclude if the benefits can compensate or weigh more than the losses.

**Step 8: Presentation of results**
In the last step it is good to create a clear, user-friendly, and reproducible CBA. This is done by including the most important results of each alternative in a table, with the benefits and costs and overall balance.
Furthermore, the results should indicate unquantified effects and the important uncertainties.

### *Limitations of the CBA*

CBA as an evaluation method also has limitations. These limitations, with some of them cannot be resolved, should be recognized in the light of this study. The most important limitations for this study will be discussed more thoroughly, other limitations will be shortly mentioned.

The first limitation, a CBA is always incomplete. Effects on welfare can be overlooked or impossible to include in a CBA (not even qualitatively). Effects have to show causality, effects can be intangible and effects can be positioned at a grey area where is discussed if the effect is part of the project (Mouter et al., 2014).

Second, results of a CBA are always carrying uncertainty. The first reason for a level of uncertainty is that assumptions take place when carrying out a CBA. And second, estimation of effects is subject to time (and in professional situations money) restrictions. Not every effect can be researched from top to bottom (Mouter et al., 2014).

Third, effects that are difficult to estimate have weaker positions in the CBA as they are tended to be included in a qualitative score instead of quantitative or monetized. The results of the difficult to estimate effects are not watched with the same interest of the monetized effects. Therefore, this can lead to a bias or overlook negative impacts (Bakker et al., 2009).

Fourth, prices set do not represent the real price due to imperfect conditions. Especially in transport, where there are externalities influencing society. But the costs of transport are not levelled with the externalities caused. By applying shadow prices this can be resolved, however the calculation of these shadow prices is disputed (Dreze and Stern, 1994).

These three limitations form the most important limitations for this research. However, there are more limitations, which will be shortly discussed.
CBA can be difficult to understand, for decision makers but also for the public. CBAs are complex as there is a lot of information and research behind the results. Therefore, decision makers and the public may find CBA untransparent (Bakker et al., 2009). Furthermore, the CBA can be misused or used opportunistic (Mouter, 2017)(Mouter al., 2014).

Next a CBA does not provide insights in the distribution of effects for social groups. Furthermore, CBA does not consider the marginal utility for citizens. Thus, the CBA does not take into account the distribution of social equity of appraisal projects (Eijgenraam et al., 2000).

# Appendix B: Pipeline network in the ARRRA region

In this annex a summary of important pipelines is summarized in terms of the types of products, origin and destination, the diameter of the pipeline.

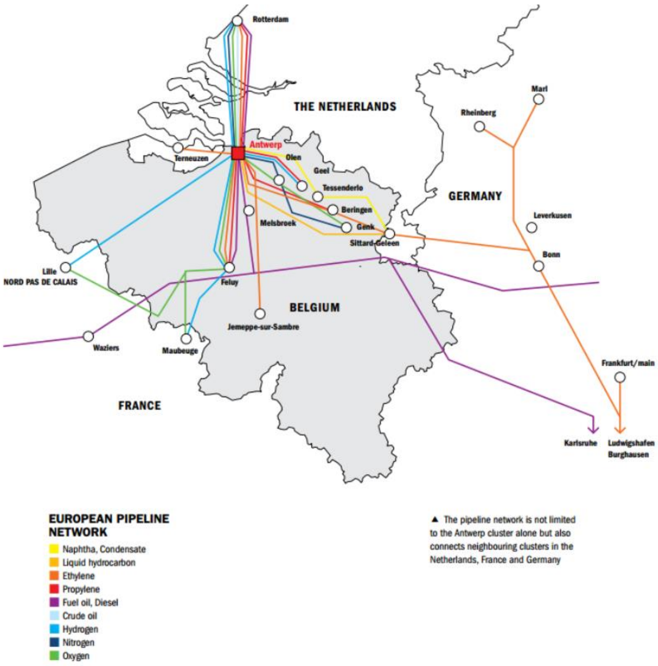


Figure B.1: Pipeline systems in the ARRRA region (Port of Antwerp, n.d.)

With this summary an overview of all pipeline systems is made in combination with their transported products. This is important as pipeline systems are a quite unknown infrastructure. The pipelines are underground and most of the public will not see pipelines. Important is to gain the knowledge where pipelines are located and what is transport.

# Table B.2: Pipelines in the ARRRA region (PPS, n.d.).

| **Name** | **Route (OD)** | **Product** | **Important clusters (and companies)** | **Diameter (inch)** |
|---|---|---|---|---|
| **PRB** | Pipeline Rotterdam Beek | liquid hydrocarbons (naphta, gascondensate) | Rotterdam<br>Chemelot | 8 |
| **PALL** | Pipeline Antwerp Limburg Luik | liquid hydrocarbons (naphtha, natural gas condensate) | Albertkanaal | 18 |
| **ARG** | Antwerp<br>Geleen Chemelot<br>Cologne<br>Ruhr | Ethene (Ruhr)<br>Monovinylchloride (Tessenderloo)<br>Vinylchloride (Chemelot) | Antwerpen: BASF<br>Beringen: Borealis<br>Cologne: Infeneum, Ineos, Braskem<br>Gelsenkirchen: BP<br>Ekeren: Exxon<br>Geel: Ineos<br>Geleen: Sabic, Celanese emulsions<br>Herne: Ineos<br>Chemiepark Marle<br>Meerhout: Exxon<br>Oberhausen: OQ chemicals, OXEA<br>Rheinberg: Inovyn<br>Tessenderloo: Vynova | 10 |
| **MVC VYNOVA** | Tessenderloo - Beek | monovinylchloride | Tessenderloo | 4 |
| **Nitraco** | Port of Antwerp right bank - left bank.<br>Lommel- Tessenderloo. | nitrogen | Tessenderloo<br>Lommel | 3 tot 10 |
| **Praxair** | Port of Antwerp right bank - left bank | Oxygen | Beringen | 3 tot 10 |
| **NMP Borealis** | Antwerp - Beringen | Propene/Propylene | Geel | 6 |
| **NMP Ineos** | Antwerp - Geel | Propene | Geel | 6 |
| **Air liquide** | Antwerpen - Rotterdam - Geleen - Luik and more out of ARRRA region | Oxygen<br>Nitrogen<br>Hydrogen | Geleen.<br>Antwerp.<br>Albertkanaal<br>Connections with multiple seaport (Rotterdam, antwerpen, zeebrugge, gent) | - |
| **RAPL** | Antwerpen - Rotterdam | Oil | Antwerpen<br>Rotterdam | 34 |
| **RC2** | Antwerpen - Rotterdam | ethylene | Antwerpen<br>Rotterdam | - |
| **RRP** | Rotterdam<br>Rhine<br>Main Mainleitung | Europoort - Ruhr: olie. Pernis - Ruhr: petroleum products | Frankfurt<br>Gelsenkirchen<br>Godorf<br>Ludwigshafen<br>Venlo<br>Wesseling | - |
| **CEPS** | NATO pipeline system airports | petroleum products | (military) airports in Europe | - |
| **DOW** | DOW pipeline Rotterdam - Terneuzen | porpoylene | Rotterdam<br>Terneuzen | - |
| **TOTAL** | Rotterdam - Vlissingen | oil products | Rotterdam<br>Vlissingen | - |
| **OCAP** | CO2 transport Amsterdam - Rotterdam | CO2 | Amsterdam<br>Rotterdam | - |

# Appendix C: Data set

In this annex the following topics are discussed:

- Data derivation
- Observed NUTS zones
- Data observation & preparation

### *Data derivation*

The acquired data is derived from the department of Mobility of Flanders. The OD data is created with the use of a generation model based on the production and attraction of freight transport per NUTS zone. The data for production and attraction within Belgium is based on demographics and employment rates within certain industries. The figure which follows on this production and attraction model is adjusted by observed data per NST product category and per NUTS zone (Vanderhoydonck & Borremans, 2020). Furthermore, traffic counts are applied to validate the data developed by the generation model and production and attraction of the transported tons in freight transport.

An important remark is that the figures in the OD data are the transported tons per product per transport mode for the base year 2010. In contrast to passenger transport, the OD matrix in freight transport will not show symmetrical figures between OD pairs. As passenger transport trips usually start at home and will end at home, this is not the case for freight transport.

### *Observed NUTS zones*

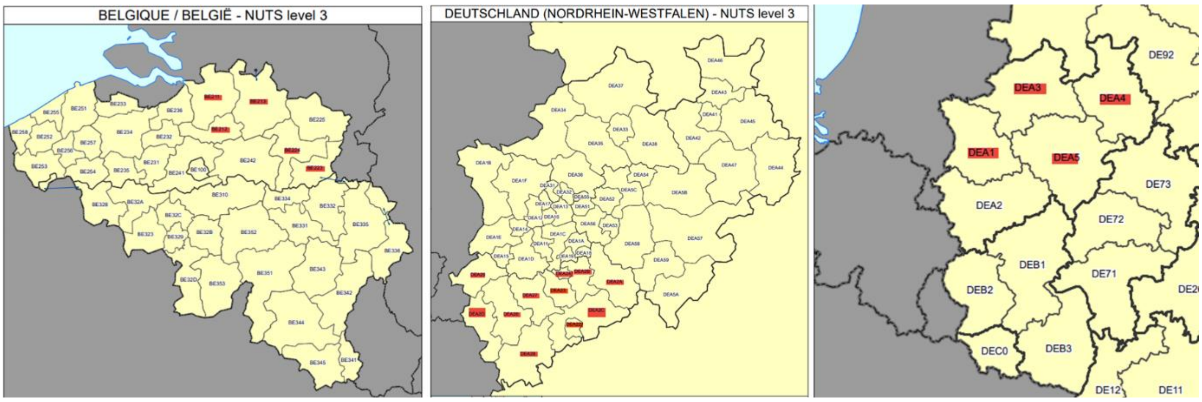
The observed NUTS zones form a selection of the acquired data, not every zone is relevant for this research as the focus is on specific zones in Flanders and NRW. Section 2.2 and 4.1 already gave a notion to the relevant zones, this paragraph will highlight the reasoning behind the observed zones and some specific details used in the modelling of these zones.

The selection of observed zones is based on the scope of the research, where the geographical area and project alternatives are or importance.

The scope states that the observed area includes Flanders, the Netherlands and NRW. In this area alternatives for current transport are under review in this research. To compare the alternatives, the relevant areas of importance and availability of transport modes must be in line. Which leads to a limited number of observed zones, this will also lead to a better overview.

So, the observed NUTS zones are located in Flanders and the German state North-Rhine Westfalen. For the observed zones in Belgium NUTS3 data is available, while for the German NUTS zones both NUTS2 and NUTS3 zone data is acquired. Data about the southern part of Limburg (NL) is not available unfortunately.

The figure below describes with red marking the observed NUTS3 zones in Flanders (most left), NUTS3 zones in the greater NUTS2 zone of Cologne (middle) and the remaining NUTS2 zones in NRW.



Figures C.1-C.3: Observed NUTS zones in Flanders, Cologne and NRW.

To get in more detail the NUTS zones in Europe are coupled with an arrondissement, larger city, metropolitan area, industrial zone etc. and coupled with a NUTS code to recognize the zones in a data set. The observed zones with corresponding city and codes in Flanders are:

Table C.1: Observed NUTS3 zones in Flanders.

| | NUTS2 | NUTS3 |
|---|---|---|
| Antwerp | | BE211 |
| Mechelen | | BE212 |
| Turnhout | | BE213 |
| Hasselt | | BE221 |
| Port of Antwerp Left bank | | * |
| Port of Antwerp Right bank | | * |

*: No NUTS zone specified in 2007 NUTS zone grouping from the EU, however included in acquired data.

Table C.2: Observed zones in North-Rhine Westfalen.

| | NUTS2 | NUTS3 | Centre of gravity |
|---|---|---|---|
| Aachen Kreisfreie stadt | | DEA21/DEA2D[6] | |
| Bonn Kreisfreie stadt | | DEA22 | |
| Köln Kreisfreie stadt | | DEA23 | |
| Leverkusen Kreisfreie stadt | | DEA24 | |
| Aachen Kreis | | DEA25[7] | |
| Düren | | DEA26 | |
| Rhein-Erft-Kreis | | DEA27 | |
| Euskirchen | | DEA28 | |
| Heinsberg | | DEA29 | |
| Oberbergischer Kreis | | DEA2A | |
| Rheinisch-Bergischer Kreis | | DEA2B | |
| Rhein-Sieg-Kreis | | DEA2C | |

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[6] The NUTS zones codes differ over the years (different versions), The city of Aachen has changed between DEA21 and DEA2D.

[7] Aachen Kreis is part of a newer version, however the acquired data does not include DEA25.

| | | | |
|---|---|---|---|
| Düsseldorf (Duisburg, Essen, Krefeld, Mönchengladbach, Oberhausen) | DEA1 | DEA12 | Duisburg |
| Münster (Bottrop, Gelsenkirchen) | DEA3 | DEA33 | Munster |
| Detmold (Bielefeld) | DEA4 | DEA41 | Bielefeld |
| Arnsberg (Koblens) | DEA5 | DEA52 | Dortmund |

The observed NUTS2 zones in NRW are the zones of Duisburg, Münster, Bielefeld and Dortmund. The data from these zones is only available in NUTS2 data not in NUTS3 data. For every mode of transport, the centroid to determine the distance between zones will be different. As the centroid for road transport will differ to the available waterways or railroad tracks.

### *Data observation and preparation*

### *Observation*

The first glance of the data tells that freight from Belgian NUTS zones to German NUTS zones is more extensive than the other way around.

The gross tons of products in the NST categories 2, 7 and 8 are transported with the destination in the Flanders region. Especially for chemical products, 81% of the transported tons has the destination in Flanders, while only 19% is transported with the end destination in NRW.

Table C.3: Distribution of transport volumes between Flanders and NRW per product group.

| | **Flanders** | **NRW** |
|---|---|---|
| **NST2** | 63% | 37% |
| **NST7** | 71% | 29% |
| **NST8** | 81% | 19% |

So, in terms of percentages the transport is for the fair share headed to Flanders according to this data set. However, in terms of gross tons the NST8 category is significantly larger than the two other modes, more than twice the size.

Table C.4: Volumes in tonnes between Flanders and NRW per product group.

| Destination | **Flanders** | **NRW** | Total |
|---|---|---|---|
| **NST2** | 4,056,376 | 2,217,868 | 6,274,243 |
| **NST7** | 4,751,746 | 1,821,780 | 6,573,526 |
| **NST8** | 12,636,108 | 2,953,748 | 15,589,856 |

Another notable issue is the fact that the data set has no registered transport between the zones in NRW. In other words, according to the acquired data there is no transport between the German zones in NRW and Flanders.

### *Preparation*

The original data set from the Flemish government contained 43 NUTS zones. Where 27 NUTS3 zones are located in Flanders and the remaining 16 are located in North-Rhine Westfalen. The NUTS zones in NRW are divided in to 12 NUTS3 zones for the larger, overarching NUTS2 zone of Cologne. And 4 NUTS2 zones representing four zones in NRW which are geographically located further from the Belgian border.

In the data preparation the 22 zones stated in the section 'Observed NUTS zones' should be selected.

This means that the other zones, which are all zones in Flanders and Wallonia are disregarded in this research.
The list below states all NUTS zones that are not included in the research:

Table C.5: Not included NUTS zones in Flanders.

| **Belgian NUTS zones not included:** |
|---|
| AALST |
| DENDERMONDE |
| EEKLO |
| GENT |
| OUDENAARDE |
| SINT-NIKLAAS |
| HALLE-VILVOORDE |
| LEUVEN |
| BRUGGE |
| DIKSMUIDE |
| IEPER |
| KORTRIJK |
| OOSTENDE |
| ROESELARE |
| TIELT |
| VEURNE |
| Haven GENT |
| Haven ZEEBRUGGE |
| BRUCARGO |

# Appendix D: Freight demand data construction

In this appendix the input for the freight demand forecast is further discussed and explained. The appendix contains:

- Skim matrix
- Impedance matrix
- Region matrix
- Growth model

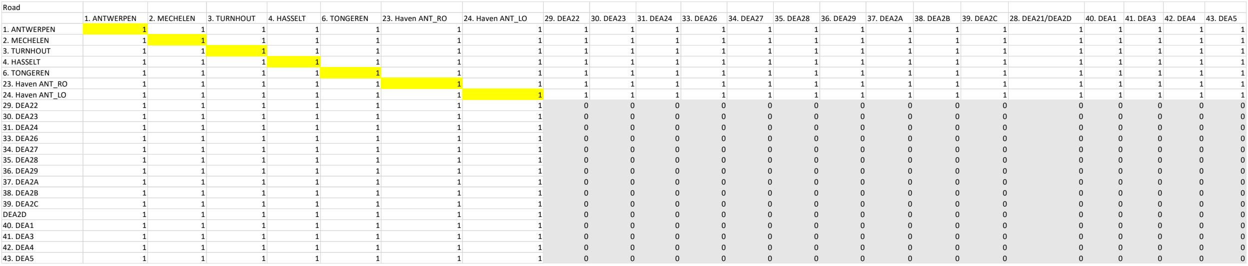
### *Skim matrix*

The first input is the skim matrix, this matrix is based on the infrastructure analysis as transport modes need infrastructure between origin and destination. Without infrastructure there is no potential transport between the zones possible unless multi-modal transport is considered. However, the obtained data set does not allow to distinguish multi-modal transport.

For the skim matrix a simple binary logic is used, a ‘1’ for an OD pair indicates that direct transport between is possible, a ‘0’ indicates no direct form of transport is possible due to a lack of infrastructural possibilities.

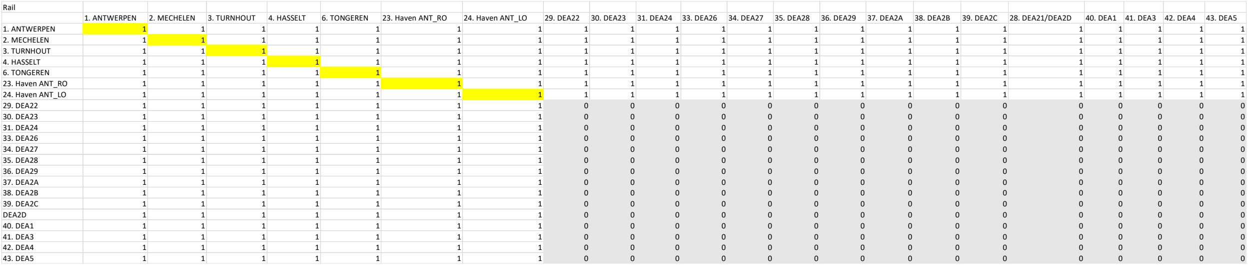
The infrastructure analysis indicates that both road and rail transport do have infrastructural relations to all observed NUTS zones.
For the constructed skim matrix this is displayed as:

Table D.1: Skim matrix road transport



| Road | 1. ANTWERPEN | 2. MECHELEN | 3. TURNHOUT | 4. HASSELT | 6. TONGEREN | 23. Haven ANT_RO | 24. Haven ANT_LO | 29. DEA22 | 30. DEA23 | 31. DEA24 | 33. DEA26 | 34. DEA27 | 35. DEA28 | 36. DEA29 | 37. DEA2A | 38. DEA2B | 39. DEA2C | 28. DEA21/DEA2D | 40. DEA1 | 41. DEA3 | 42. DEA4 | 43. DEA5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. ANTWERPEN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2. MECHELEN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3. TURNHOUT | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4. HASSELT | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6. TONGEREN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 23. Haven ANT_RO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 24. Haven ANT_LO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 29. DEA22 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30. DEA23 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31. DEA24 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33. DEA26 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34. DEA27 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35. DEA28 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36. DEA29 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37. DEA2A | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38. DEA2B | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39. DEA2C | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| DEA2D | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40. DEA1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41. DEA3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42. DEA4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43. DEA5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table D.2: Skim matrix rail transport



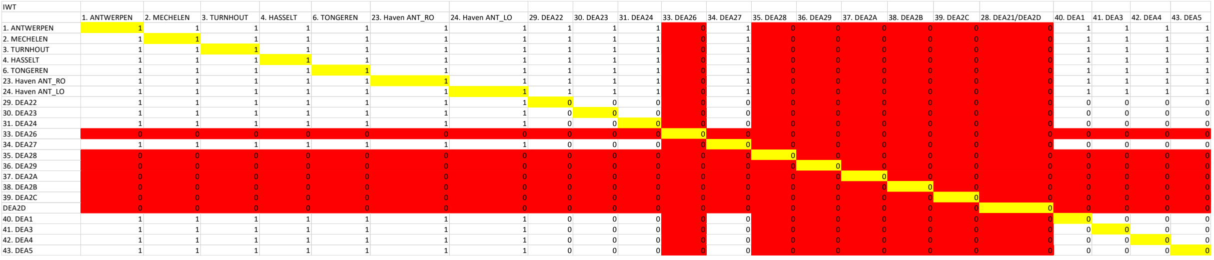
| Rail | 1. ANTWERPEN | 2. MECHELEN | 3. TURNHOUT | 4. HASSELT | 6. TONGEREN | 23. Haven ANT_RO | 24. Haven ANT_LO | 29. DEA22 | 30. DEA23 | 31. DEA24 | 33. DEA26 | 34. DEA27 | 35. DEA28 | 36. DEA29 | 37. DEA2A | 38. DEA2B | 39. DEA2C | 28. DEA21/DEA2D | 40. DEA1 | 41. DEA3 | 42. DEA4 | 43. DEA5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. ANTWERPEN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2. MECHELEN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3. TURNHOUT | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4. HASSELT | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6. TONGEREN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 23. Haven ANT_RO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 24. Haven ANT_LO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 29. DEA22 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30. DEA23 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31. DEA24 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33. DEA26 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34. DEA27 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35. DEA28 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36. DEA29 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37. DEA2A | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38. DEA2B | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39. DEA2C | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| DEA2D | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40. DEA1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41. DEA3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42. DEA4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43. DEA5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

One can notice the grey plane on the right bottom of both matrices. This is indicating to the missing information in the data set for transported tons between the German NUTS zones in NRW. All these OD pairs are indicated with a ‘0’, as there is no information it is not meaningful to further display the transported tons between the regions as it will be zero.
The yellow cells are intra-zonal transport.

For inland water transport the skim matrix does show multiple OD pairs where no direct transport is possible. What can be concluded is that the NUTS zones in Flanders are well connected via

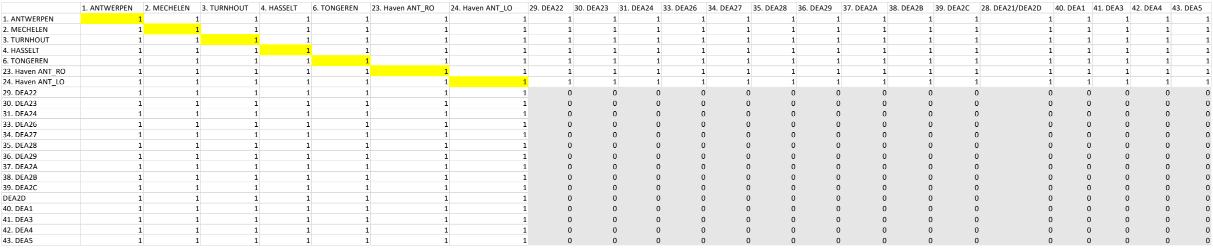
waterways. In contrary the German NUTS zones are less connected to waterways.
Cells marked red are OD pairs with no direct infrastructural relation via waterways.

Table D.3: Skim matrix IWT.



| IWT | 1. ANTWERPEN | 2. MECHELEN | 3. TURNHOUT | 4. HASSELT | 6. TONGEREN | 23. Haven ANT_RO | 24. Haven ANT_LO | 29. DEA22 | 30. DEA23 | 31. DEA24 | 33. DEA26 | 34. DEA27 | 35. DEA28 | 36. DEA29 | 37. DEA2A | 38. DEA2B | 39. DEA2C | 28. DEA21/DEA2D | 40. DEA1 | 41. DEA3 | 42. DEA4 | 43. DEA5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. ANTWERPEN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 2. MECHELEN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 3. TURNHOUT | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 4. HASSELT | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 6. TONGEREN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 23. Haven ANT_RO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 24. Haven ANT_LO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 |
| 29. DEA22 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30. DEA23 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31. DEA24 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33. DEA26 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34. DEA27 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35. DEA28 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36. DEA29 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37. DEA2A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38. DEA2B | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39. DEA2C | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| DEA2D | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40. DEA1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41. DEA3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42. DEA4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43. DEA5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Table D.4: Skim matrix pipeline



| | 1. ANTWERPEN | 2. MECHELEN | 3. TURNHOUT | 4. HASSELT | 6. TONGEREN | 23. Haven ANT_RO | 24. Haven ANT_LO | 29. DEA22 | 30. DEA23 | 31. DEA24 | 33. DEA26 | 34. DEA27 | 35. DEA28 | 36. DEA29 | 37. DEA2A | 38. DEA2B | 39. DEA2C | 28. DEA21/DEA2D | 40. DEA1 | 41. DEA3 | 42. DEA4 | 43. DEA5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. ANTWERPEN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 2. MECHELEN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 3. TURNHOUT | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 4. HASSELT | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 6. TONGEREN | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 23. Haven ANT_RO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 24. Haven ANT_LO | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 29. DEA22 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30. DEA23 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31. DEA24 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33. DEA26 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34. DEA27 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35. DEA28 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36. DEA29 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37. DEA2A | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38. DEA2B | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39. DEA2C | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| DEA2D | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40. DEA1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41. DEA3 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42. DEA4 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43. DEA5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

### *Impedance: Time and Distance matrix*

The impedance matrix is consisting of two factors in this research, the distance, and the travel time. For these matrices reference is made to the attached Excel file, as the figures in the matrix would be unreadable.

Road transport matrix is based on the centroid distances between NUTS zones. The information for the distances between the NUTS zones is derived from the European Union (European Commission, n.d.).
For intra-zonal freight transport an assumed 30 kilometre distance is used.
From these distances and the assumed average speed of trucks a time matrix can be constructed by dividing the distance by average speed.

Rail transport matrix is based on open-source data that uses timetables of railway operators (Beyssac, n.d.). The open-source data includes distance and time between railway stations of railway locations.
A likewise approach was used for inland water transport, the branche organisation Bureau Voorlichting Binnenvaart introduced a waterway map including distance and time for inland water vessels to travel between ports (Bureau Voorlichting Binnenvaart, n.d.).

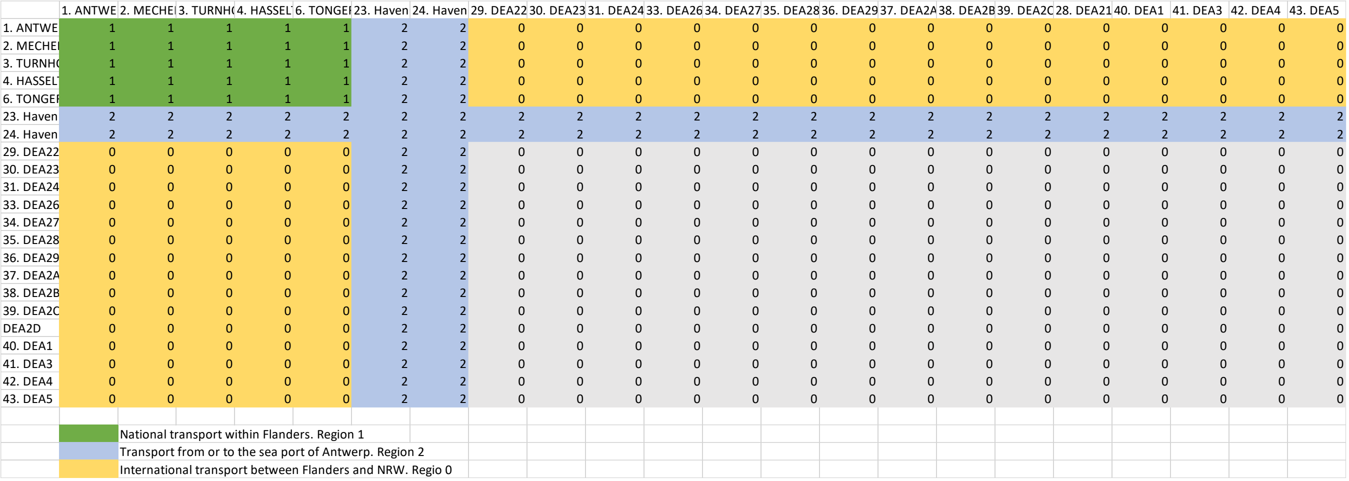
### *Region matrix*

The region matrix for model 3 of the modal split model supposes a deterrence function differing per distinguished region. This mostly has to do with the observation from the data that, train and inland water transport are more often used from or to the port of Antwerp, and the distance train and inland water vessels cover is longer. A separate deterrence function that can model those longer distances and highlight the function of the port of Antwerp can add value to the modal split model.

Below the region matrix is displayed, where there is a division in three regions. The cells marked green represent national transport within Flanders. The light blue cells indicate transport from or to the port of Antwerp and the yellow cells indicate international transport.

Again, a large grey plane is marked as these OD pairs representing these cells contain no data of transported tons.

Table D.5: Region matrix.



| | 1. ANTWE | 2. MECHE | 3. TURNH | 4. HASSEL | 6. TONGE | 23. Haven | 24. Haven | 29. DEA22 | 30. DEA23 | 31. DEA24 | 33. DEA26 | 34. DEA27 | 35. DEA28 | 36. DEA29 | 37. DEA2A | 38. DEA2B | 39. DEA2C | 28. DEA21 | 40. DEA1 | 41. DEA3 | 42. DEA4 | 43. DEA5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. ANTWE | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 2. MECHE | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3. TURNH | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4. HASSEL | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 6. TONGE | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 23. Haven | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 24. Haven | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 29. DEA22 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 30. DEA23 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 31. DEA24 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 33. DEA26 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 34. DEA27 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 35. DEA28 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 36. DEA29 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 37. DEA2A | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 38. DEA2B | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 39. DEA2C | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| DEA2D | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 40. DEA1 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 41. DEA3 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 42. DEA4 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 43. DEA5 | 0 | 0 | 0 | 0 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | |
|---|---|
| 🟩 | National transport within Flanders. Region 1 |
| 🟦 | Transport from or to the sea port of Antwerp. Region 2 |
| 🟨 | International transport between Flanders and NRW. Regio 0 |

# Appendix E: Calibration modal split model

### *Calibration*

The methodology used for calibrating the modal split model is herewith explained. The modal split model in the Excel file calculates the share of the considered transport mode. To calibrate the parameters of the modal split model, the values of the shares of the base year 2010 should be known. The data for this base year is provided by the Flemish government.

This research has developed three modal split models with linear utility functions. The utility functions are derived from Jourquin (2016). The three models are defined as followed:

$$V_m = \beta_m D_m + \gamma_m TT_m \qquad \text{(E.1)}$$

$$V_m = 2\alpha_{m,p} FC_{m,p} + \beta_m D_m + \gamma_m TT_m \qquad \text{(E.2)}$$

$$V_{m,r} = 2\alpha_{m,p} * FC_{m,p} + \beta_{m,r} * D_m + \gamma_{m,r} * TT_m \qquad \text{(E.3)}$$

$$V_{m,1} = 2\alpha_1 * FC_{m,p} + \beta_1 * t_1 + \gamma_1 * d_1 \qquad \text{(E.4)}$$

$$V_{m,2} = 2\alpha_2 * FC_{m,p} + \beta_2 * t_2 + \gamma_2 * d_2 \qquad \text{(E.5)}$$

$$V_{m,0} = 2\alpha_0 * FC_{m,p} + \beta_0 * t_0 + \gamma_0 * d_0 \qquad \text{(E.6)}$$

Where:

V = the (dis)utility of the total deterrence function
FC = fixed costs
D = distance
m = transport mode
r = region
p = product type (NST product category)
α = parameter for warehousing, loading, unloading per product type and transport mode
β = parameter for distance per transport mode
γ = parameter for travel time per transport mode

When the (dis)utility is calculated, the modal share is calculated by a multinomial logit (MNL) function. The share is expressed in a probability, as can be seen in function (E.7).

$$\Pr(m) = \frac{\exp\,(V_m^{\mu})}{\sum_{n=1}^{N} \exp\,(V_n^{\mu})} \qquad \text{(E.7)}$$

Where:

Pr = probability of mode m
$V_m$ = utility of mode m
$V_n$ = sum of utility for mode n=1 to N
μ = the dispersion factor per transport mode

The parameters for the different models are calibrated by using Microsoft Excel solver function to minimize the total sum of square errors:

$$SE = \sum_{O,D} \left(\Pr\,(m)_{(O,D),obs} - \Pr\,(m)_{(O,D),model}\right)^2 \qquad \text{(E.8)}$$

The three different models are calibrated per NST product type, which results in nine models in total.

Table E.1: Overview of accuracy and parameters models NST2.

| **NST2** | **Model 1** | **Model 2** | **Model 3** | | |
|---|---|---|---|---|---|
| **μ Road** | -0.575 | -0.185 | -0.077 | | |
| **μ Rail** | -0.467 | -0.502 | -0.460 | | |
| **μ IWT** | -1.000 | -0.376 | -0.148 | | |
| | | | **Region 1** | **Region 2** | **Region 0** |
| **α Road** | N/A | 1.000 | 0.506 | 0.497 | 0.407 |
| **α Rail** | N/A | 0.598 | 0.814 | 0.706 | 0.486 |
| **α IWT** | N/A | 0.604 | 0.634 | 0.378 | 0.533 |
| **β Road** | 0.000 | 0.820 | 0.635 | 0.496 | 0.453 |
| **β Rail** | 0.000 | 0.776 | 0.566 | 0.424 | 0.175 |
| **β IWT** | 0.000 | 0.748 | 0.322 | 0.515 | 0.531 |
| **γ Road** | 0.363 | 0.302 | 0.484 | 0.493 | 0.762 |
| **γ Rail** | 0.806 | 0.404 | 0.541 | 0.452 | 0.697 |
| **γ IWT** | 1.000 | 0.036 | 0.812 | 0.114 | 0.081 |
| | | | | | |
| **SSE** | 15.87 | 7.73 | 5.13 | | |
| **Average error per OD pair** | 0.033 | 0.016 | 0.011 | | |
| **RMSE** | 0.181 | 0.126 | 0.103 | | |

Table E.2: Overview of accuracy and parameters models NST7.

| **NST7** | **Model 1** | **Model 2** | **Model 3** | | |
|---|---|---|---|---|---|
| **μ Road** | 0.000 | -0.096 | -0.058 | | |
| **μ Rail** | -0.737 | -0.491 | -0.479 | | |
| **μ IWT** | -0.378 | -0.166 | -0.088 | | |
| | | | **Region 1** | **Region 2** | **Region 0** |
| **α Road** | N/A | 0.618 | 0.825 | 0.382 | 0.371 |
| **α Rail** | N/A | 0.507 | 0.422 | 0.814 | 0.735 |
| **α IWT** | N/A | 0.996 | 0.696 | 0.322 | 0.442 |
| **β Road** | 0.107 | 0.437 | 0.357 | 0.557 | 0.563 |
| **β Rail** | 0.569 | 0.246 | 0.536 | 0.437 | 0.497 |
| **β IWT** | 0.996 | 0.499 | 0.736 | 0.803 | 0.731 |
| **γ Road** | 0.054 | 0.558 | 0.716 | 0.519 | 0.930 |
| **γ Rail** | 0.626 | 0.138 | 0.560 | 0.358 | 0.546 |
| **γ IWT** | 0.632 | 0.178 | 0.509 | 0.164 | 0.214 |
| | | | | | |
| **SSE** | 14.00 | 7.15 | 6.41 | | |
| **Average error per OD pair** | 0.029 | 0.01 | 0.013 | | |
| **RMSE** | 0.170 | 0.12 | 0.115 | | |

Table E.3: Overview of accuracy and parameters models NST8.

| NST8 | Model 1 | Model 2 | Model 3 | | |
|---|---|---|---|---|---|
| **μ Road** | -0.327 | -0.030 | -0.047 | | |
| **μ Rail** | -0.966 | -0.872 | -0.484 | | |
| **μ IWT** | -0.378 | -0.032 | -0.058 | | |
| | | | **Region 1** | **Region 2** | **Region 0** |
| **α Road** | N/A | 0.181 | 0.366 | 0.439 | 0.303 |
| **α Rail** | N/A | 0.490 | 0.671 | 0.079 | 0.641 |
| **α IWT** | N/A | 0.433 | 0.633 | 0.515 | 0.440 |
| **β Road** | 0.425 | 0.847 | 0.408 | 0.964 | 0.466 |
| **β Rail** | 0.959 | 0.470 | 0.356 | 0.988 | 0.626 |
| **β IWT** | 0.638 | 0.402 | 0.327 | 0.457 | 0.223 |
| **γ Road** | 0.762 | 0.670 | 0.410 | 0.516 | 0.440 |
| **γ Rail** | 0.383 | 0.590 | 0.308 | 0.009 | 0.414 |
| **γ IWT** | 0.976 | 0.172 | 0.274 | 0.102 | 0.061 |
| | | | | | |
| **SSE** | 38.34 | 19.81 | 17.44 | | |
| **Average error per OD pair** | 0.079 | 0.041 | 0.036 | | |
| **RMSE** | 0.281 | 0.202 | 0.190 | | |

In this research model 3 is used, because model 3 is accurate model among these three. It is the most accurate as it is the most extensive model. In some cases, a more extensive requires much more interpretation, but in this case the degree of accuracy is the main reason for model 3.

### *Modal split model output*

In table E.4 the modal split share in terms of transported tonnes is displayed for the observed NUTS zones (thus the observed origins and destinations).
The table shows that road transport has the highest share of the transport modes across all observed product groups. The share of road transport ranges from 65.94% for the NST2 products to 74.11% for the NST7 products.

Table E.4: Modal split in ton% for observed data.

| Modal split observed data | Road | Rail | IWT |
|---|---|---|---|
| **NST2** | 65.94% | 74.11% | 66.90% |
| **NST7** | 0.03% | 0.87% | 4.20% |
| **NST8** | 34.04% | 25.01% | 28.90% |

In terms of transported tons, the NST8 product group is the largest in volume. Table D.5 indicates that the NST8 product group is the size of almost 15.6 million tons in the base year 2010. Followed by NST7 almost 6.7 million tonnes and NST2 little over 6.4 million tons.
Therefore the share of IWT in NST8 is the lowest when expressing the share in percentages, but it is the largest share when the total volume of the NST8 product group is considered.

Table E.5: Modal share in tons.

| Observed | NST2 | NST7 | NST8 |
|---|---|---|---|
| Road | 4,224,372 | 4,953,491 | 10,428,915 |
| Rail | 1,734 | 58,458 | 654,843 |
| IWT | 2,180,591 | 1,671,661 | 4,506,097 |

The mode choice model calibrated for the base year has the following output, which can be seen in table E.6 and E.7. The calculated shares of the mode choice model are overestimating the share of road transport, while rail and especially inland water transport are underestimated by the model.

Table E.6: Modal split in ton% for model 3.

| Calculated | NST2 | NST7 | NST8 |
|---|---|---|---|
| Road | 79.18% | 78.48% | 77.93% |
| Rail | 0.00% | 0.00% | 2.40% |
| IWT | 20.82% | 21.52% | 19.67% |

Table E.7: %Error for modal split model 3.

| % Error | NST2 | NST7 | NST8 |
|---|---|---|---|
| Road | 13.24% | 4.37% | 11.03% |
| Rail | -0.03% | -0.87% | -1.80% |
| IWT | -13.22% | -3.49% | -9.23% |

The error in percentual share shows that the mode choice model overestimates the share of road transport, while the shares of IWT and rail may be higher. In the other tested models, the error was larger, as indicated by tables E.1-3.

Next to the general error in mode share, tables E.8-10 indicate that there are differences in over- and underestimating between regions.

Table E.8: Observed mode share in ton% per NST group and region.

| | NST2 | | | NST7 | | | NST8 | | |
|---|---|---|---|---|---|---|---|---|---|
| Observed | Region 1 | Region 2 | Region 0 | Region 1 | Region 2 | Region 0 | Region 1 | Region 2 | Region 0 |
| Road | 99.55% | 56.33% | 97.96% | 97.61% | 66.25% | 98.22% | 95.29% | 55.67% | 64.88% |
| Rail | 0.01% | 0.03% | 0.01% | 0.18% | 1.10% | 0.07% | 0.02% | 5.45% | 7.57% |
| IWT | 0.44% | 43.64% | 2.03% | 2.21% | 32.65% | 1.71% | 4.70% | 38.88% | 27.54% |

Table E.9: Calculated mode share in ton% per NST group and region.

| | NST2 | | | NST7 | | | NST8 | | |
|---|---|---|---|---|---|---|---|---|---|
| Calculated | Region 1 | Region 2 | Region 0 | Region 1 | Region 2 | Region 0 | Region 1 | Region 2 | Region 0 |
| Road | 100.00% | 73.88% | 96.74% | 98.75% | 72.67% | 81.98% | 99.78% | 71.30% | 81.98% |
| Rail | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 0.00% | 3.34% | 0.00% |
| IWT | 0.00% | 26.12% | 3.26% | 1.25% | 27.33% | 18.02% | 0.22% | 25.35% | 18.02% |

Table E.10: %Error in mode share in ton% per NST group and region.

| | NST2 | | | NST7 | | | NST8 | | |
|---|---|---|---|---|---|---|---|---|---|
| Error | Region 1 | Region 2 | Region 0 | Region 1 | Region 2 | Region 0 | Region 1 | Region 2 | Region 0 |
| Road | 0.45% | 17.55% | -1.22% | 1.14% | 6.43% | -16.24% | 4.49% | 15.63% | 17.10% |
| Rail | -0.01% | -0.03% | -0.01% | -0.18% | -1.10% | -0.07% | -0.02% | -2.10% | -7.57% |
| IWT | -0.44% | -17.52% | 1.23% | -0.96% | -5.32% | 16.31% | -4.47% | -13.53% | -9.52% |

Table E.10 shows that for IWT, product group NST2 and NST7 region 0, in some cases an overestimation is made by the chosen mode choice model (which is model 3).
This can be explained by the way the model works. The model contains three explanatory variables, fixed costs, costs for time and costs for distance. The transport modes are modelled and calibrated

that rail and especially IWT have a lower distance and time costs (thus lower transport cost per unit over longer distances). Region 0 are OD pairs between Flanders and NRW, thus that indicates longer distances. Thus, this is ascribed to the mode choice model.

# Appendix F: Tables results modal split estimation – project alternative

In this appendix the results of the mode choice model are shown for the project alternative. As there was no historical OD data acquired for the project alternative the research has applied utility function scenarios.

The different scenarios for the parameters in the utility or deterrence function for the pipeline are displayed below in table F.1. In scenario 1 to 4 a slight increase in fixed costs for the parameter alpha is issued. This increases to 20% for scenario 5 to 8 and to 30% for scenario 9 to 12.
The parameters for distance and time (beta and gamma) decrease as section 4.4 proposed the hypothesis that variable costs of pipeline transport are lower compared to the other transport modes. For the variable costs the decrease ranges between 10% and 40%.

Table F.1: Scenarios for parameter mode pipeline.

| **Scenario** | **Fixed costs (α)** | **Variable costs (β, γ)** |
|---|---|---|
| **1** | +10% | -10% |
| **2** | +10% | -20% |
| **3** | +10% | -30% |
| **4** | +10% | -40% |
| **5** | +20% | -10% |
| **6** | +20% | -20% |
| **7** | +20% | -30% |
| **8** | +20% | -40% |
| **9** | +30% | -10% |
| **10** | +30% | -20% |
| **11** | +30% | -30% |
| **12** | +30% | -40% |

With the use of these deterrence function scenarios a mode choice model is estimated for the three trajectories, their configuration and corresponding distance and time matrices. And for the different growth scenarios (low, medium, high).

The tables F.2-4 show the share in terms of ton-km per trajectory, growth scenario and deterrence function scenario. It indicates the North trajectory is less attractive from a transport perspective, as the Central and South trajectory (which are significantly shorter) are assigned more ton-km by the mode choice mode.

Table F.2: Estimated modal split North trajectory (in ton-km) (own creation).

| **Low** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 41.10% | 0.06% | 50.95% | 7.88% |
| **Scenario2** | 40.11% | 0.06% | 47.44% | 12.39% |
| **Scenario3** | 39.13% | 0.06% | 41.86% | 18.95% |
| **Scenario4** | 38.22% | 0.06% | 34.63% | 27.09% |
| **Scenario5** | 43.13% | 0.06% | 53.81% | 2.99% |
| **Scenario6** | 42.46% | 0.06% | 52.62% | 4.86% |
| **Scenario7** | 41.71% | 0.06% | 50.20% | 8.02% |
| **Scenario8** | 41.00% | 0.06% | 45.81% | 13.13% |
| **Scenario9** | 44.08% | 0.07% | 54.63% | 1.22% |
| **Scenario10** | 43.76% | 0.07% | 54.31% | 1.87% |
| **Scenario11** | 43.27% | 0.06% | 53.60% | 3.07% |
| **Scenario12** | 42.67% | 0.06% | 52.05% | 5.22% |

| **Medium** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 41.13% | 0.04% | 51.64% | 7.19% |
| **Scenario2** | 40.12% | 0.04% | 47.84% | 11.99% |
| **Scenario3** | 39.18% | 0.04% | 41.55% | 19.23% |
| **Scenario4** | 38.35% | 0.04% | 33.05% | 28.57% |
| **Scenario5** | 43.09% | 0.04% | 54.43% | 2.44% |
| **Scenario6** | 42.40% | 0.04% | 53.37% | 4.18% |
| **Scenario7** | 41.66% | 0.04% | 50.96% | 7.34% |
| **Scenario8** | 40.99% | 0.04% | 46.13% | 12.84% |
| **Scenario9** | 43.92% | 0.04% | 55.06% | 0.98% |
| **Scenario10** | 43.63% | 0.04% | 54.83% | 1.50% |
| **Scenario11** | 43.15% | 0.04% | 54.28% | 2.53% |
| **Scenario12** | 42.54% | 0.04% | 52.89% | 4.53% |

| **High** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 41.10% | 0.02% | 52.36% | 6.51% |
| **Scenario2** | 40.12% | 0.02% | 48.24% | 11.61% |
| **Scenario3** | 39.23% | 0.02% | 41.28% | 19.46% |
| **Scenario4** | 38.50% | 0.02% | 31.46% | 30.01% |
| **Scenario5** | 42.95% | 0.02% | 55.03% | 2.00% |
| **Scenario6** | 42.25% | 0.02% | 54.13% | 3.59% |
| **Scenario7** | 41.52% | 0.02% | 51.77% | 6.69% |
| **Scenario8** | 40.91% | 0.02% | 46.53% | 12.53% |
| **Scenario9** | 43.67% | 0.03% | 55.48% | 0.82% |
| **Scenario10** | 43.42% | 0.02% | 55.33% | 1.23% |
| **Scenario11** | 42.94% | 0.02% | 54.92% | 2.11% |
| **Scenario12** | 42.30% | 0.02% | 53.75% | 3.93% |

Table F.3: Estimated modal split Central trajectory (in ton-km) (own creation).

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 38.00% | 0.06% | 32.42% | 29.52% |
| **Scenario2** | 37.34% | 0.05% | 28.41% | 34.20% |
| **Scenario3** | 36.59% | 0.05% | 25.39% | 37.97% |
| **Scenario4** | 35.83% | 0.05% | 23.30% | 40.82% |
| **Scenario5** | 40.83% | 0.06% | 43.98% | 15.12% |
| **Scenario6** | 40.44% | 0.06% | 39.62% | 19.88% |
| **Scenario7** | 40.02% | 0.06% | 34.96% | 24.97% |
| **Scenario8** | 39.50% | 0.05% | 30.72% | 29.73% |
| **Scenario9** | 42.54% | 0.06% | 51.29% | 6.11% |
| **Scenario10** | 42.17% | 0.06% | 49.14% | 8.63% |
| **Scenario11** | 41.84% | 0.06% | 46.03% | 12.07% |
| **Scenario12** | 41.55% | 0.06% | 41.99% | 16.40% |

| Medium | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 38.15% | 0.04% | 30.48% | 31.33% |
| **Scenario2** | 37.50% | 0.04% | 26.08% | 36.39% |
| **Scenario3** | 36.72% | 0.04% | 23.11% | 40.13% |
| **Scenario4** | 35.95% | 0.03% | 21.29% | 42.73% |
| **Scenario5** | 40.85% | 0.04% | 44.02% | 15.10% |
| **Scenario6** | 40.55% | 0.04% | 38.81% | 20.59% |
| **Scenario7** | 40.25% | 0.04% | 33.23% | 26.48% |
| **Scenario8** | 39.79% | 0.04% | 28.45% | 31.73% |
| **Scenario9** | 42.40% | 0.04% | 52.16% | 5.40% |
| **Scenario10** | 42.04% | 0.04% | 49.94% | 7.98% |
| **Scenario11** | 41.76% | 0.04% | 46.46% | 11.74% |
| **Scenario12** | 41.58% | 0.04% | 41.62% | 16.77% |

| High | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 38.32% | 0.02% | 28.52% | 33.14% |
| **Scenario2** | 37.64% | 0.02% | 23.85% | 38.48% |
| **Scenario3** | 36.82% | 0.02% | 21.09% | 42.06% |
| **Scenario4** | 36.03% | 0.02% | 19.59% | 44.35% |
| **Scenario5** | 40.80% | 0.02% | 44.13% | 15.05% |
| **Scenario6** | 40.63% | 0.02% | 38.01% | 21.33% |
| **Scenario7** | 40.48% | 0.02% | 31.44% | 28.06% |
| **Scenario8** | 40.06% | 0.02% | 26.22% | 33.70% |
| **Scenario9** | 42.16% | 0.02% | 53.06% | 4.75% |
| **Scenario10** | 41.82% | 0.02% | 50.85% | 7.30% |
| **Scenario11** | 41.60% | 0.02% | 47.06% | 11.32% |
| **Scenario12** | 41.54% | 0.02% | 41.32% | 17.12% |

Table F.4: Estimated modal split South trajectory (in ton-km) (own creation).

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 38.27% | 0.06% | 34.48% | 27.19% |
| **Scenario2** | 37.61% | 0.05% | 29.91% | 32.42% |
| **Scenario3** | 36.85% | 0.05% | 26.34% | 36.76% |
| **Scenario4** | 36.05% | 0.05% | 23.85% | 40.05% |
| **Scenario5** | 41.02% | 0.06% | 45.69% | 13.23% |
| **Scenario6** | 40.59% | 0.06% | 41.46% | 17.89% |
| **Scenario7** | 40.17% | 0.06% | 36.59% | 23.18% |
| **Scenario8** | 39.67% | 0.06% | 31.91% | 28.36% |
| **Scenario9** | 42.71% | 0.06% | 52.00% | 5.23% |
| **Scenario10** | 42.31% | 0.06% | 50.11% | 7.52% |
| **Scenario11** | 41.95% | 0.06% | 47.24% | 10.75% |
| **Scenario12** | 41.63% | 0.06% | 43.29% | 15.02% |

| Medium | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 38.40% | 0.04% | 32.86% | 28.70% |
| **Scenario2** | 37.77% | 0.04% | 27.68% | 34.52% |
| **Scenario3** | 36.99% | 0.04% | 24.00% | 38.97% |
| **Scenario4** | 36.17% | 0.03% | 21.75% | 42.05% |
| **Scenario5** | 41.00% | 0.04% | 46.00% | 12.96% |
| **Scenario6** | 40.66% | 0.04% | 41.02% | 18.28% |
| **Scenario7** | 40.37% | 0.04% | 35.16% | 24.44% |
| **Scenario8** | 39.95% | 0.04% | 29.76% | 30.25% |
| **Scenario9** | 42.57% | 0.04% | 52.85% | 4.54% |
| **Scenario10** | 42.17% | 0.04% | 50.96% | 6.83% |
| **Scenario11** | 41.85% | 0.04% | 47.85% | 10.27% |
| **Scenario12** | 41.62% | 0.04% | 43.20% | 15.14% |

| High | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 38.55% | 0.02% | 31.25% | 30.18% |
| **Scenario2** | 37.93% | 0.02% | 25.48% | 36.56% |
| **Scenario3** | 37.11% | 0.02% | 21.88% | 40.98% |
| **Scenario4** | 36.25% | 0.02% | 19.95% | 43.77% |
| **Scenario5** | 40.92% | 0.02% | 46.38% | 12.68% |
| **Scenario6** | 40.69% | 0.02% | 40.63% | 18.66% |
| **Scenario7** | 40.55% | 0.02% | 33.68% | 25.75% |
| **Scenario8** | 40.23% | 0.02% | 27.59% | 32.16% |
| **Scenario9** | 42.33% | 0.02% | 53.71% | 3.94% |
| **Scenario10** | 41.94% | 0.02% | 51.90% | 6.14% |
| **Scenario11** | 41.65% | 0.02% | 48.61% | 9.71% |
| **Scenario12** | 41.54% | 0.02% | 43.23% | 15.21% |

As can be seen in the tables F.2-4, scenario 1 to 4 show the highest share of transport for pipeline. In case of the Central and South trajectory, the shares are considerable reaching over 30% to 40% in case of scenario 1 to 4. These scenarios are the most favourable deterrence function scenarios for pipeline transport. The share gradually decreases for scenario 5 to 12.

Tables F.5-7 display the assigned ton share for the mode choice model with the different scenarios.

Table F.5: Estimated modal split North trajectory (in tons transported) (own creation).

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 76.71% | 0.03% | 23.26% | |
| **Scenario1** | 69.03% | 0.03% | 21.80% | 9.14% |
| **Scenario2** | 67.66% | 0.03% | 20.18% | 12.14% |
| **Scenario3** | 66.13% | 0.03% | 17.77% | 16.07% |
| **Scenario4** | 64.55% | 0.02% | 14.87% | 20.55% |
| **Scenario5** | 72.62% | 0.03% | 23.28% | 4.07% |
| **Scenario6** | 71.80% | 0.03% | 22.70% | 5.47% |
| **Scenario7** | 70.81% | 0.03% | 21.58% | 7.58% |
| **Scenario8** | 69.67% | 0.03% | 19.65% | 10.66% |
| **Scenario9** | 74.39% | 0.03% | 23.72% | 1.86% |
| **Scenario10** | 73.99% | 0.03% | 23.56% | 2.43% |
| **Scenario11** | 73.39% | 0.03% | 23.22% | 3.37% |
| **Scenario12** | 72.58% | 0.03% | 22.50% | 4.89% |

| Medium | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 77.41% | 0.02% | 22.56% | |
| **Scenario1** | 70.31% | 0.02% | 21.52% | 8.16% |
| **Scenario2** | 68.88% | 0.02% | 19.73% | 11.37% |
| **Scenario3** | 67.27% | 0.02% | 17.00% | 15.71% |
| **Scenario4** | 65.60% | 0.02% | 13.64% | 20.74% |
| **Scenario5** | 73.61% | 0.02% | 22.96% | 3.41% |
| **Scenario6** | 72.82% | 0.02% | 22.43% | 4.73% |
| **Scenario7** | 71.84% | 0.02% | 21.29% | 6.84% |
| **Scenario8** | 70.70% | 0.02% | 19.14% | 10.15% |
| **Scenario9** | 75.12% | 0.02% | 23.29% | 1.58% |
| **Scenario10** | 74.76% | 0.02% | 23.17% | 2.04% |
| **Scenario11** | 74.19% | 0.02% | 22.91% | 2.88% |
| **Scenario12** | 73.40% | 0.02% | 22.26% | 4.33% |

| High | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 77.59% | 0.01% | 22.40% | |
| **Scenario1** | 71.34% | 0.01% | 21.43% | 7.23% |
| **Scenario2** | 69.89% | 0.01% | 19.46% | 10.65% |
| **Scenario3** | 68.23% | 0.01% | 16.41% | 15.34% |
| **Scenario4** | 66.51% | 0.01% | 12.59% | 20.89% |
| **Scenario5** | 74.26% | 0.01% | 22.81% | 2.91% |
| **Scenario6** | 73.50% | 0.01% | 22.36% | 4.12% |
| **Scenario7** | 72.55% | 0.01% | 21.22% | 6.21% |
| **Scenario8** | 71.41% | 0.01% | 18.84% | 9.74% |
| **Scenario9** | 75.53% | 0.01% | 23.05% | 1.40% |
| **Scenario10** | 75.23% | 0.01% | 22.98% | 1.78% |
| **Scenario11** | 74.69% | 0.01% | 22.78% | 2.52% |
| **Scenario12** | 73.90% | 0.01% | 22.22% | 3.87% |

Table F.6: Estimated modal split Central trajectory (in tons transported) (own creation).

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 76.71% | 0.03% | 23.26% | |
| **Scenario1** | 64.37% | 0.02% | 14.02% | 21.58% |
| **Scenario2** | 63.39% | 0.02% | 12.50% | 24.10% |
| **Scenario3** | 62.44% | 0.02% | 11.35% | 26.18% |
| **Scenario4** | 61.56% | 0.02% | 10.56% | 27.86% |
| **Scenario5** | 69.43% | 0.03% | 18.87% | 11.67% |
| **Scenario6** | 68.62% | 0.02% | 17.09% | 14.26% |
| **Scenario7** | 67.80% | 0.02% | 15.24% | 16.94% |
| **Scenario8** | 66.98% | 0.02% | 13.59% | 19.40% |
| **Scenario9** | 72.53% | 0.03% | 22.16% | 5.27% |
| **Scenario10** | 71.88% | 0.03% | 21.22% | 6.88% |
| **Scenario11** | 71.19% | 0.03% | 19.89% | 8.90% |
| **Scenario12** | 70.47% | 0.03% | 18.22% | 11.29% |

| Medium | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 77.41% | 0.02% | 22.56% | |
| **Scenario1** | 65.40% | 0.01% | 12.68% | 21.91% |
| **Scenario2** | 64.37% | 0.01% | 11.05% | 24.57% |
| **Scenario3** | 63.39% | 0.01% | 9.95% | 26.64% |
| **Scenario4** | 62.50% | 0.01% | 9.27% | 28.22% |
| **Scenario5** | 70.41% | 0.02% | 18.24% | 11.33% |
| **Scenario6** | 69.60% | 0.02% | 16.12% | 14.26% |
| **Scenario7** | 68.79% | 0.02% | 13.94% | 17.26% |
| **Scenario8** | 67.97% | 0.01% | 12.12% | 19.89% |
| **Scenario9** | 73.33% | 0.02% | 21.92% | 4.73% |
| **Scenario10** | 72.68% | 0.02% | 20.93% | 6.37% |
| **Scenario11** | 71.98% | 0.02% | 19.43% | 8.57% |
| **Scenario12** | 71.25% | 0.02% | 17.43% | 11.30% |

| High | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 77.59% | 0.01% | 22.40% | |
| **Scenario1** | 66.25% | 0.01% | 11.51% | 22.23% |
| **Scenario2** | 65.19% | 0.01% | 9.81% | 24.99% |
| **Scenario3** | 64.19% | 0.01% | 8.81% | 26.99% |
| **Scenario4** | 63.30% | 0.01% | 8.25% | 28.44% |
| **Scenario5** | 71.09% | 0.01% | 17.81% | 11.09% |
| **Scenario6** | 70.29% | 0.01% | 15.32% | 14.38% |
| **Scenario7** | 69.50% | 0.01% | 12.80% | 17.70% |
| **Scenario8** | 68.69% | 0.01% | 10.85% | 20.45% |
| **Scenario9** | 73.82% | 0.01% | 21.90% | 4.27% |
| **Scenario10** | 73.18% | 0.01% | 20.90% | 5.92% |
| **Scenario11** | 72.48% | 0.01% | 19.23% | 8.28% |
| **Scenario12** | 71.75% | 0.01% | 16.85% | 11.39% |

Table F.7: Estimated modal split South trajectory (in tons transported) (own creation).

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 76.71% | 0.03% | 23.26% | |
| **Scenario1** | 64.79% | 0.02% | 14.82% | 20.37% |
| **Scenario2** | 63.74% | 0.02% | 13.07% | 23.17% |
| **Scenario3** | 62.73% | 0.02% | 11.71% | 25.53% |
| **Scenario4** | 61.79% | 0.02% | 10.77% | 27.42% |
| **Scenario5** | 69.77% | 0.03% | 19.60% | 10.61% |
| **Scenario6** | 68.93% | 0.03% | 17.83% | 13.21% |
| **Scenario7** | 68.08% | 0.02% | 15.88% | 16.02% |
| **Scenario8** | 67.22% | 0.02% | 14.05% | 18.71% |
| **Scenario9** | 72.78% | 0.03% | 22.48% | 4.71% |
| **Scenario10** | 72.12% | 0.03% | 21.64% | 6.21% |
| **Scenario11** | 71.41% | 0.03% | 20.40% | 8.16% |
| **Scenario12** | 70.67% | 0.03% | 18.75% | 10.56% |

| Medium | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 77.41% | 0.02% | 22.56% | |
| **Scenario1** | 65.84% | 0.02% | 13.58% | 20.57% |
| **Scenario2** | 64.74% | 0.01% | 11.64% | 23.61% |
| **Scenario3** | 63.70% | 0.01% | 10.28% | 26.01% |
| **Scenario4** | 62.73% | 0.01% | 9.44% | 27.82% |
| **Scenario5** | 70.76% | 0.02% | 19.08% | 10.14% |
| **Scenario6** | 69.92% | 0.02% | 17.00% | 13.06% |
| **Scenario7** | 69.06% | 0.02% | 14.68% | 16.24% |
| **Scenario8** | 68.21% | 0.01% | 12.62% | 19.16% |
| **Scenario9** | 73.58% | 0.02% | 22.24% | 4.17% |
| **Scenario10** | 72.92% | 0.02% | 21.39% | 5.68% |
| **Scenario11** | 72.21% | 0.02% | 20.03% | 7.75% |
| **Scenario12** | 71.46% | 0.02% | 18.08% | 10.45% |

| High | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 77.59% | 0.01% | 22.40% | |
| **Scenario1** | 66.72% | 0.01% | 12.51% | 20.76% |
| **Scenario2** | 65.58% | 0.01% | 10.40% | 24.01% |
| **Scenario3** | 64.50% | 0.01% | 9.10% | 26.39% |
| **Scenario4** | 63.53% | 0.01% | 8.39% | 28.07% |
| **Scenario5** | 71.44% | 0.01% | 18.78% | 9.77% |
| **Scenario6** | 70.60% | 0.01% | 16.37% | 13.02% |
| **Scenario7** | 69.77% | 0.01% | 13.64% | 16.58% |
| **Scenario8** | 68.93% | 0.01% | 11.36% | 19.70% |
| **Scenario9** | 74.06% | 0.01% | 22.20% | 3.73% |
| **Scenario10** | 73.41% | 0.01% | 21.37% | 5.21% |
| **Scenario11** | 72.71% | 0.01% | 19.90% | 7.37% |
| **Scenario12** | 71.96% | 0.01% | 17.63% | 10.40% |

# Appendix G: FCBA

In this appendix the results of the FCBA are presented. The appendix contains the NPV of the different scenarios and the results of the tariff estimations (based on the operational costs).

### *NPV, Operational costs & Tariffs*

The net present value of the FCBA indicates the financial benefits or losses generated by the project. In case of the project alternative the NPV is negative. This would mean the project alternative is not financially profitable. However, the revenues (and operational costs) are estimated with the use of transported tariffs without margin. The transport tariffs are estimated at operational costs.

$$Revenue = tariff * volume \qquad \text{(G.1)}$$

$$Tariff_t = \frac{Cost\ of\ operation_t}{Volume_t} * \frac{(1+DR)^t}{1} \qquad \text{(G.2)}$$

Where:

Tariff = yearly cost of transporting one ton of product in €/ton.
Cost of operation = yearly total cost of operating and transporting in €.
Volume = yearly estimated volume in ton.
DR = discount rate (4.5%)
t = year of FCBA.

The operational costs are the yearly depreciation of the infrastructural investments at an economic lifespan of 30 years. The yearly maintenance costs, the loss of space costs, required energy, labour and costs of service.
The tariffs are estimated by dividing the operational costs, divided by the volume (in tons or ton-kms) estimated by the mode choice model. Times the factor for the discount rate to cancel out the discount rate.

$$Cost\ of\ operation_t = Depreciation + Maintenance_t + Labour_t + Service_t + Energy_t \qquad \text{(G.3)}$$

$$Volume_t = V_{NST2,t} + V_{NST7,t} + V_{NST8,t} \qquad \text{(G.4)}$$

### *NPV results*

The results for the NPVs in the FCBA are all negative. As discussed, the revenues are estimated at operational costs by the assigned volumes. Therefore, the negative result of the FCBAs is the residual depreciation costs of the pipeline infrastructure.

Table G.1: NPV overview FCBA.

| **NPV** (in € million) | **Low** | **Medium** | **High** |
|---|---|---|---|
| **North** | € - 189.8 | € - 219.3 | € - 248.7 |
| **Central** | € - 127.1 | € - 145.7 | € - 164.4 |
| **South** | € - 135.7 | € - 155.2 | € - 174.8 |

What can be concluded is that the North trajectory is less financially attractive, mainly due to the longer trajectory. That influences the infrastructural investments and maintenance costs. The negative results are the residual depreciation of 4 years as the assumption is that construction of the pipeline takes 5 years and that leaves 26 years of operation (30 year economic lifespan).

### *Tariff estimation*

The tariff estimation is a more interesting factor as it displays the transport tariffs for every scenario. As can be seen in the first part of this appendix in formula G.1 and G.2 the tariff is much dependent on the volume. Therefore, the growth scenarios, utility function scenarios and the trajectory are the most important factors that will influence the assignment of volume to the project alternative in the mode choice model.

The tables and figures below show the transport tariff for the trajectory, growth scenario and utility function scenario. In the figure the red line indicates the competitive transport tariff named in a feasibility study by ARG from 1999, which was €0.109 per tonkm.

Table G.2: Tariff estimation North trajectory (€/tonkm).

| **North** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Scenario1** | € 0.420 | € 0.467 | € 0.506 |
| **Scenario2** | € 0.271 | € 0.285 | € 0.289 |
| **Scenario3** | € 0.182 | € 0.183 | € 0.179 |
| **Scenario4** | € 0.132 | € 0.128 | € 0.121 |
| **Scenario5** | € 1.112 | € 1.391 | € 1.668 |
| **Scenario6** | € 0.681 | € 0.804 | € 0.919 |
| **Scenario7** | € 0.415 | € 0.460 | € 0.495 |
| **Scenario8** | € 0.258 | € 0.268 | € 0.270 |
| **Scenario9** | € 2.734 | € 3.463 | € 4.013 |
| **Scenario10** | € 1.784 | € 2.269 | € 2.704 |
| **Scenario11** | € 1.082 | € 1.333 | € 1.568 |
| **Scenario12** | € 0.636 | € 0.744 | € 0.842 |

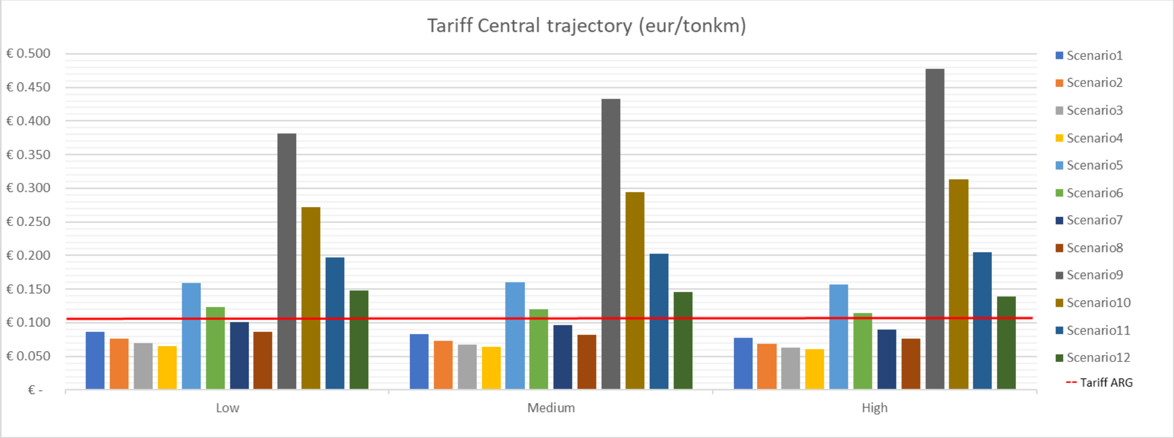


Figure G.1: Tariff North trajectory (€/tonkm).

Table G.3: Tariff estimation Central trajectory (€/tonkm).

| **Central** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Scenario1** | € 0.087 | € 0.083 | € 0.078 |
| **Scenario2** | € 0.076 | € 0.073 | € 0.068 |
| **Scenario3** | € 0.070 | € 0.067 | € 0.063 |
| **Scenario4** | € 0.066 | € 0.064 | € 0.061 |
| **Scenario5** | € 0.159 | € 0.160 | € 0.157 |
| **Scenario6** | € 0.124 | € 0.121 | € 0.114 |
| **Scenario7** | € 0.101 | € 0.096 | € 0.090 |
| **Scenario8** | € 0.086 | € 0.082 | € 0.077 |
| **Scenario9** | € 0.381 | € 0.432 | € 0.478 |
| **Scenario10** | € 0.272 | € 0.295 | € 0.313 |
| **Scenario11** | € 0.197 | € 0.203 | € 0.205 |
| **Scenario12** | € 0.147 | € 0.145 | € 0.139 |

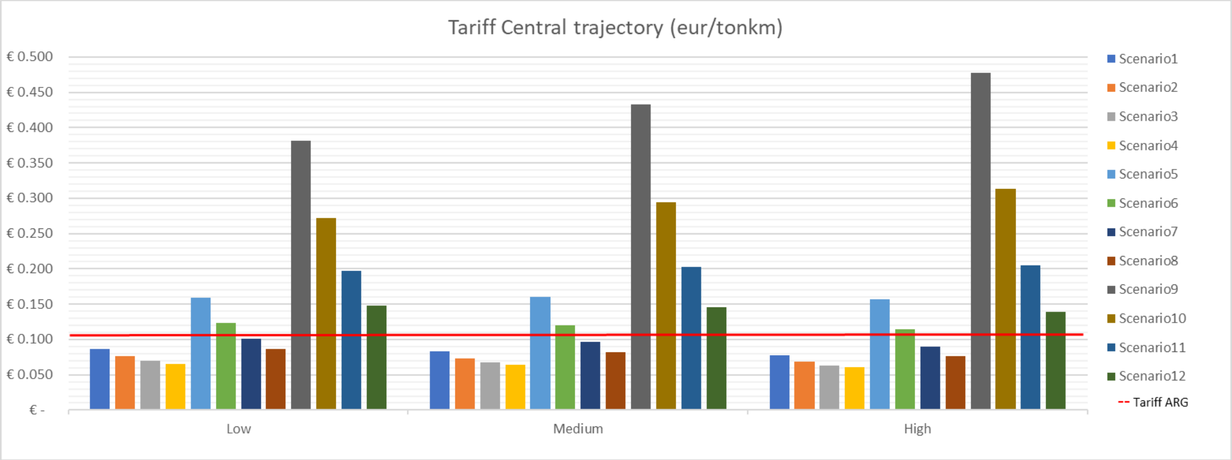


Figure G.2: Tariff Central trajectory (€/tonkm).

Table G.4: Tariff estimation South trajectory (€/tonkm).

| **South** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Scenario1** | € 0.098 | € 0.094 | € 0.088 |
| **Scenario2** | € 0.084 | € 0.080 | € 0.075 |
| **Scenario3** | € 0.075 | € 0.072 | € 0.068 |
| **Scenario4** | € 0.070 | € 0.068 | € 0.064 |
| **Scenario5** | € 0.189 | € 0.194 | € 0.193 |
| **Scenario6** | € 0.143 | € 0.141 | € 0.135 |
| **Scenario7** | € 0.113 | € 0.109 | € 0.102 |
| **Scenario8** | € 0.094 | € 0.090 | € 0.084 |
| **Scenario9** | € 0.468 | € 0.540 | € 0.605 |
| **Scenario10** | € 0.327 | € 0.361 | € 0.390 |
| **Scenario11** | € 0.231 | € 0.243 | € 0.249 |
| **Scenario12** | € 0.168 | € 0.168 | € 0.163 |

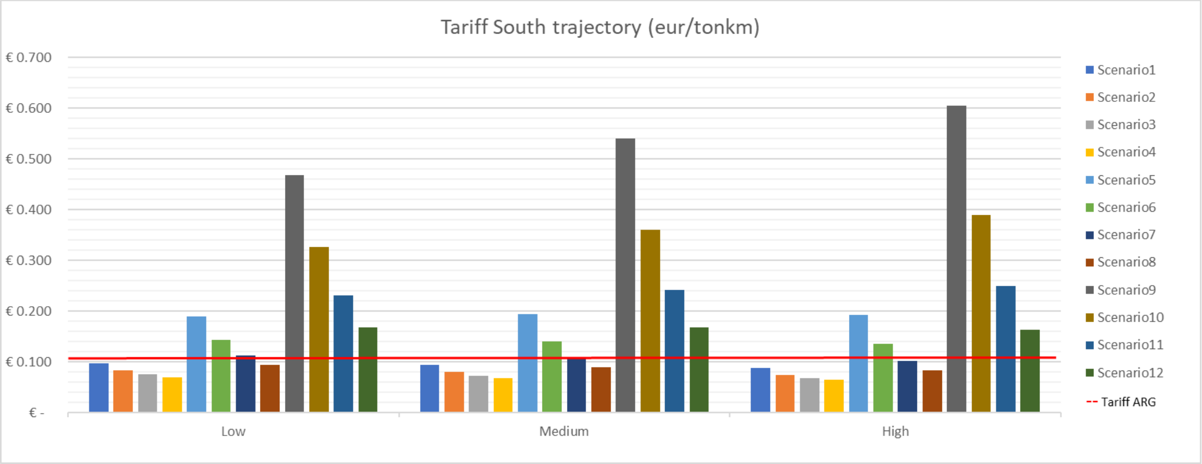


Figure G.3: Tariff South trajectory (€/tonkm).

Again, one can see that the Central and South trajectory are more attractive from a transport perspective (more volume is assigned to the transport mode), therefore reducing the transport tariffs as no margin is applied.

Section 5.2 also strived to put a conclusion on which utility function scenario(s) seem most realistic compared to the found tariff in the feasibility study of ARG (1999). Section 5.2 concluded scenarios 5 to 8 seem to be most realistic for trajectories Central and South, as these scenarios report tariffs that are well placed below and above the reported tariff by ARG, which could function as a benchmark. It should be noted that the tariff of ARG is likely to be calculated at a margin, but it is also likely costs for transport have risen over time.

# Appendix H: SCBA

In this appendix the SCBA and results are shown.

### *Base case alternative*

### *Sum of external effects costs of transport*

In the base case alternative, or zero alternative, there are three growth scenarios for the SCBA.

Table H.1: External effects Low scenario Base Case.

| **Low** (in €million) | **Road** | **Rail** | **IWT** |
|---|---|---|---|
| **Air pollution** | € -234.87 | € -0.05 | € -467.44 |
| **Climate change costs** | € -162.25 | € -0.03 | € -95.82 |
| **Congestion costs** | € -284.58 | € - | € - |
| **Noise costs** | € -144.70 | € -0.48 | € - |
| **Safety** | € -448.26 | € -0.05 | € -23.67 |
| **Loss of habitat costs** | € -67.88 | € -0.18 | € -79.17 |
| | | | |
| **Transit time benefits** | 0 | 0 | 0 |
| **Toll and taxes revenues** | 0 | 0 | 0 |

Table H.2: External effects Medium scenario Base Case.

| **Medium** (in €million) | **Road** | **Rail** | **IWT** |
|---|---|---|---|
| **Air pollution** | € -259.89 | € -0.04 | € -477.36 |
| **Climate change costs** | € -179.52 | € -0.02 | € -97.86 |
| **Congestion costs** | € -315.93 | € - | € - |
| **Noise costs** | € -160.64 | € -0.37 | € - |
| **Safety** | € -497.63 | € -0.04 | € -24.17 |
| **Loss of habitat costs** | € -75.36 | € -0.14 | € -80.86 |
| | | | |
| **Transit time benefits** | 0 | 0 | 0 |
| **Toll and taxes revenues** | 0 | 0 | 0 |

Table H.3: External effects High scenario Base Case

| **High** (in €million) | **Road** | **Rail** | **IWT** |
|---|---|---|---|
| **Air pollution** | € -289.17 | € -0.03 | € -584.10 |
| **Climate change costs** | € -199.75 | € -0.01 | € -119.74 |
| **Congestion costs** | € -351.79 | € - | € - |
| **Noise costs** | € -178.87 | € -0.24 | € - |
| **Safety** | € -554.12 | € -0.02 | € -29.66 |
| **Loss of habitat costs** | € -83.91 | € -0.09 | € -99.22 |
| | | | |
| **Transit time benefits** | 0 | 0 | 0 |
| **Toll and taxes revenues** | 0 | 0 | 0 |

The results show that air pollution for IWT is a considerable contributor to the total external effects across all scenarios. IWT is seen as an environmentally friendly transport mode, as CO2 emissions are lower compared to road transport. However, in air polluting substances as NOx, SO2, PM the external costs factor is higher than road transport.
Also air pollution in road transport is still a large contributor, due to the significant share of road transport. Furthermore, road congestion costs and safety costs in road transport form large contributors to the external effects costs.

The total NPV of the base case scenarios is issued in table H.4 below. The low scenario has the lowest NPV as this scenario has the least transport volume among the three scenarios.

Table H.4: NPV of Base Case scenarios.

| In €million | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Total** | € -2,009.43 | € -2,169.83 | € -2,490.74 |

### *Project alternative*

In the project alternative there are more scenarios as multiple scenarios were needed to approach the deterrence function of pipeline transport.
The project alternative also has three configurations, or trajectories. So, the project alternative results consist of three growth scenarios, with twelve utility function scenarios for three different trajectories.

### *Sum of external effects costs of transport*

Table H.5: Sum of external effects Central trajectory.

| **North (in €million)** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Scenario1** | € -1,845.34 | € -2,047.44 | € -2,313.82 |
| **Scenario2** | € -1,769.43 | € -1,957.36 | € -2,205.44 |
| **Scenario3** | € -1,669.07 | € -1,835.08 | € -2,056.02 |
| **Scenario4** | € -1,554.35 | € -1,693.17 | € -1,879.32 |
| **Scenario5** | € -1,938.70 | € -2,149.34 | € -2,425.11 |
| **Scenario6** | € -1,903.10 | € -2,111.51 | € -2,384.82 |
| **Scenario7** | € -1,847.62 | € -2,048.96 | € -2,314.02 |
| **Scenario8** | € -1,766.36 | € -1,951.80 | € -2,196.80 |
| **Scenario9** | € -1,975.45 | € -2,184.20 | € -2,458.05 |
| **Scenario10** | € -1,962.12 | € -2,171.86 | € -2,446.64 |
| **Scenario11** | € -1,938.62 | € -2,148.43 | € -2,423.26 |
| **Scenario12** | € -1,899.42 | € -2,106.67 | € -2,378.74 |

Table H.6: Sum of external effects Central trajectory.

| **Central (in €million)** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Scenario1** | € -1,521.61 | € -1,653.12 | € -1,829.72 |
| **Scenario2** | € -1,457.14 | € -1,577.62 | € -1,740.98 |
| **Scenario3** | € -1,403.41 | € -1,518.45 | € -1,676.03 |
| **Scenario4** | € -1,360.55 | € -1,474.07 | € -1,630.15 |
| **Scenario5** | € -1,736.81 | € -1,915.01 | € -2,150.73 |
| **Scenario6** | € -1,668.59 | € -1,829.65 | € -2,042.95 |
| **Scenario7** | € -1,598.20 | € -1,742.32 | € -1,933.73 |
| **Scenario8** | € -1,532.47 | € -1,664.17 | € -1,841.00 |
| **Scenario9** | € -1,884.48 | € -2,090.03 | € -2,360.33 |
| **Scenario10** | € -1,842.94 | € -2,042.30 | € -2,305.67 |
| **Scenario11** | € -1,789.99 | € -1,978.25 | € -2,227.87 |
| **Scenario12** | € -1,727.04 | € -1,898.97 | € -2,126.57 |

Table H.7: Sum of external effects South trajectory.

| South (in €million) | Low | Medium | High |
|---|---|---|---|
| **Scenario1** | € -1,553.41 | € -1,691.81 | € -1,877.32 |
| **Scenario2** | € -1,481.70 | € -1,605.85 | € -1,773.44 |
| **Scenario3** | € -1,420.88 | € -1,537.28 | € -1,696.28 |
| **Scenario4** | € -1,372.28 | € -1,485.93 | € -1,642.15 |
| **Scenario5** | € -1,765.08 | € -1,949.96 | € -2,194.26 |
| **Scenario6** | € -1,696.62 | € -1,864.85 | € -2,087.60 |
| **Scenario7** | € -1,622.68 | € -1,772.42 | € -1,970.92 |
| **Scenario8** | € -1,551.44 | € -1,686.33 | € -1,866.75 |
| **Scenario9** | € -1,899.62 | € -2,106.83 | € -2,378.89 |
| **Scenario10** | € -1,860.81 | € -2,063.14 | € -2,329.90 |
| **Scenario11** | € -1,809.79 | € -2,002.60 | € -2,258.03 |
| **Scenario12** | € -1,746.74 | € -1,924.01 | € -2,158.95 |

The highest (thus least negative) NPVs are in the Central trajectory, followed by the South trajectory. The North trajectory is the least beneficial from a societal perspective. This trajectory has the lowest NPVs and is therefore inducing the most costs to society.

### *NPV SCBA*

In the tables below the delta between the base case alternative and the project alternative are displayed. In the tables a positive figure indicates a reduction in estimated external effects between the base case alternative and the project alternative. A negative indicates an increase in estimated external effects.

The North trajectory is least beneficial from a societal perspective, as it decreases the external effects the least among the three trajectories. The Central trajectory is reducing the most external effects across all scenarios, closely followed by the South trajectory.

Table H.8: NPV North trajectory.

| **NPV** (in €million) | Low | Medium | High |
|---|---|---|---|
| **Scenario1** | € 164.09 | € 122.38 | € 176.92 |
| **Scenario2** | € 239.99 | € 212.47 | € 285.30 |
| **Scenario3** | € 340.36 | € 334.74 | € 434.73 |
| **Scenario4** | € 455.08 | € 476.66 | € 611.42 |
| **Scenario5** | € 70.73 | € 20.48 | € 65.63 |
| **Scenario6** | € 106.32 | € 58.31 | € 105.92 |
| **Scenario7** | € 161.81 | € 120.86 | € 176.72 |
| **Scenario8** | € 243.06 | € 218.02 | € 293.95 |
| **Scenario9** | € 33.98 | € -14.37 | € 32.70 |
| **Scenario10** | € 47.31 | € -2.04 | € 44.10 |
| **Scenario11** | € 70.81 | € 21.39 | € 44.10 |
| **Scenario12** | € 110.00 | € 63.15 | € 112.00 |

Table H.9: NPV Central trajectory.

| NPV (in €million) | Low | Medium | High |
|---|---|---|---|
| **Scenario1** | € 487.81 | € 516.71 | € 661.02 |
| **Scenario2** | € 552.28 | € 592.21 | € 749.76 |
| **Scenario3** | € 606.02 | € 651.37 | € 814.71 |
| **Scenario4** | € 648.88 | € 695.75 | € 860.59 |
| **Scenario5** | € 272.62 | € 254.82 | € 340.01 |
| **Scenario6** | € 340.83 | € 340.18 | € 447.79 |
| **Scenario7** | € 411.23 | € 427.51 | € 557.01 |
| **Scenario8** | € 476.95 | € 505.65 | € 649.74 |
| **Scenario9** | € 124.95 | € 79.80 | € 130.41 |
| **Scenario10** | € 166.49 | € 127.53 | € 185.08 |
| **Scenario11** | € 219.43 | € 191.57 | € 262.87 |
| **Scenario12** | € 282.39 | € 270.86 | € 364.17 |

Table H.10: NPV South trajectory.

| NPV (in €million) | Low | Medium | High |
|---|---|---|---|
| Scenario1 | € 456.02 | € 478.01 | € 613.42 |
| Scenario2 | € 527.73 | € 563.98 | € 717.31 |
| Scenario3 | € 588.55 | € 632.54 | € 794.47 |
| Scenario4 | € 637.15 | € 683.90 | € 848.60 |
| Scenario5 | € 244.35 | € 219.87 | € 296.49 |
| Scenario6 | € 312.81 | € 304.97 | € 403.14 |
| Scenario7 | € 386.75 | € 397.41 | € 519.82 |
| Scenario8 | € 457.99 | € 483.50 | € 623.99 |
| Scenario9 | € 109.80 | € 62.99 | € 111.86 |
| Scenario10 | € 148.62 | € 106.69 | € 160.84 |
| Scenario11 | € 199.64 | € 167.22 | € 160.84 |
| Scenario12 | € 262.69 | € 245.82 | € 331.79 |

Table H.11: Qualitative score tolls and tax revenues North.

| North | Low | Medium | High |
|---|---|---|---|
| Base case | 0 | 0 | 0 |
| Scenario1 | 0 | 0 | 0 |
| Scenario2 | 0 | 0 | 0 |
| Scenario3 | 0 | 0 | 0 |
| Scenario4 | - | - | - |
| Scenario5 | 0 | 0 | 0 |
| Scenario6 | 0 | 0 | 0 |
| Scenario7 | 0 | 0 | 0 |
| Scenario8 | 0 | 0 | 0 |
| Scenario9 | 0 | 0 | 0 |
| Scenario10 | 0 | 0 | 0 |
| Scenario11 | 0 | 0 | 0 |
| Scenario12 | 0 | 0 | 0 |

Table H.12: Qualitative score tolls and tax revenues Central.

| Central | Low | Medium | High |
|---|---|---|---|
| Base case | 0 | 0 | 0 |
| Scenario1 | - | - | - |
| Scenario2 | - | - | - |
| Scenario3 | - | - | - |
| Scenario4 | - | - | - |
| Scenario5 | 0 | 0 | 0 |
| Scenario6 | 0 | 0 | 0 |
| Scenario7 | 0 | 0 | - |
| Scenario8 | - | - | - |
| Scenario9 | 0 | 0 | 0 |
| Scenario10 | 0 | 0 | 0 |
| Scenario11 | 0 | 0 | 0 |
| Scenario12 | 0 | 0 | 0 |

Table H.13: Qualitative score tolls and tax revenues South.

| South | Low | Medium | High |
|---|---|---|---|
| Base case | 0 | 0 | 0 |
| Scenario1 | 0 | 0 | 0 |
| Scenario2 | 0 | 0 | 0 |
| Scenario3 | - | - | - |
| Scenario4 | - | - | - |

| | | | |
|---|---|---|---|
| **Scenario5** | 0 | 0 | 0 |
| **Scenario6** | 0 | 0 | 0 |
| **Scenario7** | 0 | 0 | 0 |
| **Scenario8** | 0 | 0 | 0 |
| **Scenario9** | 0 | 0 | 0 |
| **Scenario10** | 0 | 0 | 0 |
| **Scenario11** | 0 | 0 | 0 |
| **Scenario12** | 0 | 0 | 0 |

Table H.14: Qualitative score transit time benefits North.

| North | Low | Medium | High |
|---|---|---|---|
| **Base case** | 0 | 0 | 0 |
| **Scenario1** | 0 | 0 | 0 |
| **Scenario2** | 0 | 0 | 0 |
| **Scenario3** | 0 | 0 | 0 |
| **Scenario4** | 0 | 0 | 0 |
| **Scenario5** | 0 | 0 | 0 |
| **Scenario6** | 0 | 0 | 0 |
| **Scenario7** | 0 | 0 | 0 |
| **Scenario8** | 0 | 0 | 0 |
| **Scenario9** | 0 | 0 | 0 |
| **Scenario10** | 0 | 0 | 0 |
| **Scenario11** | 0 | 0 | 0 |
| **Scenario12** | 0 | 0 | 0 |

Table H.15: Qualitative score transit time benefits Central.

| North | Low | Medium | High |
|---|---|---|---|
| **Base case** | 0 | 0 | 0 |
| **Scenario1** | 0 | 0 | 0 |
| **Scenario2** | 0 | 0 | 0 |
| **Scenario3** | 0 | 0 | 0 |
| **Scenario4** | 0 | 0 | 0 |
| **Scenario5** | 0 | 0 | 0 |
| **Scenario6** | 0 | 0 | 0 |
| **Scenario7** | 0 | 0 | 0 |
| **Scenario8** | 0 | 0 | 0 |
| **Scenario9** | 0 | 0 | 0 |
| **Scenario10** | 0 | 0 | 0 |
| **Scenario11** | 0 | 0 | 0 |
| **Scenario12** | 0 | 0 | 0 |

Table H.16: Qualitative score transit time benefits South.

| North | Low | Medium | High |
|---|---|---|---|
| **Base case** | 0 | 0 | 0 |
| **Scenario1** | 0 | 0 | 0 |
| **Scenario2** | 0 | 0 | 0 |
| **Scenario3** | 0 | 0 | 0 |
| **Scenario4** | 0 | 0 | 0 |
| **Scenario5** | 0 | 0 | 0 |
| **Scenario6** | 0 | 0 | 0 |
| **Scenario7** | 0 | 0 | 0 |
| **Scenario8** | 0 | 0 | 0 |
| **Scenario9** | 0 | 0 | 0 |
| **Scenario10** | 0 | 0 | 0 |
| **Scenario11** | 0 | 0 | 0 |
| **Scenario12** | 0 | 0 | 0 |

# Appendix I: Sensitivity Analysis

This research has carried out multiple sensitivity analyses. In this appendix all the corresponding tables, those included and not included in the main text are displayed in this appendix.

### *Dispersion factor (μ) of pipeline transport*

The dispersion factor is increased and decreased with 25% of the mode pipeline. The dispersion factor of this mode could not be calibrated and was iteratively found to function well at μ=-0.090.
In this sensitivity analysis the dispersion factor is part of a sensitivity analysis as the factor could not be calibrated.
The dispersion factor is increased with 25% with the expectation that the transport mode will become less attractive, a more negative dispersion factor will decrease the share of the mode. When the dispersion factor is decreased with 25%, the transport mode will become less attractive.

Table I.1: Values of μ in sensitivity analysis.

| | |
|---|---|
| **μ** | -0.090 |
| **μ +25%** | -0.113 |
| **μ -25%** | -0.068 |

### *Dispersion factor +25%*

The share of transport mode decreases considerably across all scenarios.
For the North trajectory the share of pipeline transport in ton-km decreases across all scenarios below 1%, except for one. For the Central and South trajectory, the decline is also considerable. The share in ton-km decreases below 5% in ton-km.

Table I.2: Transport share in ton-km for μ +25% North trajectory.

| **Low** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 44.57% | 0.07% | 54.90% | 0.47% |
| **Scenario2** | 44.51% | 0.07% | 54.87% | 0.56% |
| **Scenario3** | 44.40% | 0.07% | 54.79% | 0.74% |
| **Scenario4** | 44.16% | 0.07% | 54.59% | 1.19% |
| **Scenario5** | 44.70% | 0.07% | 54.92% | 0.31% |
| **Scenario6** | 44.67% | 0.07% | 54.91% | 0.35% |
| **Scenario7** | 44.63% | 0.07% | 54.89% | 0.41% |
| **Scenario8** | 44.56% | 0.07% | 54.86% | 0.51% |
| **Scenario9** | 44.79% | 0.07% | 54.93% | 0.21% |
| **Scenario10** | 44.76% | 0.07% | 54.93% | 0.25% |
| **Scenario11** | 44.72% | 0.07% | 54.92% | 0.29% |
| **Scenario12** | 44.69% | 0.07% | 54.91% | 0.34% |

| **Medium** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 44.33% | 0.04% | 55.22% | 0.42% |
| **Scenario2** | 44.28% | 0.04% | 55.20% | 0.48% |
| **Scenario3** | 44.20% | 0.04% | 55.16% | 0.60% |
| **Scenario4** | 43.99% | 0.04% | 55.03% | 0.94% |
| **Scenario5** | 44.43% | 0.04% | 55.23% | 0.30% |
| **Scenario6** | 44.40% | 0.04% | 55.22% | 0.33% |
| **Scenario7** | 44.38% | 0.04% | 55.21% | 0.37% |
| **Scenario8** | 44.32% | 0.04% | 55.20% | 0.44% |
| **Scenario9** | 44.52% | 0.04% | 55.24% | 0.20% |
| **Scenario10** | 44.48% | 0.04% | 55.23% | 0.24% |
| **Scenario11** | 44.45% | 0.04% | 55.23% | 0.28% |
| **Scenario12** | 44.42% | 0.04% | 55.22% | 0.32% |

| **High** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 44.02% | 0.03% | 55.57% | 0.39% |
| **Scenario2** | 43.98% | 0.03% | 55.56% | 0.43% |
| **Scenario3** | 43.92% | 0.03% | 55.54% | 0.52% |
| **Scenario4** | 43.73% | 0.03% | 55.47% | 0.77% |
| **Scenario5** | 44.11% | 0.03% | 55.58% | 0.29% |
| **Scenario6** | 44.08% | 0.03% | 55.57% | 0.32% |
| **Scenario7** | 44.05% | 0.03% | 55.57% | 0.35% |
| **Scenario8** | 44.01% | 0.03% | 55.56% | 0.40% |
| **Scenario9** | 44.19% | 0.03% | 55.59% | 0.20% |
| **Scenario10** | 44.16% | 0.03% | 55.58% | 0.24% |
| **Scenario11** | 44.12% | 0.03% | 55.58% | 0.27% |
| **Scenario12** | 44.09% | 0.03% | 55.57% | 0.31% |

Table I.3: Transport share in ton-km for μ +25% Central trajectory.

| **Low** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 44.12% | 0.07% | 54.48% | 1.34% |
| **Scenario2** | 43.83% | 0.06% | 54.09% | 2.01% |
| **Scenario3** | 43.45% | 0.06% | 53.35% | 3.13% |
| **Scenario4** | 43.04% | 0.06% | 51.96% | 4.94% |
| **Scenario5** | 44.54% | 0.07% | 54.83% | 0.56% |
| **Scenario6** | 44.44% | 0.07% | 54.76% | 0.73% |
| **Scenario7** | 44.30% | 0.07% | 54.62% | 1.01% |
| **Scenario8** | 44.11% | 0.07% | 54.35% | 1.47% |
| **Scenario9** | 44.67% | 0.07% | 54.90% | 0.36% |
| **Scenario10** | 44.63% | 0.07% | 54.89% | 0.42% |
| **Scenario11** | 44.57% | 0.07% | 54.86% | 0.51% |
| **Scenario12** | 44.48% | 0.07% | 54.81% | 0.64% |

| **Medium** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 43.96% | 0.04% | 54.96% | 1.04% |
| **Scenario2** | 43.69% | 0.04% | 54.68% | 1.59% |
| **Scenario3** | 43.31% | 0.04% | 54.09% | 2.57% |
| **Scenario4** | 42.87% | 0.04% | 52.84% | 4.24% |
| **Scenario5** | 44.30% | 0.04% | 55.18% | 0.48% |
| **Scenario6** | 44.21% | 0.04% | 55.14% | 0.60% |
| **Scenario7** | 44.09% | 0.04% | 55.06% | 0.81% |
| **Scenario8** | 43.92% | 0.04% | 54.88% | 1.17% |
| **Scenario9** | 44.41% | 0.04% | 55.22% | 0.33% |
| **Scenario10** | 44.37% | 0.04% | 55.21% | 0.38% |
| **Scenario11** | 44.31% | 0.04% | 55.20% | 0.45% |
| **Scenario12** | 44.23% | 0.04% | 55.17% | 0.56% |

| **High** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 43.72% | 0.02% | 55.42% | 0.83% |
| **Scenario2** | 43.47% | 0.02% | 55.23% | 1.28% |
| **Scenario3** | 43.08% | 0.02% | 54.79% | 2.11% |
| **Scenario4** | 42.62% | 0.02% | 53.73% | 3.62% |
| **Scenario5** | 43.99% | 0.03% | 55.55% | 0.43% |
| **Scenario6** | 43.92% | 0.03% | 55.53% | 0.53% |
| **Scenario7** | 43.81% | 0.03% | 55.48% | 0.68% |
| **Scenario8** | 43.65% | 0.02% | 55.37% | 0.95% |
| **Scenario9** | 44.08% | 0.03% | 55.57% | 0.32% |
| **Scenario10** | 44.05% | 0.03% | 55.57% | 0.36% |
| **Scenario11** | 44.00% | 0.03% | 55.56% | 0.41% |
| **Scenario12** | 43.92% | 0.03% | 55.55% | 0.51% |

Table I.4: Transport share in ton-km for μ +25% South trajectory.

| **Low** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 44.22% | 0.07% | 54.58% | 1.13% |
| **Scenario2** | 43.95% | 0.07% | 54.28% | 1.71% |
| **Scenario3** | 43.58% | 0.06% | 53.67% | 2.68% |
| **Scenario4** | 43.16% | 0.06% | 52.47% | 4.31% |
| **Scenario5** | 44.57% | 0.07% | 54.85% | 0.51% |
| **Scenario6** | 44.48% | 0.07% | 54.80% | 0.65% |
| **Scenario7** | 44.35% | 0.07% | 54.68% | 0.90% |
| **Scenario8** | 44.17% | 0.07% | 54.45% | 1.31% |
| **Scenario9** | 44.69% | 0.07% | 54.91% | 0.34% |
| **Scenario10** | 44.65% | 0.07% | 54.90% | 0.39% |
| **Scenario11** | 44.59% | 0.07% | 54.87% | 0.47% |
| **Scenario12** | 44.51% | 0.07% | 54.83% | 0.60% |

| **Medium** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 44.05% | 0.04% | 55.03% | 0.88% |
| **Scenario2** | 43.80% | 0.04% | 54.82% | 1.34% |
| **Scenario3** | 43.44% | 0.04% | 54.35% | 2.17% |
| **Scenario4** | 43.00% | 0.04% | 53.32% | 3.65% |
| **Scenario5** | 44.32% | 0.04% | 55.19% | 0.44% |
| **Scenario6** | 44.25% | 0.04% | 55.16% | 0.54% |
| **Scenario7** | 44.14% | 0.04% | 55.10% | 0.73% |
| **Scenario8** | 43.98% | 0.04% | 54.95% | 1.04% |
| **Scenario9** | 44.42% | 0.04% | 55.22% | 0.32% |
| **Scenario10** | 44.39% | 0.04% | 55.22% | 0.36% |
| **Scenario11** | 44.34% | 0.04% | 55.21% | 0.42% |
| **Scenario12** | 44.26% | 0.04% | 55.18% | 0.52% |

| **High** | **Road** | **Rail** | **IWT** | **Pipeline** |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 43.80% | 0.03% | 55.46% | 0.71% |
| **Scenario2** | 43.58% | 0.02% | 55.33% | 1.07% |
| **Scenario3** | 43.22% | 0.02% | 54.99% | 1.77% |
| **Scenario4** | 42.75% | 0.02% | 54.15% | 3.08% |
| **Scenario5** | 44.01% | 0.03% | 55.56% | 0.40% |
| **Scenario6** | 43.95% | 0.03% | 55.54% | 0.48% |
| **Scenario7** | 43.85% | 0.03% | 55.51% | 0.62% |
| **Scenario8** | 43.71% | 0.02% | 55.42% | 0.85% |
| **Scenario9** | 44.09% | 0.03% | 55.57% | 0.31% |
| **Scenario10** | 44.06% | 0.03% | 55.57% | 0.34% |
| **Scenario11** | 44.02% | 0.03% | 55.57% | 0.39% |
| **Scenario12** | 43.95% | 0.03% | 55.55% | 0.48% |

As the shares decrease the reduction in external effects diminish.

Table I.5: NPV external effects North trajectory.

| **NPV (in €million)** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Scenario1** | € 17.17 | € -28.77 | € 19.89 |
| **Scenario2** | € 19.22 | € -27.19 | € 21.16 |
| **Scenario3** | € 23.38 | € -23.89 | € 23.82 |
| **Scenario4** | € 32.81 | € -15.63 | € 31.20 |
| **Scenario5** | € 13.45 | € -31.98 | € 16.92 |
| **Scenario6** | € 14.43 | € -31.06 | € 17.86 |
| **Scenario7** | € 15.68 | € -30.07 | € 18.74 |
| **Scenario8** | € 18.13 | € -28.14 | € 20.33 |
| **Scenario9** | € 11.11 | € -34.46 | € 14.13 |
| **Scenario10** | € 12.02 | € -33.45 | € 15.32 |
| **Scenario11** | € 12.96 | € -32.46 | € 16.40 |
| **Scenario12** | € 14.06 | € -31.46 | € 17.40 |

Table I.6: NPV external effects Central trajectory.

| **NPV (in €million)** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Scenario1** | € 35.77 | € -13.25 | € 32.99 |
| **Scenario2** | € 49.30 | € -0.45 | € 45.07 |
| **Scenario3** | € 70.42 | € 20.77 | € 66.43 |
| **Scenario4** | € 102.56 | € 54.92 | € 102.59 |
| **Scenario5** | € 19.17 | € -27.25 | € 21.13 |
| **Scenario6** | € 22.86 | € -24.09 | € 23.96 |
| **Scenario7** | € 28.75 | € -18.95 | € 28.54 |
| **Scenario8** | € 38.05 | € -10.58 | € 36.09 |
| **Scenario9** | € 14.50 | € -31.07 | € 17.77 |
| **Scenario10** | € 15.83 | € -29.89 | € 18.91 |
| **Scenario11** | € 17.82 | € -28.14 | € 20.54 |
| **Scenario12** | € 20.88 | € -25.39 | € 23.23 |

Table I.7: NPV external effects South trajectory.

| **NPV (in €million)** | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Scenario1** | € 31.58 | € -17.05 | € 29.55 |
| **Scenario2** | € 43.29 | € -6.22 | € 39.55 |
| **Scenario3** | € 62.11 | € 12.30 | € 57.80 |
| **Scenario4** | € 91.64 | € 43.12 | € 89.93 |
| **Scenario5** | € 18.02 | € -28.20 | € 20.31 |
| **Scenario6** | € 21.18 | € -25.55 | € 22.63 |
| **Scenario7** | € 26.39 | € -21.02 | € 26.72 |
| **Scenario8** | € 34.80 | € -13.57 | € 33.34 |
| **Scenario9** | € 14.07 | € -31.44 | € 17.42 |
| **Scenario10** | € 15.23 | € -30.42 | € 18.40 |
| **Scenario11** | € 17.03 | € -28.84 | € 19.88 |
| **Scenario12** | € 19.82 | € -26.33 | € 22.31 |

At last, the increase of the dispersion factor influences the FCBA, especially the operational costs and tariffs. Tariffs rise to high values as the transport volumes decrease, tariffs are multiplied several times compared to μ=-0.090.

Table I.8: Tariffs for the three trajectories when μ +25%.

| North | Low | Medium | High |
|---|---|---|---|
| **Scenario1** | € 7.007 | € 7.939 | € 8.325 |
| **Scenario2** | € 5.963 | € 7.027 | € 7.579 |
| **Scenario3** | € 4.505 | € 5.601 | € 6.333 |
| **Scenario4** | € 2.825 | € 3.622 | € 4.265 |
| **Scenario5** | € 10.339 | € 10.973 | € 10.985 |
| **Scenario6** | € 9.209 | € 9.898 | € 9.960 |
| **Scenario7** | € 8.124 | € 9.004 | € 9.214 |
| **Scenario8** | € 6.499 | € 7.594 | € 8.078 |
| **Scenario9** | € 15.122 | € 16.139 | € 16.355 |
| **Scenario10** | € 12.758 | € 13.459 | € 13.440 |
| **Scenario11** | € 11.040 | € 11.679 | € 11.678 |
| **Scenario12** | € 9.597 | € 10.347 | € 10.460 |

| Central | Low | Medium | High |
|---|---|---|---|
| **Scenario1** | € 1.765 | € 2.288 | € 2.755 |
| **Scenario2** | € 1.164 | € 1.485 | € 1.799 |
| **Scenario3** | € 0.745 | € 0.916 | € 1.084 |
| **Scenario4** | € 0.472 | € 0.552 | € 0.630 |
| **Scenario5** | € 4.172 | € 4.877 | € 5.196 |
| **Scenario6** | € 3.219 | € 3.887 | € 4.257 |
| **Scenario7** | € 2.341 | € 2.918 | € 3.319 |
| **Scenario8** | € 1.607 | € 2.042 | € 2.406 |
| **Scenario9** | € 6.360 | € 6.836 | € 6.888 |
| **Scenario10** | € 5.499 | € 6.033 | € 6.157 |
| **Scenario11** | € 4.567 | € 5.139 | € 5.343 |
| **Scenario12** | € 3.602 | € 4.145 | € 4.366 |

| South | Low | Medium | High |
|---|---|---|---|
| **Scenario1** | € 2.196 | € 2.840 | € 3.381 |
| **Scenario2** | € 1.447 | € 1.861 | € 2.257 |
| **Scenario3** | € 0.916 | € 1.141 | € 1.362 |
| **Scenario4** | € 0.569 | € 0.676 | € 0.780 |
| **Scenario5** | € 4.820 | € 5.542 | € 5.823 |
| **Scenario6** | € 3.788 | € 4.520 | € 4.900 |
| **Scenario7** | € 2.769 | € 3.412 | € 3.820 |
| **Scenario8** | € 1.905 | € 2.414 | € 2.823 |
| **Scenario9** | € 7.043 | € 7.503 | € 7.516 |
| **Scenario10** | € 6.162 | € 6.698 | € 6.792 |
| **Scenario11** | € 5.161 | € 5.757 | € 5.949 |
| **Scenario12** | € 4.087 | € 4.665 | € 4.887 |

### *Dispersion factor -25%*

The -25% has the expectation to increase the share of pipeline transport. This also happens, shares increase swiftly over 50% and 60% in many scenarios (ton-km).

Table I.9: Transport share in ton-km for μ -25% North trajectory.

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 26.59% | 0.05% | 18.72% | 54.64% |
| **Scenario2** | 25.38% | 0.05% | 17.16% | 57.41% |
| **Scenario3** | 24.01% | 0.05% | 15.25% | 60.69% |
| **Scenario4** | 22.64% | 0.05% | 13.26% | 64.05% |
| **Scenario5** | 30.03% | 0.05% | 21.85% | 48.06% |
| **Scenario6** | 29.15% | 0.05% | 20.19% | 50.61% |
| **Scenario7** | 28.15% | 0.05% | 18.81% | 52.98% |
| **Scenario8** | 26.98% | 0.05% | 17.19% | 55.79% |
| **Scenario9** | 33.41% | 0.05% | 26.51% | 40.03% |
| **Scenario10** | 32.60% | 0.05% | 23.42% | 43.93% |
| **Scenario11** | 31.74% | 0.05% | 21.47% | 46.73% |
| **Scenario12** | 30.87% | 0.05% | 20.12% | 48.97% |

| Medium | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 26.24% | 0.03% | 17.42% | 56.31% |
| **Scenario2** | 24.99% | 0.03% | 16.04% | 58.94% |
| **Scenario3** | 23.51% | 0.03% | 14.13% | 62.33% |
| **Scenario4** | 22.07% | 0.03% | 12.09% | 65.81% |
| **Scenario5** | 29.63% | 0.03% | 20.15% | 50.19% |
| **Scenario6** | 28.79% | 0.03% | 18.80% | 52.38% |
| **Scenario7** | 27.82% | 0.03% | 17.68% | 54.46% |
| **Scenario8** | 26.61% | 0.03% | 16.17% | 57.19% |
| **Scenario9** | 33.08% | 0.04% | 24.36% | 42.53% |
| **Scenario10** | 32.30% | 0.03% | 21.45% | 46.21% |
| **Scenario11** | 31.48% | 0.03% | 19.86% | 48.63% |
| **Scenario12** | 30.64% | 0.03% | 18.84% | 50.48% |

| High | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 25.95% | 0.02% | 16.32% | 57.71% |
| **Scenario2** | 24.64% | 0.02% | 15.07% | 60.26% |
| **Scenario3** | 23.01% | 0.02% | 13.15% | 63.82% |
| **Scenario4** | 21.51% | 0.02% | 11.04% | 67.43% |
| **Scenario5** | 29.25% | 0.02% | 18.72% | 52.01% |
| **Scenario6** | 28.45% | 0.02% | 17.67% | 53.86% |
| **Scenario7** | 27.51% | 0.02% | 16.76% | 55.70% |
| **Scenario8** | 26.26% | 0.02% | 15.32% | 58.39% |
| **Scenario9** | 32.75% | 0.02% | 22.37% | 44.86% |
| **Scenario10** | 32.00% | 0.02% | 19.76% | 48.22% |
| **Scenario11** | 31.19% | 0.02% | 18.54% | 50.24% |
| **Scenario12** | 30.40% | 0.02% | 17.81% | 51.76% |

Table I.10: Transport share in ton-km for μ -25% Central trajectory.

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 22.35% | 0.05% | 12.74% | 64.85% |
| **Scenario2** | 21.61% | 0.05% | 11.87% | 66.46% |
| **Scenario3** | 20.96% | 0.05% | 11.24% | 67.74% |
| **Scenario4** | 20.37% | 0.05% | 10.79% | 68.79% |
| **Scenario5** | 26.67% | 0.05% | 16.60% | 56.68% |
| **Scenario6** | 25.80% | 0.05% | 15.32% | 58.83% |
| **Scenario7** | 24.91% | 0.05% | 14.11% | 60.93% |
| **Scenario8** | 24.06% | 0.05% | 13.11% | 62.78% |
| **Scenario9** | 30.70% | 0.05% | 19.73% | 49.52% |
| **Scenario10** | 30.06% | 0.05% | 18.86% | 51.02% |
| **Scenario11** | 29.35% | 0.05% | 17.84% | 52.75% |
| **Scenario12** | 28.56% | 0.05% | 16.68% | 54.71% |

| Medium | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 21.77% | 0.03% | 11.59% | 66.60% |
| **Scenario2** | 21.06% | 0.03% | 10.81% | 68.09% |
| **Scenario3** | 20.45% | 0.03% | 10.29% | 69.22% |
| **Scenario4** | 19.90% | 0.03% | 9.93% | 70.14% |
| **Scenario5** | 26.28% | 0.03% | 15.56% | 58.13% |
| **Scenario6** | 25.33% | 0.03% | 14.21% | 60.43% |
| **Scenario7** | 24.39% | 0.03% | 12.96% | 62.62% |
| **Scenario8** | 23.52% | 0.03% | 12.00% | 64.45% |
| **Scenario9** | 30.51% | 0.03% | 18.54% | 50.91% |
| **Scenario10** | 29.88% | 0.03% | 17.82% | 52.26% |
| **Scenario11** | 29.17% | 0.03% | 16.86% | 53.94% |
| **Scenario12** | 28.34% | 0.03% | 15.67% | 55.95% |

| High | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 21.19% | 0.02% | 10.58% | 68.21% |
| **Scenario2** | 20.51% | 0.02% | 9.91% | 69.55% |
| **Scenario3** | 19.95% | 0.02% | 9.49% | 70.54% |
| **Scenario4** | 19.45% | 0.02% | 9.20% | 71.33% |
| **Scenario5** | 25.89% | 0.02% | 14.68% | 59.40% |
| **Scenario6** | 24.86% | 0.02% | 13.22% | 61.90% |
| **Scenario7** | 23.84% | 0.02% | 11.93% | 64.21% |
| **Scenario8** | 22.94% | 0.02% | 11.02% | 66.01% |
| **Scenario9** | 30.30% | 0.02% | 17.59% | 52.08% |
| **Scenario10** | 29.69% | 0.02% | 17.00% | 53.29% |
| **Scenario11** | 28.97% | 0.02% | 16.07% | 54.94% |
| **Scenario12** | 28.09% | 0.02% | 14.83% | 57.05% |

Table I.11: Transport share in ton-km for μ -25% South trajectory.

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 22.71% | 0.05% | 13.23% | 64.02% |
| **Scenario2** | 21.89% | 0.05% | 12.19% | 65.87% |
| **Scenario3** | 21.17% | 0.05% | 11.44% | 67.34% |
| **Scenario4** | 20.53% | 0.05% | 10.91% | 68.51% |
| **Scenario5** | 27.04% | 0.05% | 17.15% | 55.76% |
| **Scenario6** | 26.14% | 0.05% | 15.84% | 57.97% |
| **Scenario7** | 25.21% | 0.05% | 14.52% | 60.22% |
| **Scenario8** | 24.30% | 0.05% | 13.39% | 62.26% |
| **Scenario9** | 30.95% | 0.05% | 20.09% | 48.90% |
| **Scenario10** | 30.31% | 0.05% | 19.23% | 50.41% |
| **Scenario11** | 29.60% | 0.05% | 18.22% | 52.13% |
| **Scenario12** | 28.80% | 0.05% | 17.04% | 54.11% |

| Medium | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 48.59% | 0.05% | 51.36% | |
| **Scenario1** | 22.12% | 0.03% | 12.05% | 65.79% |
| **Scenario2** | 21.32% | 0.03% | 11.09% | 67.55% |
| **Scenario3** | 20.65% | 0.03% | 10.45% | 68.87% |
| **Scenario4** | 20.06% | 0.03% | 10.02% | 69.89% |
| **Scenario5** | 26.67% | 0.03% | 16.13% | 57.17% |
| **Scenario6** | 25.71% | 0.03% | 14.75% | 59.50% |
| **Scenario7** | 24.71% | 0.03% | 13.37% | 61.89% |
| **Scenario8** | 23.76% | 0.03% | 12.26% | 63.95% |
| **Scenario9** | 30.75% | 0.03% | 18.82% | 50.39% |
| **Scenario10** | 30.13% | 0.03% | 18.14% | 51.70% |
| **Scenario11** | 29.42% | 0.03% | 17.23% | 53.32% |
| **Scenario12** | 28.59% | 0.03% | 16.04% | 55.33% |

| High | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 45.63% | 0.02% | 54.35% | |
| **Scenario1** | 21.54% | 0.02% | 11.01% | 67.43% |
| **Scenario2** | 20.76% | 0.02% | 10.14% | 69.08% |
| **Scenario3** | 20.13% | 0.02% | 9.62% | 70.23% |
| **Scenario4** | 19.59% | 0.02% | 9.28% | 71.11% |
| **Scenario5** | 26.31% | 0.02% | 15.28% | 58.38% |
| **Scenario6** | 25.27% | 0.02% | 13.81% | 60.90% |
| **Scenario7** | 24.18% | 0.02% | 12.34% | 63.46% |
| **Scenario8** | 23.19% | 0.02% | 11.26% | 65.53% |
| **Scenario9** | 30.53% | 0.02% | 17.80% | 51.64% |
| **Scenario10** | 29.93% | 0.02% | 17.27% | 52.78% |
| **Scenario11** | 29.22% | 0.02% | 16.44% | 54.32% |
| **Scenario12** | 28.36% | 0.02% | 15.22% | 56.39% |

When μ is decreased the shares rise, thus also more reduction in external effects is estimated.

Table I.12: NPV external effects North trajectory.

| NPV (in €million) | Low | | Medium | | High | |
|---|---|---|---|---|---|---|
| Scenario1 | € | 894.26 | € | 967.49 | € | 1,166.78 |
| Scenario2 | € | 936.57 | € | 1,012.75 | € | 1,216.80 |
| Scenario3 | € | 984.72 | € | 1,067.62 | € | 1,281.64 |
| Scenario4 | € | 1,033.42 | € | 1,123.15 | € | 1,346.57 |
| Scenario5 | € | 785.55 | € | 853.68 | € | 1,045.47 |
| Scenario6 | € | 824.42 | € | 891.68 | € | 1,083.04 |
| Scenario7 | € | 861.61 | € | 928.84 | € | 1,121.01 |
| Scenario8 | € | 903.87 | € | 974.56 | € | 1,171.99 |
| Scenario9 | € | 657.64 | € | 716.37 | € | 897.26 |
| Scenario10 | € | 712.80 | € | 774.20 | € | 957.59 |
| Scenario11 | € | 755.30 | € | 816.05 | € | 998.99 |
| Scenario12 | € | 790.91 | € | 850.19 | € | 1,032.19 |

Table I.13: NPV external effects Central trajectory.

| NPV (in €million) | Low | | Medium | | High | |
|---|---|---|---|---|---|---|
| Scenario1 | € | 1,045 | € | 1,136 | € | 1,361 |
| Scenario2 | € | 1,069 | € | 1,162 | € | 1,388 |
| Scenario3 | € | 1,090 | € | 1,182 | € | 1,409 |
| Scenario4 | € | 1,107 | € | 1,199 | € | 1,427 |
| Scenario5 | € | 916 | € | 989 | € | 1,189 |
| Scenario6 | € | 948 | € | 1,025 | € | 1,233 |
| Scenario7 | € | 978 | € | 1,061 | € | 1,275 |
| Scenario8 | € | 1,006 | € | 1,092 | € | 1,310 |
| Scenario9 | € | 799 | € | 858 | € | 1,039 |
| Scenario10 | € | 823 | € | 882 | € | 1,063 |
| Scenario11 | € | 849 | € | 910 | € | 1,094 |
| Scenario12 | € | 878 | € | 942 | € | 1,132 |

Table I.14: NPV external effects South trajectory.

| NPV (in €million) | Low | | Medium | | High | |
|---|---|---|---|---|---|---|
| Scenario1 | € | 1,032.38 | € | 1,122.30 | € | 1,345.98 |
| Scenario2 | € | 1,060.19 | € | 1,152.12 | € | 1,378.21 |
| Scenario3 | € | 1,083.26 | € | 1,175.68 | € | 1,402.42 |
| Scenario4 | € | 1,102.40 | € | 1,194.77 | € | 1,421.69 |
| Scenario5 | € | 903.01 | € | 973.66 | € | 1,171.10 |
| Scenario6 | € | 935.18 | € | 1,010.77 | € | 1,215.57 |
| Scenario7 | € | 968.01 | € | 1,048.89 | € | 1,261.34 |
| Scenario8 | € | 998.57 | € | 1,083.29 | € | 1,300.85 |
| Scenario9 | € | 789.53 | € | 848.15 | € | 1,029.23 |
| Scenario10 | € | 813.40 | € | 871.86 | € | 1,053.28 |
| Scenario11 | € | 839.67 | € | 899.47 | € | 1,082.99 |
| Scenario12 | € | 869.03 | € | 932.15 | € | 1,120.52 |

At last, the decrease of the dispersion factor influences the FCBA, especially the operational costs and tariffs. Tariffs decrease as the transport volumes rise.

Table I.15: Tariffs for the three trajectories when μ -25%.

| North | Low | Medium | High |
|---|---|---|---|
| Scenario1 | € 0.071 | € 0.071 | € 0.068 |
| Scenario2 | € 0.068 | € 0.068 | € 0.066 |
| Scenario3 | € 0.065 | € 0.065 | € 0.063 |
| Scenario4 | € 0.062 | € 0.062 | € 0.060 |
| Scenario5 | € 0.079 | € 0.078 | € 0.075 |
| Scenario6 | € 0.076 | € 0.075 | € 0.072 |
| Scenario7 | € 0.073 | € 0.073 | € 0.070 |
| Scenario8 | € 0.070 | € 0.070 | € 0.068 |
| Scenario9 | € 0.093 | € 0.090 | € 0.085 |
| Scenario10 | € 0.086 | € 0.084 | € 0.080 |
| Scenario11 | € 0.082 | € 0.080 | € 0.077 |
| Scenario12 | € 0.079 | € 0.078 | € 0.075 |

| Central | Low | Medium | High |
|---|---|---|---|
| Scenario1 | € 0.044 | € 0.044 | € 0.042 |
| Scenario2 | € 0.044 | € 0.043 | € 0.041 |
| Scenario3 | € 0.043 | € 0.042 | € 0.041 |
| Scenario4 | € 0.042 | € 0.042 | € 0.040 |
| Scenario5 | € 0.050 | € 0.049 | € 0.047 |
| Scenario6 | € 0.048 | € 0.047 | € 0.045 |
| Scenario7 | € 0.047 | € 0.046 | € 0.044 |
| Scenario8 | € 0.046 | € 0.045 | € 0.043 |
| Scenario9 | € 0.056 | € 0.055 | € 0.052 |
| Scenario10 | € 0.054 | € 0.054 | € 0.051 |
| Scenario11 | € 0.053 | € 0.052 | € 0.050 |
| Scenario12 | € 0.051 | € 0.051 | € 0.049 |

| South | Low | Medium | High |
|---|---|---|---|
| Scenario1 | € 0.047 | € 0.046 | € 0.044 |
| Scenario2 | € 0.046 | € 0.045 | € 0.043 |
| Scenario3 | € 0.045 | € 0.045 | € 0.043 |
| Scenario4 | € 0.045 | € 0.044 | € 0.042 |
| Scenario5 | € 0.053 | € 0.052 | € 0.050 |
| Scenario6 | € 0.051 | € 0.050 | € 0.048 |
| Scenario7 | € 0.049 | € 0.049 | € 0.047 |
| Scenario8 | € 0.048 | € 0.047 | € 0.045 |
| Scenario9 | € 0.059 | € 0.058 | € 0.055 |
| Scenario10 | € 0.057 | € 0.057 | € 0.054 |
| Scenario11 | € 0.056 | € 0.055 | € 0.053 |
| Scenario12 | € 0.054 | € 0.053 | € 0.051 |

### *Discount rate reduced to 3%*

The discount rate was also put in a sensitivity analysis, by reducing a discount rate the value of a cost or a benefit in the future is increased. So, costs and benefits have higher present value.
With the reduction of the discount rate the reductions in external effects increase.

Table I.16: Comparison in NPV SCBA 3% discount rate North trajectory.

| **3% DR** | | | |
|---|---|---|---|
| **North** | | | |
| **NPV (in €million)** | **Low** | **Medium** | **High** |
| **Scenario1** | € 204.55 | € 155.22 | € 221.01 |
| **Scenario2** | € 300.05 | € 269.01 | € 358.44 |
| **Scenario3** | € 426.53 | € 423.59 | € 547.80 |
| **Scenario4** | € 571.11 | € 603.14 | € 772.09 |
| **Scenario5** | € 87.44 | € 27.21 | € 81.12 |
| **Scenario6** | € 131.96 | € 74.56 | € 131.58 |
| **Scenario7** | € 201.52 | € 153.13 | € 220.62 |
| **Scenario8** | € 303.79 | € 275.84 | € 369.14 |
| **Scenario9** | € 41.78 | € -16.00 | € 40.40 |
| **Scenario10** | € 58.33 | € -0.72 | € 54.50 |
| **Scenario11** | € 87.60 | € 28.46 | € 83.63 |
| **Scenario12** | € 136.57 | € 80.65 | € 139.23 |

| **4.5% DR** | | | |
|---|---|---|---|
| **North** | | | |
| **NPV (in €million)** | **Low** | **Medium** | **High** |
| **Scenario1** | € 164.09 | € 122.38 | € 176.92 |
| **Scenario2** | € 239.99 | € 212.47 | € 285.30 |
| **Scenario3** | € 340.36 | € 334.74 | € 434.73 |
| **Scenario4** | € 455.08 | € 476.66 | € 611.42 |
| **Scenario5** | € 70.73 | € 20.48 | € 65.63 |
| **Scenario6** | € 106.32 | € 58.31 | € 105.92 |
| **Scenario7** | € 161.81 | € 120.86 | € 176.72 |
| **Scenario8** | € 243.06 | € 218.02 | € 293.95 |
| **Scenario9** | € 33.98 | € -14.37 | € 32.70 |
| **Scenario10** | € 47.31 | € -2.04 | € 44.10 |
| **Scenario11** | € 70.81 | € 21.39 | € 44.10 |
| **Scenario12** | € 110.00 | € 63.15 | € 112.00 |

Table I.17: Comparison in NPV SCBA 3% discount rate Central trajectory.

| DR 3% | | | |
|---|---|---|---|
| **Central** | | | |
| **NPV (in €million)** | **Low** | **Medium** | **High** |
| **Scenario1** | € 612.27 | € 653.67 | € 834.94 |
| **Scenario2** | € 693.04 | € 748.44 | € 946.48 |
| **Scenario3** | € 759.93 | € 822.05 | € 1,027.14 |
| **Scenario4** | € 812.91 | € 876.73 | € 1,083.46 |
| **Scenario5** | € 341.10 | € 322.48 | € 427.72 |
| **Scenario6** | € 427.20 | € 430.71 | € 564.89 |
| **Scenario7** | € 515.96 | € 541.26 | € 703.63 |
| **Scenario8** | € 598.52 | € 639.62 | € 820.49 |
| **Scenario9** | € 155.31 | € 101.53 | € 162.33 |
| **Scenario10** | € 207.45 | € 161.53 | € 231.06 |
| **Scenario11** | € 274.15 | € 242.49 | € 329.66 |
| **Scenario12** | € 353.67 | € 343.16 | € 458.92 |

| DR 4.5% | | | |
|---|---|---|---|
| **Central** | | | |
| **NPV (in €million)** | **Low** | **Medium** | **High** |
| **Scenario1** | € 487.81 | € 516.71 | € 661.02 |
| **Scenario2** | € 552.28 | € 592.21 | € 749.76 |
| **Scenario3** | € 606.02 | € 651.37 | € 814.71 |
| **Scenario4** | € 648.88 | € 695.75 | € 860.59 |
| **Scenario5** | € 272.62 | € 254.82 | € 340.01 |
| **Scenario6** | € 340.83 | € 340.18 | € 447.79 |
| **Scenario7** | € 411.23 | € 427.51 | € 557.01 |
| **Scenario8** | € 476.95 | € 505.65 | € 649.74 |
| **Scenario9** | € 124.95 | € 79.80 | € 130.41 |
| **Scenario10** | € 166.49 | € 127.53 | € 185.08 |
| **Scenario11** | € 219.43 | € 191.57 | € 185.08 |
| **Scenario12** | € 282.39 | € 270.86 | € 364.17 |

Table I.18: Comparison in NPV SCBA 3% discount rate South trajectory.

| 3% DR | | | |
|---|---|---|---|
| South | | | |
| NPV (in €mill | Low | Medium | High |
| Scenario1 | € 572.29 | € 604.85 | € 774.64 |
| Scenario2 | € 662.33 | € 713.10 | € 905.85 |
| Scenario3 | € 738.24 | € 798.70 | € 1,002.11 |
| Scenario4 | € 798.46 | € 862.17 | € 1,068.80 |
| Scenario5 | € 305.43 | € 278.21 | € 372.41 |
| Scenario6 | € 391.82 | € 386.06 | € 508.03 |
| Scenario7 | € 485.12 | € 503.20 | € 656.48 |
| Scenario8 | € 574.74 | € 611.81 | € 788.15 |
| Scenario9 | € 136.35 | € 80.48 | € 139.10 |
| Scenario10 | € 185.00 | € 135.29 | € 200.52 |
| Scenario11 | € 249.18 | € 211.65 | € 291.33 |
| Scenario12 | € 328.77 | € 311.33 | € 417.53 |

| 4.5% DR | | | |
|---|---|---|---|
| South | | | |
| NPV (in €mill | Low | Medium | High |
| Scenario1 | € 456.02 | € 478.01 | € 613.42 |
| Scenario2 | € 527.73 | € 563.98 | € 717.31 |
| Scenario3 | € 588.55 | € 632.54 | € 794.47 |
| Scenario4 | € 637.15 | € 683.90 | € 848.60 |
| Scenario5 | € 244.35 | € 219.87 | € 296.49 |
| Scenario6 | € 312.81 | € 304.97 | € 403.14 |
| Scenario7 | € 386.75 | € 397.41 | € 519.82 |
| Scenario8 | € 457.99 | € 483.50 | € 623.99 |
| Scenario9 | € 109.80 | € 62.99 | € 111.86 |
| Scenario10 | € 148.62 | € 106.69 | € 160.84 |
| Scenario11 | € 199.64 | € 167.22 | € 160.84 |
| Scenario12 | € 262.69 | € 245.82 | € 331.79 |

## *Completion date reduced*

In the completion date reduction, the project alternative is constructed in 1 year opposed to 5 years. By reducing the completion data, investment costs are put first, but the alternative is also operational earlier on.

This results in more reductions of external effects for the SCBA for Central and South trajectory, where in the North trajectory this leads to less reductions of external effects.

For the tariffs in most cases an increase can be seen, but in the high growth scenarios a reduction is common.

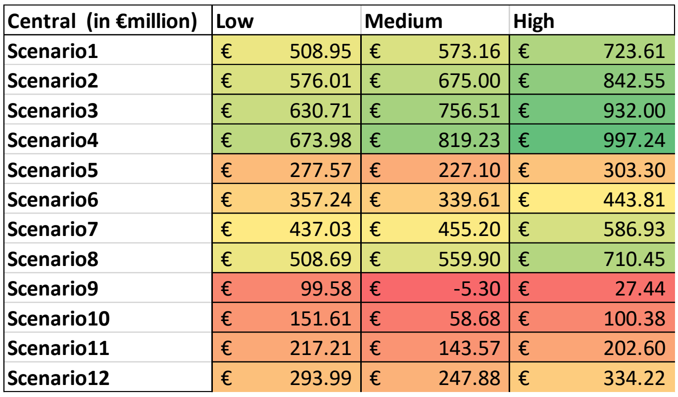
Table I.19: NPV SCBA North trajectory completion date reduced.

| North (in €million) | Low | Medium | High |
|---|---|---|---|
| Scenario1 | € 145.26 | € 50.92 | € 88.69 |
| Scenario2 | € 234.78 | € 170.33 | € 230.87 |
| Scenario3 | € 349.18 | € 331.97 | € 426.64 |
| Scenario4 | € 474.58 | € 519.73 | € 658.13 |
| Scenario5 | € 30.86 | € -85.57 | € -59.89 |
| Scenario6 | € 75.75 | € -34.33 | € -5.47 |
| Scenario7 | € 144.37 | € 49.66 | € 89.06 |
| Scenario8 | € 242.64 | € 178.68 | € 243.30 |
| Scenario9 | € -16.84 | € -134.26 | € -106.37 |
| Scenario10 | € 0.64 | € -116.90 | € -90.15 |
| Scenario11 | € 31.04 | € -84.57 | € -57.81 |
| Scenario12 | € 80.92 | € -27.72 | € 2.70 |

Table I.20: Tariffs North trajectory completion date reduced.

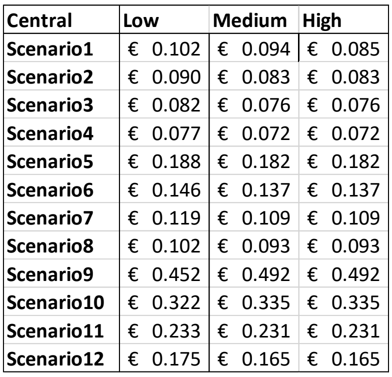
| North | Low | Medium | High |
|---|---|---|---|
| Scenario1 | € 0.444 | € 0.477 | € 0.501 |
| Scenario2 | € 0.287 | € 0.290 | € 0.286 |
| Scenario3 | € 0.192 | € 0.187 | € 0.177 |
| Scenario4 | € 0.139 | € 0.131 | € 0.120 |
| Scenario5 | € 1.175 | € 1.421 | € 1.658 |
| Scenario6 | € 0.720 | € 0.821 | € 0.912 |
| Scenario7 | € 0.438 | € 0.469 | € 0.491 |
| Scenario8 | € 0.272 | € 0.273 | € 0.267 |
| Scenario9 | € 2.891 | € 3.539 | € 3.986 |
| Scenario1 | € 1.886 | € 2.319 | € 2.687 |
| Scenario1 | € 1.144 | € 1.362 | € 1.558 |
| Scenario1 | € 0.672 | € 0.760 | € 0.837 |

Table I.21: NPV SCBA Central trajectory completion date reduced.



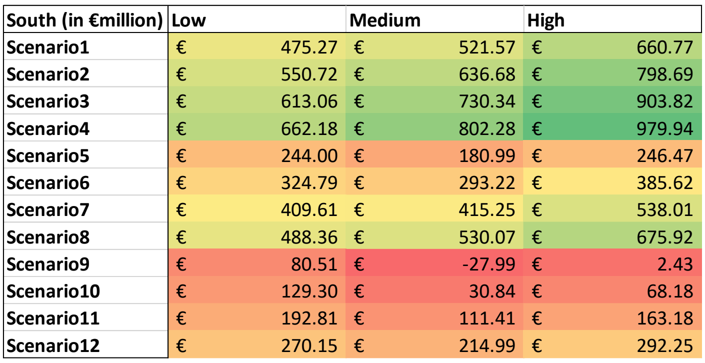
| Central (in €million) | Low | Medium | High |
|---|---|---|---|
| Scenario1 | € 508.95 | € 573.16 | € 723.61 |
| Scenario2 | € 576.01 | € 675.00 | € 842.55 |
| Scenario3 | € 630.71 | € 756.51 | € 932.00 |
| Scenario4 | € 673.98 | € 819.23 | € 997.24 |
| Scenario5 | € 277.57 | € 227.10 | € 303.30 |
| Scenario6 | € 357.24 | € 339.61 | € 443.81 |
| Scenario7 | € 437.03 | € 455.20 | € 586.93 |
| Scenario8 | € 508.69 | € 559.90 | € 710.45 |
| Scenario9 | € 99.58 | € -5.30 | € 27.44 |
| Scenario10 | € 151.61 | € 58.68 | € 100.38 |
| Scenario11 | € 217.21 | € 143.57 | € 202.60 |
| Scenario12 | € 293.99 | € 247.88 | € 334.22 |

Table I.22: Tariffs Central trajectory completion date reduced.



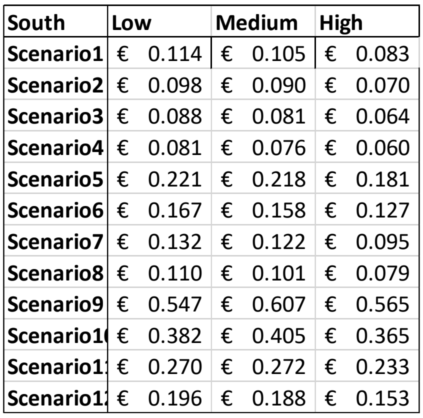
| Central | Low | Medium | High |
|---|---|---|---|
| Scenario1 | € 0.102 | € 0.094 | € 0.085 |
| Scenario2 | € 0.090 | € 0.083 | € 0.083 |
| Scenario3 | € 0.082 | € 0.076 | € 0.076 |
| Scenario4 | € 0.077 | € 0.072 | € 0.072 |
| Scenario5 | € 0.188 | € 0.182 | € 0.182 |
| Scenario6 | € 0.146 | € 0.137 | € 0.137 |
| Scenario7 | € 0.119 | € 0.109 | € 0.109 |
| Scenario8 | € 0.102 | € 0.093 | € 0.093 |
| Scenario9 | € 0.452 | € 0.492 | € 0.492 |
| Scenario10 | € 0.322 | € 0.335 | € 0.335 |
| Scenario11 | € 0.233 | € 0.231 | € 0.231 |
| Scenario12 | € 0.175 | € 0.165 | € 0.165 |

Table I.23: NPV SCBA South trajectory completion date reduced.



| South (in €million) | Low | Medium | High |
|---|---|---|---|
| Scenario1 | € 475.27 | € 521.57 | € 660.77 |
| Scenario2 | € 550.72 | € 636.68 | € 798.69 |
| Scenario3 | € 613.06 | € 730.34 | € 903.82 |
| Scenario4 | € 662.18 | € 802.28 | € 979.94 |
| Scenario5 | € 244.00 | € 180.99 | € 246.47 |
| Scenario6 | € 324.79 | € 293.22 | € 385.62 |
| Scenario7 | € 409.61 | € 415.25 | € 538.01 |
| Scenario8 | € 488.36 | € 530.07 | € 675.92 |
| Scenario9 | € 80.51 | € -27.99 | € 2.43 |
| Scenario10 | € 129.30 | € 30.84 | € 68.18 |
| Scenario11 | € 192.81 | € 111.41 | € 163.18 |
| Scenario12 | € 270.15 | € 214.99 | € 292.25 |

Table I.24: Tariffs South trajectory completion date reduced.



| South | Low | Medium | High |
|---|---|---|---|
| Scenario1 | € 0.114 | € 0.105 | € 0.083 |
| Scenario2 | € 0.098 | € 0.090 | € 0.070 |
| Scenario3 | € 0.088 | € 0.081 | € 0.064 |
| Scenario4 | € 0.081 | € 0.076 | € 0.060 |
| Scenario5 | € 0.221 | € 0.218 | € 0.181 |
| Scenario6 | € 0.167 | € 0.158 | € 0.127 |
| Scenario7 | € 0.132 | € 0.122 | € 0.095 |
| Scenario8 | € 0.110 | € 0.101 | € 0.079 |
| Scenario9 | € 0.547 | € 0.607 | € 0.565 |
| Scenario1 | € 0.382 | € 0.405 | € 0.365 |
| Scenario1 | € 0.270 | € 0.272 | € 0.233 |
| Scenario1 | € 0.196 | € 0.188 | € 0.153 |

# Appendix J: Excel guide

This research contains several Microsoft Excel files, in this appendix the Excel files are summarised and is explained which Excel files are connected/linked to each other.
Furthermore the second part of the appendix explains what can be found in every file.

## *Excel files and connections*

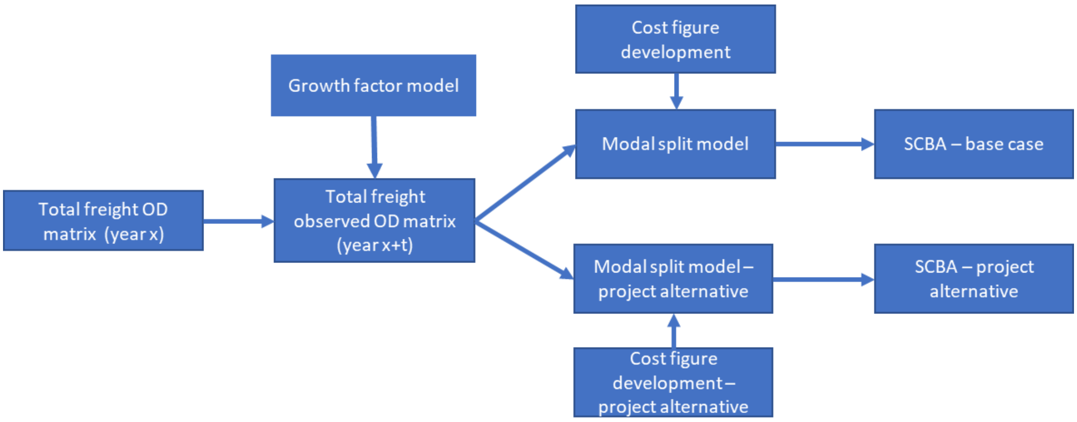


Figure J.1: Excel files and interconnections.

The top box indicates the transported tons data file provided by the Flemish department of Mobility. This file contained out of scope data and this file was filtered to the 'Transported tons OD base file'. Then separate files were created for cost figure development for the base case alternative and the project alternative. These files contain the costs of transport over time, in the project alternative file the pipeline is added to the other transport modes.
Furthermore, a growth factor model was constructed to simulate the growth of transport.
Hereafter, again two files are made for the modal split model, one for the base case and one for the project alternative.
Then, the SCBA base case and SCBA project alternative files follow. In these files the assignment of tons to transport modes in the appraisal period is made. Followed by the resulting tons transport per transport, modal share and modal share in ton-km.
Furthermore, the SCBA with quantifiable external effects are developed in these files.

The SCBA base case alternative file also contains the FCBA for the project alternative, output of various transport metrics in the different scenarios and tabs with the sensitivity analysis.

## *Excel files contents*

### *Total freight OD matrix*

The total matrix of transported tonnes file is called 'Ton-HB-Vlaanderen-Ruhrgebied-perVVW&NST'. This file contains the data acquired form the Flemish department of Mobility. It contains the origin and destination of transport for three transport modes (road, rail and inland water transport). The transported tonnes are for the base year 2010.
Furthermore, the file is split per tab for every NST product group.

### *Total freight observed OD matrix*

The next file is This file is called 'Tonnen vervoerd (opgeschoond bestand) (version 10 juli)'. The file contains the data from the Total freight OD matrix but is filtered to the observed zones of the geographical scope of this research. Therefore, this file contains the data on the three transport modes, the three observed NST product groups and the NUTS zones observed.

### *Growth factor model*

The growth factor model contains the expected growth of transport streams.
The growth models are low, medium, high and have the following growth rates per product group.

Table J.1: Transport demand forecast until 2030.

| Present – 2030 | Low | Medium | High |
|---|---|---|---|
| NST2 | -0.4% | -0.2% | +0.1% |
| NST7 | -0.2% | -0.1% | +0.1% |
| NST8 | +1.8% | +2.3% | +2.9% |

Table J.2: Transport demand forecast 2031-2055.

| 2031 – 2050 | Low | Medium | High |
|---|---|---|---|
| NST2 | -0.6% | -0.3% | +0.1% |
| NST7 | -0.4% | -0.2% | +0.1% |
| NST8 | +0.6% | +1.0% | +1.3% |

Table J.1 displays the cost figure increases or decreases on a yearly basis up to 2030. So, with the OD data used these figures are used to represent the growth figures from 2010 to 2030.
Table J.2 displays the costs figure increases and decreases for the product groups from 2031 up to 2055.

### *Cost figure development (- transport alternative)*

The cost figure development file is made for the base case and for the project alternative.
The cost figure increases are discussed in section 4.4 and visualized in table J.3.

Table J.3: Transport costs growth (own creation).

| | **Low** | **Medium** | **High** |
|---|---|---|---|
| **Road** | +2.1% | +2.6% | +3.1% |
| **Rail** | +2.5% | +3.0% | +3.5% |
| **IWT** | +1.9% | +2.4% | +2.9% |
| **Pipeline** | +1.9% | +2.4% | +2.9% |

The figures for the growth of costs are based on the utility functions and their calibrated parameters for the modes of road, rail and IWT. For pipeline the parameters are based on the parameters of the calibrated modes and the utility function scenarios.

The cost figure development file is consisting of various tabs, one tab for every NST product group and their corresponding growth scenario. So, there are nine tabs with three growth scenarios per product group. The cost figures are displayed for every year of the appraisal period.

The file 'cost figure development' contains three transport modes, road, rail and IWT. The other file, 'Cost figure development – project alternative' also includes the pipeline transport mode.

### *Modal split model (- project alternative)*

The model split model contains multiple tabs, all will be shortly discussed in this section. Again, for the base case and the project alternative separate files are used. The base case file is called 'Model split model', for the calibrated modes of transport. And the file containing the project alternative is called 'Modal split model – project alternative'.

### *NST2/7/8*

First tabs are containing the filtered data for the observed OD pairs. This contains the plain data that is filtered from the large OD data file.

### *Mode choice models*

Then the mode choice models have separate tabs per product group. The base case file will have separate product groups and contains different models, which can be recognized by 'NST.. model ..'. The project alternative file only contains model 3, as model 3 was deemed most precise considering the used explanatory variables.
These tabs will contain the result of the deterrence function and the values of the parameters. Followed by the calculated shares for the base year 2010 and next to that the observed shares.

The modal split file for the base case then displays metrics to calculate the sum of squared errors (SSE) and Standard Error (SE).

### *Calibration results*

In the file 'Modal split model' a tab for the calibration results is added. On this tab all the tables which are in Annex D are displayed and discussed.

### *Calculation sheet*

In the tab 'Calculation sheet' some calculations are made, and some important constants are stated. For example, transport characteristics, average operating speed of road transport and the average batch sizes of the product groups. And a zoning system, which corresponds to the Region matrix (also separate tab).

### *Skim*

The skim matrix tab consists of the infrastructural link matrices, also discussed in Annex D. Every mode has a skim matrix. The skim matrix tells the mode choice model either if there is an infrastructural link (1) or is no infrastructural link (0).

### *Distance and time matrix*

The following tab is providing the distance matrix for every transport mode between the OD pairs. The time and distance are used in the modal split models. Time and distance for rail and IWT is derived from open-source tools of Bureau Voorlichting Binnenvaart and Signal. Road transport distances are calculated using TERCET data files by the European Union and an average speed of 50 km/h based on research.

### *Region matrix*

The region matrix tells the division of regions assumed in the modal split model. There are three regions modelled, national transport within Flanders this is region 1. International transport between Flanders and NRW, this is region 0. And at last, region 2 which is transport from or to the Port of Antwerp.

### NUTS zones

At last, the modal split files contain a tab with information on the NUTS zones. The German NUTS zones are displayed as a ‘DEA..’, this tab indicates which district this is.

### *SCBA (- project alternative)*

The SCBA (- project alternative) files are linked to the modal split models, but also the cost figure development models and the growth scenario model files.
The SCBA file for the base case is called ‘SCBA base case – incl results project alternative’, this file is also containing the results of the project alternatives, so including the SCBA and FCBA of the project alternative.
The file for the project alternative, ‘SCBA project alternative’, is limited to the results of the external effects for the project alternative and partially the FCBA of the project alternative. For the complete overview, the ‘SCBA base case – incl results project alternative’ file with tabs FCBA is complete.

Both the SCBA files contain the results of the SCBA, and external effects estimates on the results tabs. Furthermore, this file contains the detailed results on volume, ton-kms and external effects per mode, product group and growth scenario.
As the project alternative contains multiple scenarios a special tab in the ‘SCBA base case – incl results project alternative’ is made on tab ‘Scenario mgmt sheet’, via this tab all scenarios can viewed and it is possible to make pivot tables of the scenarios.

There are two FCBA tabs in the ‘SCBA base case – incl results project alternative’, one estimates the tariffs in €/ton-km and the other tab estimates the tariffs on €/ton.

# Appendix K: Scientific paper

# Mode choice model with limited data: Case pipeline transport in the Antwerp – Ruhr region

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**Abstract -** The Flemish government is in pursuit of reaching their mobility and environment goals for 2040 and onwards. Therefore, the Flemish government sees building pipeline infrastructure as an option for transport of liquid bulk goods in the Antwerp – Ruhr trajectory. Pipeline transport is considered as an environmental friendly transport mode, which also offers opportunities to relief the stress on the Flemish transport infrastructure. At present, several pipeline systems operate in this region, though (chemical) companies in Flanders and the Ruhr region request for additional pipelines and capacity. As of 2016 the Flemish government is researching the need and opportunities for additional pipeline infrastructure. This paper is focused on developing a mode choice model with limited to missing aggregated transport data between origin and destination pairs, suitable for estimating effects in cost-benefit analysis. Mode choice models can be a tool to support substantiation of the estimated effects in the cost-benefit analysis. The objective is to develop a mode choice model that provides sufficient accuracy to estimate the effects of a cost-benefit analysis, with the limited amount of data and information at hand. The paper tests a proposed model, using aggregate origin-destination (hereafter, OD) data, open-source information and various scenarios for liquid bulk transport in the geographical scope of the paper. This paper concludes that with limited and even missing data, the approach of this paper can provide insights for estimating effects cost-benefit analysis. Nevertheless, the need for more accuracy and the limitations of the data/information should be taken into account.

**Keywords -** mode choice model, aggregate data, scenarios, cost-benefit analysis, freight transport.

## 1. Introduction

In December 2020 the Flemish government approved the start of an infrastructural reconnaissance project, called a GRUP (in Dutch:‘gewestelijk ruimtelijk uitvoeringsplan). The GRUP is a procedure for reserving land for substrate pipeline infrastructure in Flanders. Current areas and locations designated for pipeline infrastructure were deemed insufficient or there is no adequate space for additional pipeline infrastructure (Antea Group, 2016).

The potential pipeline should flow from the industrialised banks of the port of Antwerp towards the Ruhr area (Germany) in the east. Therefore, crossing the border with the Netherlands in the southern part of the province of Limburg. Meanwhile the potential pipeline infrastructure shall connect industries around the Albertkanaal in Flanders (Departement Omgeving, 2020).

The cause of the infrastructure reconnaissance project lies in the sustainability goals for 2040 of the Flemish government. The Flemish government states that Flanders has a unique and dense transport network, consisting of dense road, water and rail networks. The opportunity to transport via this network needs to be preserved, but also be sustainable in the future. Furthermore, zero emissions, zero fatalities, fluent and seamless infrastructure are core goals of the mobility vision for 2050 (Vlaamse overheid, 2021). Pipeline transport is seen as an option to meet the goals of the Flemish government as pipeline transport is believed to reduce emissions and improve the living environment (Departement Omgeving, 2019).

As of writing this paper, the spatial planning project has identified three possible trajectories in Flanders: North, Central and South. The North trajectory is the longest, while the Central and South trajectory are significantly shorter. However, the North trajectory crosses through the less inhabited areas and agricultural land, while the Central and South trajectory cross more inhabited areas and nature (Departement Omgeving, 2020).

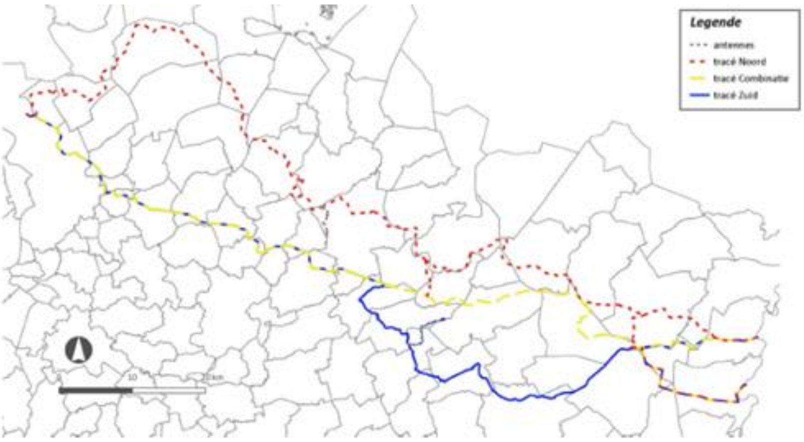

Figure 1: GRUP trajectories (Departement omgeving, 2020)

The objective of this paper is to develop a mode choice model with limited and even missing aggregated OD data. In this paper aggregated OD data between NUTS zones in Flanders and North-Rhine Westfalen (hereafter, NRW) is acquired from the Flemish department of Mobility. This data includes the volume of NST specified products between OD pairs in Flanders and NRW, split for three transport modes: road, rail and inland water transport (hereafter IWT). No OD data for pipeline transport could be acquired from either companies or the Flemish government. This is no coincidence as pipeline transport is often excluded from mode choice modelling or transport appraisal projects, as pipeline transport is a commodity and location specific transport mode (de Jong, 2013). Furthermore, the data is business sensitive information. Therefore, the goal of this paper is to examine how to develop a mode choice model suitable for a cost-benefit analysis (hereafter, CBA) with limited and missing data, applied to this case in Flanders.

The scope of this paper is limited to a geographical area. The geographical area is Flanders, a small part of Southern Limburg in the Netherland and the state North-Rhine Westfalen in Germany. Furthermore, this paper limits itself to certain product types, only liquid bulk goods are within the scope of this paper. As the acquired OD data allows to split the transport volume in NST product groups, only NST 2, 7 and 8 products fit in the liquid bulk products[8] (Centraal Bureau voor de Statistiek, n.d.). At last, this paper does not carry out the CBAs itself, the paper is only examining how to develop a mode choice model that can be used for a CBA. CBA is a commonly used evaluation method in transport appraisal (Beria et al., 2012). Therefore, the paper will also apply an appraisal period for the mode choice models, which will be the time period 2025 to 2055.

This paper is structured as follows. In section 2 mode choice model is discussed and the gap of this paper is addressed. Section 3 provides the approach to address the gap identified. Then in section 4 the results of the mode choice model with respect to the case in Flanders are discussed. At last section 5 contains the conclusions and recommendations for future research.

## 2. Literature review

Mode choice models or modal split models describe the distribution of the total freight demand over the available transport modes (de Jong, 2013). Which modes are available between origins and destinations is dependent on the geographical scope of the model and the infrastructure in the area. In the four-stage model of transport, mode choice is the third step after the generation and distribution of transport (de Dios Ortuzar & Willumsen, 2011). Where generation and distribution are less sensitive to changes in the environment or policies, mode choice is (de Jong, 2013). Policies or infrastructural changes can affect the travel time or costs, where mode choice is sensitive to these changes. Due to this sensitivity mode choice models form a suitable tool for examining the effects for new pipeline infrastructure in Flanders. Furthermore, the mode choice is an explanatory factor in estimating emissions and other external factors of transport (de Jong, 2013), therefore be useful input for a CBA.

An important division in mode choice modelling, especially in freight transport modelling are aggregate and disaggregate models. In aggregate data collection the aggregate of decision makers is the unit of observation, while in disaggregate data collection the decision maker is the unit of observation (de Jong, 2013).

Disaggregate data collection is less common in freight transport than in passenger transport. Reason for this is that companies do not wish to share sensitive commercial information. This paper acquired aggregate OD data

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[8] NST2 products include coal, lignite, crude petroleum and natural gas. NST7 products include cokes and refined petroleum products. And NST8 products are chemicals, chemical products, man-made fibers, rubber and plastic products and nuclear fuel.

dating from 2010 at NUTS2/3 level from the Flemish department of Mobility. The same data is also used in the Flemish freight transport model ‘Svrm’ (van Houwe et al., 2019).

Calibration and validation of aggregate, thus limited, data in mode choice models can de difficult. Especially in freight models as there are few explanatory variables available (Jourquin, 2016). Therefore Jourquin (2016) proposes a mode choice model that can be based on accessible explanatory variables as travel distance, travel time and transport cost. The following model by Jourquin (2016) is used in this paper:

$$V_{m,p,r} = 2\alpha_{m,p,r}FC_{p.m} + \beta_{m,r}D_m + \gamma_{m,r}TT_m$$

Where:

V = the (dis)utility of the total deterrence function
FC = fixed costs
D = distance
TT = travel time
m = transport mode
r = region
p = product type (NST product category)
α = parameter for fixed costs
β = parameter for distance
γ = parameter for travel time

The model includes parameters to calibrate for each coefficient. The coefficients for travel time and distance are derived from open-source tools and specific per transport mode (Beyssac, n.d.) (European Commission, n.d.) (Bureau Voorlichting Binnenvaart, n.d.). The distance and travel time between OD pairs are documented in time and distance matrices. Furthermore, the models should be able to exclude transport modes, if there is no connection possible between an origin and a destination (de Jong, 2013). Therefore, a skim matrix is drafted, based on an infrastructural network analysis.

Furthermore, in order to comply and be able to estimate effects for a CBA in an appraisal period, a volume growth model for product types and expected cost figure development of transport modes need to be included. The volume growth model is based on forecasts and prognosis and the growth rates are multiplied to the historical OD data. There can be multiple scenarios addressing the volume growth. This paper includes a low, medium and high scenario in terms of expected volume growth. Balancing the OD data is based on the Fratar method (Dragu & Roman, n.d.). The cost figure development will be a yearly expected increase of transport costs, the growth rates are added to the results of the utility functions over the appraisal period.

The model exists of a fixed costs parameter that is connected to the product group transported. The fixed costs consist of costs before any kilometre has been travelled, the costs consist of loading, unloading, warehousing, keeping products under compression etc. The different product groups in the scope of this research have varying average shipment sizes. Based on the shipment size the fixed costs coefficient is determined.

Table 1: Average shipment size per product group (Vanderhoydonck & Borremans, 2020).

| | **Average volume per transport (in ton)** |
|---|---|
| **NST2** | 82.1 |
| **NST7** | 103.8 |
| **NST8** | 160.8 |

Rodrigue (2020) visualizes the mode choice with linear function and a fixed cost this in the following figure.

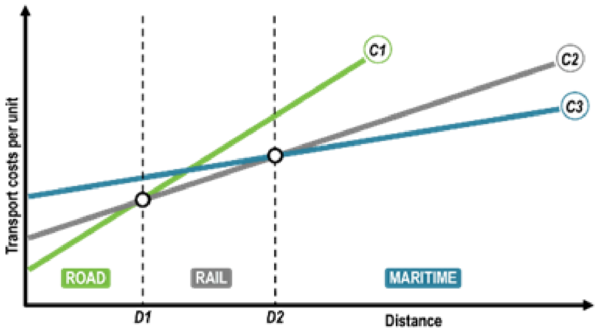


Figure 2: Transport cost per unit over distance (Rodrigue, 2020).

Rodrigue (2020) indicates that different transport modes have varying costs, even if there has been no distance covered (y-axis). The figure visualizes that road transport is also dominant on shorter distances than rail or maritime transport, but the variable costs (after time and distance are covered, x-axis) of these other modes creates an advantage over longer distances.

In this paper, four transport modes are included: road, rail, inland water and pipeline transport. The model tries to capture the mode choice including these fixed costs and accentuate the mode choice for short distances and longer distances differ due to lower variable costs of transport modes rail, IWT and pipeline (ITF, 2022) (Goor & van Amstel, 2003).

Additionally, the model incorporates different parameters to the coefficient as variation between regions was discovered in the OD data. Therefore, three regions are identified. Region 1 is national transport within Flanders. Region 2 is transport from or to the Port of Antwerp, and at last Region 0 is international transport between Flanders and NRW.

Then, the calculated utilities per transport mode between origins and destinations have to put in a multinomial logit (MNL) function to determine the modal share per OD pair (de Jong, 2013).

$$\mathrm{Pr}(m) = \frac{\exp\,(V_m^{\mu_m})}{\sum_{n=1}^{N} \exp\,(V_n^{\mu_n})}$$

Where:
Pr = probability of mode m
Vm = utility of mode m
Vn = sum of utility for mode n=1 to N
µ = the dispersion factor per transport mode

One could have noticed that the models do not contain an error term in the utility functions. In regular cases an error term is included, however Jourquin (2016) indicates such a mode can provide sufficient accuracy. Furthermore, it fits in the strategy of the paper to create a relatively simple mode choice model within time constraints.

The calibration of the models will be carried out via a straightforward iterative algorithm, discussed in Jourquin (2016), where the parameters and their calculated global estimated shares are compared to the observed shares in the OD data. When after several iterations an (sub)optimum is reached, Microsoft Excel solver is used to calculate the parameter values at the lowest sum of squared errors (SSE) at OD pair level.

The proposed validation of the aggregate mode choice models is based on Zhang (2013). For aggregate data the validation is carried out on a more global level, where the shares are compared to the modal share of the observed OD data. And on a more local level for the modal shares between calculated shares and observed shares between OD pairs.

As of this point the paper has identified the theory and approach for estimating a mode choice model with aggregate OD data of three transport modes in the case for Flanders (road, rail and IWT). However, no OD data is acquired for pipeline transport.

The missing OD data, in combination with the fact that pipeline transport is often excluded in mode choice models (de Jong, 2013), is identified as the gap of this paper. Therefore, the objective of this paper is to develop an approach to estimate mode choice models with missing OD data for a transport mode. In the next section the methodology for addressing this gap is introduced.

## 3. Methodology

### *A. Approach*

The proposed approach to develop a mode choice model including the pipeline mode is to use the calibrated parameters of the three transport modes discussed in section 2. The calibrated parameters of these three transport modes can be validated by comparing the results of the mode choice model to the observed OD data. In order to use the calibrated parameters, it is necessary to define how pipeline transport relates to the calibrated transport modes. Therefore, it is proposed to analyse the different transport modes based on logistic characteristics and highlight similarities and differences between the considered transport modes.

Based on the logistic characteristics it is proposed to develop multiple scenarios for the deterrence function of the pipeline mode. The scenarios will address the different parameters in the deterrence function, therefore varying in the fixed costs and variable costs (time and distance) coefficients of the calibrated parameters.

### *B. Logistic characteristics*

The logistic characteristics are reviewed for the four transport modes considered. Four logistic characteristics are reviewed, that are related to the explanatory variables in the mode choice models. These four indicators are:

- Capacity of the transport mode
- Distance covered
- Transport time and speed
- Transport cost per unit

The capacity of transport modes they can ship stands in relation to the average shipment size mentioned in section 2. Product types with high average shipment sizes are more likely to be transported with transport modes that can handle larger volumes (ITF, 2022)

Then, the distance covered, and transport time largely have to do with the available infrastructure and operating speeds of the transport modes.

At last, the transport cost per unit also mentioned in section 2 in the figure of Rodrigue (2020). This characteristic is dependent on the transport mode, therefore advantages can arise for certain transport modes when longer distances and longer travel time are required.

The table below scores the logistic characteristics qualitatively.

Table 2: Logistic indicators performance.

| **Mode** | **Capacity** | **Distance covered** | **Transport time** | **Transport cost per unit** |
|---|---|---|---|---|
| **Truck** | Low | Short to moderate | High | High |
| **Pipeline** | (very) high | Long | Low | Very low |
| **IWT** | High | Moderate to long | Low | Low |
| **Rail** | Moderate | Moderate to long | Moderate | Low |

First the capacity of the transport modes is varying widely. A regular truck carrying liquid bulk cargo is transporting between 13 to 20 tons, compared to the other transport modes this is significantly less. Inland water vessels transport has capacities between 1200 tons for smaller inland vessels and can go up to more than 3000 tons for large inland vessels. This number is close to the average of 2800 tons in rail transport (van der Meulen et al., 2020). For pipelines the throughput can be very large and continuous depending on the diameter of the pipe, the pressure and number of (Smart Freight Centre & Cefic, 2021) (Smirnov & Smirnova, 2019). Natural gas pipelines can transport billions of cubic meters per year (Energy Charter Secretariat, 2006).

Second, covered distance by the transport mode, with this indicator a rule-of-thumb of the general trip length is meant. In general trucks perform better at the short to moderate distances, while rail, inland water transport and pipelines range from several hundred kilometres to over several thousand kilometres (Rodrigue, 2020).

Then the travel time and correlated speed of operation of the transport modes. The travel time is partially dependent on the operating speed and the available infrastructure for a transport mode. Truck transport is the quickest transport mode, with fairly high operating speeds (65-100 km/hr) and a dense transport network of roads, trucks tend to be the quickest transport mode. Rail transport has a moderate operating speed, around 40 km/hr, followed by inland water vessels with an operating speed ranging between 10 to 25 km/hr (van Essen et al., 2003)(Rodrigue, 2020). Pipeline is the slowest transport mode of the four considered (Verweij et al., 2009), however the speed of pipelines is dependent on multiple factors, like the product itself, temperature, the amount of pressure and the amount of pressure stations (NEA & Haskoning, 1993). The operating speed of pipelines is between 5-13 km/h (Pienaar, 2008)(Cheng et al., 2017)(Petroleum.co.uk, n.d.).

At last, the transport cost per unit, this indicator has relation to most of the indicators discussed in this paragraph. Speed, door-to-door delivery, distance, wages, toll etc. all affect the cost. However, the cost per unit function differs per transport mode over the covered distance (Rodrigue, 2020). Road transport tends to have lower total transport cost over short distances, while the cost per unit for transport mode like maritime and rail increase at a lower rate than road transport. At certain distances the cost functions of transport modes will cross, and theoretical break-even points arise (see figure 2) (Rodrigue, 2020). The transport cost per unit is the steepest for trucks and therefore the highest. Rail and inland water transport have a less increasing cost function (ITF, 2022). The costs for transporting a unit via a pipeline is lowest (Goor & van Amstel, 2003).

### C. *Application*

The logistic indicators scores reveal that pipeline transport is a mode that is likely to compete with IWT or rail transport. The capacity of pipeline transport is very high compared to other transport modes, furthermore, the pipeline mode is relatively slow in terms of operating speeds and has low transport costs per unit. This fits to figure 2 from Rodrigue (2020), where the slower transport modes with higher capacities (rail and maritime) benefit for transport over longer distances as the transport cost per unit over longer distances is competitive.

Therefore, the hypothesis of this paper is that pipeline transport has a higher fixed costs than IWT, rail and road transport as the higher capacities, required infrastructure for pipelines, storing and compression demand higher costs without any distance has been covered. Furthermore, pipeline transport is infrastructure bound and the infrastructural network is not dense, therefore the choice to use pipeline transport should be less attractive on short distances, resulting in an assumed higher fixed cost. The hypothesis on the variable costs is that pipeline transport costs per kilometre are lower compared to road, rail and IWT. So, that means that the parameters of pipeline transport are lower in the deterrence function.

The hypothesis is visualized based on Rodrigue (2020) in figure 3 below. The intersection of pipeline transport on the vertical axis is placed higher than the other three modes. The slope of the functions in figure 3 represent the variable costs, or transport costs per kilometre. The transport costs per unit of pipeline transport were concluded to be lower compared to the other three modes. As these costs are lower it is expected that the deterrence function of the pipeline will intersect with deterrence functions of the other modes at a certain point which is dependent on distance and time (variable costs).

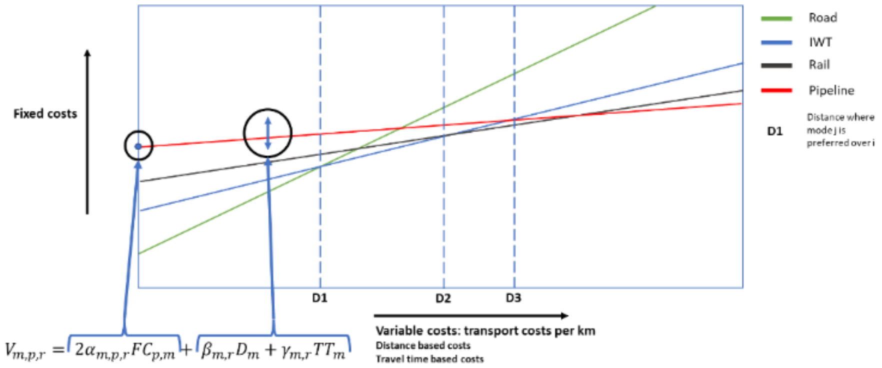


Figure 3: Conceptual deterrence function (based on Rodrique (2020)).

Now that is substantiated what the logistic characteristic are compared to the other transport modes and the hypothesis towards the deterrence function of pipeline transport. The approach stated to create scenarios based on the calibrated parameters of the mode choice model.

For parameter α, connected to the fixed costs, the highest calibrated value among parameter α for road, rail and IWT is used. The hypothesis stated that the initial fixed costs are highest for pipeline transport compared to the other modes. For parameter β and γ, the transport time and distance parameters in the deterrence function, the values are multiplied with the corresponding calibrated β and γ of IWT. As this section concluded that pipeline and IWT are the most comparable based on their logistic indicators. The following utility function scenarios are drafted for the pipeline deterrence function:

Table 3: Utility function scenarios.

| **Scenario** | **Fixed costs (α)** | **Variable costs (β,γ)** |
|---|---|---|
| **1** | +10% | -10% |
| **2** | +10% | -20% |
| **3** | +10% | -30% |
| **4** | +10% | -40% |
| **5** | +20% | -10% |
| **6** | +20% | -20% |
| **7** | +20% | -30% |
| **8** | +20% | -40% |
| **9** | +30% | -10% |
| **10** | +30% | -20% |
| **11** | +30% | -30% |
| **12** | +30% | -40% |

In the next section, first the mode choice model is calibrated for the three transport modes with OD data discussed in section 2. Thereafter, the utility function scenarios for pipeline transport are added to the MNL model and the results in modal shares are discussed.

## 4. Results

### *A. Calibration mode choice model.*

The calibration of the parameters is carried out for the transport modes, road, rail and inland water transport. For pipeline transport no OD data was acquired. Calibration is performed by using the iterative algorithm proposed by Jourquin (2016) to reach a suboptimal solution. After iteratively reaching the suboptimum, a solver within the Microsoft Excel package is used to minimize the sum of squares (SSE) by adjusting the parameters of the models.

Table 4: Calibration results parameters

| | **NST2** | | | **NST7** | | | **NST8** | | |
|---|---|---|---|---|---|---|---|---|---|
| **μ Road** | -0.077 | | | -0.058 | | | -0.047 | | |
| **μ Rail** | -0.460 | | | -0.479 | | | -0.484 | | |
| **μ IWT** | -0.148 | | | -0.088 | | | -0.058 | | |
| | **Region 1** | **Region 2** | **Region 0** | **Region 1** | **Region 2** | **Region 0** | **Region 1** | **Region 2** | **Region 0** |
| **α Road** | 0.506 | 0.497 | 0.407 | 0.825 | 0.382 | 0.371 | 0.366 | 0.439 | 0.303 |
| **α Rail** | 0.814 | 0.706 | 0.486 | 0.422 | 0.814 | 0.735 | 0.671 | 0.079 | 0.641 |
| **α IWT** | 0.634 | 0.378 | 0.533 | 0.696 | 0.322 | 0.442 | 0.633 | 0.515 | 0.440 |
| **β Road** | 0.635 | 0.496 | 0.453 | 0.357 | 0.557 | 0.563 | 0.408 | 0.964 | 0.466 |
| **β Rail** | 0.566 | 0.424 | 0.175 | 0.536 | 0.437 | 0.497 | 0.356 | 0.988 | 0.626 |
| **β IWT** | 0.322 | 0.515 | 0.531 | 0.736 | 0.803 | 0.731 | 0.327 | 0.457 | 0.223 |
| **γ Road** | 0.484 | 0.493 | 0.762 | 0.716 | 0.519 | 0.930 | 0.410 | 0.516 | 0.440 |
| **γ Rail** | 0.541 | 0.452 | 0.697 | 0.560 | 0.358 | 0.546 | 0.308 | 0.009 | 0.414 |
| **γ IWT** | 0.812 | 0.114 | 0.081 | 0.509 | 0.164 | 0.214 | 0.274 | 0.102 | 0.061 |

Table 5: Mode choice accuracy metrics.

| | **NST2** | **NST7** | **NST8** |
|---|---|---|---|
| **Sum squared error (SSE)** | 5.134 | 6.411 | 17.440 |
| **Average error per OD pair** | 0.011 | 0.013 | 0.036 |
| **RMSE** | 0.103 | 0.115 | 0.190 |

The average error per observation, so per OD pair, is ranging between 1% and 3.6%. Therefore, the model can be considered sufficient accurate for the purposes of this study.

Validation is performed by a global perspective of the modal share and on OD pair level. The validation of a modal share level indicate that road transport is generally overestimated in the model. This is to a greater extent at the expense of inland water transport, and to a lesser extent, at the expense over railway transport. An explanation for the error in market share can be largely attributed to the explanatory power of the model's attributes.

Table 5: Percentual error between observed and calculated market shares.

| **% Error** | **NST2** | **NST7** | **NST8** |
|---|---|---|---|
| **Road** | 13.24% | 4.37% | 11.03% |
| **Rail** | -0.03% | -0.87% | -1.80% |
| **IWT** | -13.22% | -3.49% | -9.23% |

On OD pair level the validation looks at outliers, in other words OD pairs with high degrees of errors (20% or higher). Also, on the OD pair level it is clear that the model overestimates road transport, at the expense of rail and inland water transport. Road transport is overestimated for Region 2 OD pairs (OD pairs to or from the Port of Antwerp), again this is at the expense of IWT. Furthermore, Region 0 OD pairs (international transport) do have considerable higher error rates for NST7 and NST8 products.

The model and its parameters are calibrated to capture reality, where literature has shown that rail and inland water transport benefit from longer distances and less time constraining transport. However, it is difficult to model rail and IWT, which is visible in the overestimation of road transport in the mode choice model.

### *B. Modal share results.*

The modal share is the output of the calibrated mode choice model and the MNL function. The modal share for the observed OD pairs is calculated in ton-kms, as this forms a suitable output for estimating effects in a CBA. Therefore, the research uses modal share from the MNL function per OD pair and multiplies this with the distance matrix, which was constructed for every individual transport mode.

This paper conducts the mode choice model with the vision to use the results in a CBA. Because of that, the calibrated mode choice model serves as a base case alternative. The results of the utility function scenarios for pipeline transport in table 3 can be seen as the modal share in the project alternative.

Table 6: Estimated modal split growth scenario Low (in ton-km).

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 38.81% | 0.05% | 31.83% | 29.30% |
| **Scenario2** | 38.10% | 0.05% | 27.84% | 34.01% |
| **Scenario3** | 37.30% | 0.05% | 24.85% | 37.80% |
| **Scenario4** | 36.49% | 0.05% | 22.77% | 40.69% |
| **Scenario5** | 41.80% | 0.06% | 43.22% | 14.92% |
| **Scenario6** | 41.35% | 0.06% | 38.92% | 19.67% |
| **Scenario7** | 40.88% | 0.05% | 34.30% | 24.77% |
| **Scenario8** | 40.31% | 0.05% | 30.09% | 29.54% |
| **Scenario9** | 43.63% | 0.06% | 50.33% | 5.98% |
| **Scenario10** | 43.23% | 0.06% | 48.23% | 8.48% |
| **Scenario11** | 42.86% | 0.06% | 45.18% | 11.90% |
| **Scenario12** | 42.52% | 0.06% | 41.20% | 16.22% |

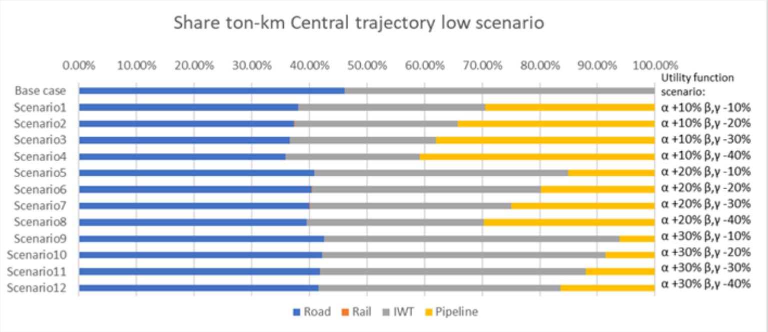


Figure 3: Modal share in ton-kms for a low scenario.

From table 6 and figure 3 can be concluded that the share of IWT decreases the most in terms of ton-km when the pipeline is added to the modal split. Road transport also decreases considerably in scenarios 1 to 4, however the share in scenario 9 to 12 remains high and decreases only a few percentage points.

The results in table 6 and figure 3 are calculated on the assumption that the dispersion factor (μ) in the MNL model is valued at *-0.090*. The results of the MNL model show expected behaviour using this value. The dispersion factor in a multinomial logit formula is always negative, however the value can be very close to zero. The rule of thumb is that the closer the dispersion factor is to zero, the less disutility is derived from the mode. And the more negative the dispersion factor, the more disutility and less attractive the mode is. The need to estimate the dispersion factor for pipeline transport also lies in the issue of missing data. The value of *-0.090* is in most cases close to the calibrated dispersion factors of IWT in table 4.

However, logit formulas are sensitive to the dispersion factor and therefore this will be included in a sensitivity analysis in the next paragraph.

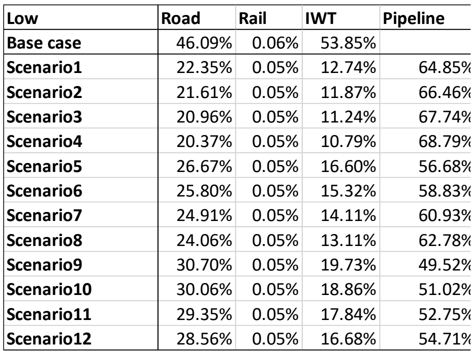
### C. *Sensitivity analysis: dispersion factor.*

In this sensitivity analysis the dispersion factor of pipeline transport is increased and decreased with 25%. So, the dispersion factor in the MNL model of pipeline transport is adjusted to *-0.113* and *-0.068*. This results in the following tables.

Table 7: modal share dispersion facrtor +25%.

| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 44.12% | 0.07% | 54.48% | 1.34% |
| **Scenario2** | 43.83% | 0.06% | 54.09% | 2.01% |
| **Scenario3** | 43.45% | 0.06% | 53.35% | 3.13% |
| **Scenario4** | 43.04% | 0.06% | 51.96% | 4.94% |
| **Scenario5** | 44.54% | 0.07% | 54.83% | 0.56% |
| **Scenario6** | 44.44% | 0.07% | 54.76% | 0.73% |
| **Scenario7** | 44.30% | 0.07% | 54.62% | 1.01% |
| **Scenario8** | 44.11% | 0.07% | 54.35% | 1.47% |
| **Scenario9** | 44.67% | 0.07% | 54.90% | 0.36% |
| **Scenario10** | 44.63% | 0.07% | 54.89% | 0.42% |
| **Scenario11** | 44.57% | 0.07% | 54.86% | 0.51% |
| **Scenario12** | 44.48% | 0.07% | 54.81% | 0.64% |

Table 8: modal share dispersion facrtor -25%.



| Low | Road | Rail | IWT | Pipeline |
|---|---|---|---|---|
| **Base case** | 46.09% | 0.06% | 53.85% | |
| **Scenario1** | 22.35% | 0.05% | 12.74% | 64.85% |
| **Scenario2** | 21.61% | 0.05% | 11.87% | 66.46% |
| **Scenario3** | 20.96% | 0.05% | 11.24% | 67.74% |
| **Scenario4** | 20.37% | 0.05% | 10.79% | 68.79% |
| **Scenario5** | 26.67% | 0.05% | 16.60% | 56.68% |
| **Scenario6** | 25.80% | 0.05% | 15.32% | 58.83% |
| **Scenario7** | 24.91% | 0.05% | 14.11% | 60.93% |
| **Scenario8** | 24.06% | 0.05% | 13.11% | 62.78% |
| **Scenario9** | 30.70% | 0.05% | 19.73% | 49.52% |
| **Scenario10** | 30.06% | 0.05% | 18.86% | 51.02% |
| **Scenario11** | 29.35% | 0.05% | 17.84% | 52.75% |
| **Scenario12** | 28.56% | 0.05% | 16.68% | 54.71% |

Based on the sensitivity analysis can be concluded that adjustments of 25% to the dispersion factor affect the mode choice model considerably. For a possible CBA this means that a dispersion factor must be chosen with care. As such variations will have large influence on the estimated effects of a CBA.

## 5. Conclusions and future research

The objective of the paper was to develop a mode choice model that provides sufficient accuracy to estimate the effects of a cost-benefit analysis, with the limited amount of data and information at hand. Applied to the case of Flanders, where the Flemish government is investigating the need for additional pipeline infrastructure connecting cluster in Flanders and the Ruhr region in Germany.

This paper concludes that the proposed approach can offer insights to the effect on the modal share, therefore it can be used to estimate effects in a CBA. Aggregate mode choice models are characterized by the limited amount of data and limited access to explanatory variables. Accuracy is therefore always an issue, though the model used in this paper provides an acceptable error per observed OD pair.

Although the calibrated mode choice model with historic OD data provides sufficient accuracy, it should be noted that proposed approach for the transport with missing data comes with multiple utility function scenarios. The probability and reasonability of these scenarios should be researched. As the results of the MNL model indicate that the effects on the mode choice vary considerably. A way to identify which or what scenarios are the most reasonable could be to perform a financial cost-benefit analysis or develop a business case to estimate what the transport tariffs for the pipeline should be in combination with the estimated modal share (e.g. ton-kms).

Furthermore, the paper concludes that dispersion factor in the MNL model is very sensitive to changes. This causes uncertainty towards the results of the modal share, thus affect the results of a possible CBA. Therefore, the paper recommends to further research the value of the dispersion factor, possibly creating more scenarios.

Overall, the paper concludes that following the approach has potential for transport infrastructure appraisal with limited and missing data. The approach can provide insights at a reconnaissance or an investigative phase of the appraisal process, ruling out or addressing the prospective of project alternatives, while emphasizing the limitations of the approach.

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