ASSESSMENT AND QUANTIFICATION OF THE EMISSION REDUCTION ON THE IJSSELDIJK ZWOLLE-OLST, DUE TO WAVE SIMULATOR RESEARCH

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Preface

In front of you lies the thesis "Assessment and quantification of the emission reduction on the IJsseldijk Zwolle-Olst, due to wave simulator research". This thesis is part of my graduation phase for the bachelor degree Civil Engineering at the University of Twente. This study is performed at Infram-Hydren from September to November 2020.

Firstly I want to thank Maarten Overduin and Jord Warmink, for their help and guidance during the execution of this project. Without their help, expertise and feedback, this thesis would not have been possible. I am grateful for the help of Jord Warmink. With his professional tips and suggestions, he put me on the right path. My gratitude goes out to Maarten Overduin for the opportunity to write my thesis at Infram-Hydren. Also, for providing me with the right literature and bringing me in contact with Waterschap Drents Overijsselse Delta.

I want to acknowledge the efforts of Maurits van Dijk, who provided me with the right data about the IJsseldijk Zwolle-Olst case and helped creating the scenarios in this study. Also, I want to acknowledge Dick van den Heuvel, for his help with the construction approach of dike cover reinforcements. Lastly, I want to acknowledge the employees of Infram-Hydren, especially Roy Mom. I want to thank them for including me in their section meetings and their help with the simulator research.

I hope you enjoy my work!

Wouter Kruis

Enschede, 20 November, 2020

Abstract

The goal of this study is to assess and quantify the potential reduction of the environmental impact on the dike reinforcement project IJsseldijk Zwolle-Olst due to the wave simulator research. This has been done for the greenhouse gas emissions in kg CO_2-eq and the environmental cost indicator (MKI) in euros.

The wave experiments showed that the inner slope of the IJsseldijk is strong enough to fulfil the legal requirements and therefore, does not have to be reinforced. This could be the case for the outer slope, if the sub-layer is strong enough. However, from discussion with WDOD it turned out that this is not the case. In this case the wave overtopping simulator experiments are responsible for the reduced emissions. To determine the reduced emissions, two systems are created for which the LCA was performed separately. The wave simulator research is the first system. The choice was made to only look at a single usage phase. Therefore, other experiments, production of the simulators and other equipment are not taken into account for the LCA. The system only deals with emissions during the experiments and site setup. This includes emissions for the electricity generators, mobile crane and transport. The total greenhouse gas emissions for the wave simulator research is 23 ton CO_2-eq, which corresponds to a MKI of €3 902. Here, the diesel for the generators has the biggest environmental footprint.

For the avoided replacement of the dike cover, it was chosen to take the full life cycle of 50 years into account. As the design for the IJsseldijk is not final yet, three possible scenarios for replacing the cover were created in collaboration with WDOD. The first scenario is the most optimistic, where the full cover of the inner slope and crest can remain in place. The second scenario focuses on locations where the provincial road is on the crest. The third scenario is the more representative scenario, as the grass cover can remain in place at all locations for which the tested slope is representative. The earth moving for the dike cover replacement existed of excavating and replacing the top 1 m of the dike crest and a tapered layer of 1 to 2 m underneath the inner slope. The top layer is sowed with D1 grass seeds which has to be maintained and mowed. Placement of erosion screens, reconstructing cycling paths and rehabilitation of the provincial road can be avoided if the cover is not replaced. The final results for the reduced emissions are calculated by subtracting the emissions of the wave research from the cover replacement emissions. The results are noted in Table 34. The biggest impact on these emissions is the backfilling process for both the crest and inner slope. This is mostly due to the amount of clay that has to be transported.

Table 1: Results for the reduced emissions per scenario

	Scenario 1		**Scenario 2**		**Scenario 3**	
	kg CO_2-eq	MKI €	kg CO_2-eq	MKI €	kg CO_2-eq	MKI €
Reduced emissions	2.31E+07	€ 3 269 525	7.72E+06	€ 1 120 533	1.78E+07	€ 2 528 306

Comparing the results of the two systems, it is concluded that the emissions of the wave experiments are insignificant. Even in scenario 2, the greenhouse gas emissions are about 0.3% of the potential reduction. In scenario 1 this is about 0.1%. For that reason, the wave experiments are valuable towards the reduction of environmental emissions.

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1. Introduction

In 2017, the Dutch government instated the Green Deal GWW[1] 2.0 (Green Deals GWW, 2018). With this method, the Dutch government wants to clear the way for green initiatives within construction projects. This is part of their climate policies which followed after the Paris Agreement. The agreement states that all new construction projects need to be finished with 49% less CO_2 emissions compared to the year 1990 (Rijksoverheid, 2017). All companies and organizations which signed the Green Deal will make an effort to make their projects more environmental friendly. The potential for increased durability is large in the construction sector. The amounts of resources and energy usages make it possible to reduce CO_2 emissions when there is a focus on the environmental part of projects. The ambition of the Green Deal GWW is to make a transition towards this reduction of emissions.

The Dutch engineering company, Infram Hydren, has this same ambition and wants to have more insights in the environmental benefits of the wave simulator. Having this insights could suggest that emissions are significantly less, causing Infram Hydren to contribute to making hydraulic engineering projects more sustainable.

From examination in 2011 it was found that the dike section IJsseldijk Zwolle-Olst did not fulfil the legal safety requirements of that moment. Therefore, the dike section was included in the Hoogwaterbeschermingsprogramma (HWBP[2]) as a part of the Deltaplan Waterveiligheid. The dike section is visualized in Figure 1. A new safety analysis was performed in 2016. It was found that most of the IJsseldijk did not meet the new legal safety norms and therefore needed to be reinforced. The dike cover was not strong enough, which means that waves and flowing water could damage the grass cover. Piping and stability are issues for this dike section as well, however these will not play a role in this research. Additionally, the regional water authority Drents Overijsselse Delta (WDOD[3]) could benefit of this knowledge as well. If the simulator research reduced emissions and the need for materials, then the water authority will have a project for a lower cost with a lower environmental impact.

To make sure that the IJsseldijk will be sufficiently safe in the future, the project IJsseldijk Zwolle-Olst started in 2017 with the exploration phase. The usual calculation strategy in the Netherlands to determine the strength of dike covers is based on dikes that are mostly constructed with clay. However, the IJsseldijk has a higher sand content, which is the reason that the dike cover did not comply with the flood standards. WDOD worked together with Infram Hydren to test the grass cover on both sides of the dike. The situation when the water level is high was created by use of a wave simulator. Erosion of the dike can occur when waves hit the cover or when water is flowing over the cover of the dike. The tests were performed to see how long the current grass cover could withstand the water and how strong the dike cover is. The results would tell whether the grass cover on the inner and outer slope needs to be replaced or not. When the grass cover is strong enough, some of these plans can be neglected. This would result in reducing the expected emissions. The problem is, that it is currently unknown to what extend the environmental impact is reduced due to the influence of the simulator research. Therefore, the goal of this study is:

[1] GWW is Grond- Weg- en Waterbouw. This translates to soil, road and water construction.

[2] Hoogwaterbeschermingsprogramma: The HWBP is a collective effort of Rijkswaterstaat and all regional water authorities. They are working together on the reinforcements of dikes to secure a water-safe Netherlands by 2050. The abbreviation HWBP will be used for further notations.

[3] Regional water authority (Waterschap) Drents Overijselse Delta. The abbreviation WDOD will be used for further notations.

"Assessing and quantifying the potential reduction of the environmental impact (especially CO2 and MKI emissions) for the dike reinforcement project IJsseldijk Zwolle-Olst due to wave simulator research"

The Life Cycle Analysis (LCA)[4] method is used in this study, because it is the most suitable method to quantify the environmental impact (Rijkswaterstaat, 2017). The LCA makes an analysis of the impact that an object or project has on the world around it (Liebsch, 2020). A more detailed explanation of the LCA is given in Chapter 3.

To complete the goal of this study, different sub-questions have been determined. These questions are based on the first three steps of the LCA. The fourth step of the LCA is part of the discussion and conclusions. The sub-questions are formulated as follows:

Q1. What will be the goal and scope of the LCA?

This question represents the first phase of the LCA. It is aimed to find out what the boundaries of the systems are and it describes the different scenarios discussed in this study.

Q2. What aspects of the wave research and dike cover replacement cause emissions?

The second phase of the LCA is aimed to inventory all aspects of both the wave research and the dike cover replacement, that will cause emissions and that are within the scope of this study. The LCA method describes this as the Life Cycle Inventory (LCI).

Q3. What is the reduced environmental impact on the IJsseldijk based on literature values?

The third question focuses on the third step of the LCA being the Life Cycle Impact Analysis (LCIA). This will determine the total emissions of the wave research and dike cover replacement systems, based on the LCI entries. By subtracting those values, the reduced emissions due to the wave research is found.

In Chapter 2 a theoretical background is given, to discuss the wave research and its results. Different tools such as the environmental cost indicator and DuboCalc are discussed here as well. Chapter 3 discusses the research methodology used in this study. The three sub-questions are answered in Chapters 4, 5 and 6 respectively. The results are discussed in Chapter 7, followed by the conclusions and recommendations in Chapter 8.

[4] LCA is the abbreviation for Lifecycle Analysis. This approach will be explained further in the research methods section. The abbreviation LCA will be used for further notations.

Figure 1: Trajectory of the IJsseldijk Zwolle-Olst

2. Theoretical Background

2.1. Failure of the dike cover

The dike cover is the first protection of the dike body against erosion due to wave impact and flow (Rijkswaterstaat, 2012). Grass is a strong cover due to different factors. The grass leaves form some surface protection and the roots keep the soil together, providing protection against erosion due to waves and water flow. The roots can keep separate clods of soil together, and cause cementation. Cementation is a process causing bindings due to precipitation of minerals, which makes the soil firm. The IJsseldijk has a soil composition which consists mostly of sand. Sand can erode relatively easy due to wave action and flowing water, however a grass cover could limit this. Though, the strength of a sand cover with grass is not known. The cover can fail due to different forms of erosion namely: the pull-out mechanism, wear out erosion, jet erosion, stripping down of the grass cover, head-cut erosion, shearing of the dike cover and wave impact. Infram Hydren has been testing the grass cover on the IJsseldijk for erosion on the inner and outer slope.

Erosion of the inner slope will most often occur due to the wave overtopping failure mechanism. Wave overtopping occurs during extreme conditions when the water level is high and the highest waves overtop the crest of the dike. Wave overtopping is described by the wave overtopping discharge or the cumulative overload method. The overtopping discharge describes how a volume of water flows over a meter of dike every second. With a distribution for wave overtopping volumes it can be determined how much water will flow over the crest, when the wave parameters are known. The cover should be strong enough to withstand that overtopping discharge. For the IJsseldijk Zwolle-Olst it was determined that the grass cover should withstand at least 10 l/s per m during the experiments.

Erosion of the outer slope can occur due to the same failure mechanisms as erosion of the inner slope. However, erosion due to wave impact can be added to the list. The failure mechanisms have an increased chance of occurring as the wave velocities are usually higher on the outer slope. Every wave will flow over the outer slope, whereas only the highest waves will flow over the inner slope of the dike. Erosion due to wave impact is created by a pulse of extreme water pressure on the dike cover due to a wave hit or breaking wave. This lowers the soil stress, causing the top layer to be in a saturated state. Around the impact zone, the soil can become plastic with bigger wave hits. Deformation can occur in this case. A steep cliff will occur that strides backwards due to the instability. In Figure 2, a schematic representation of the wave impact failure mechanism is visualised.

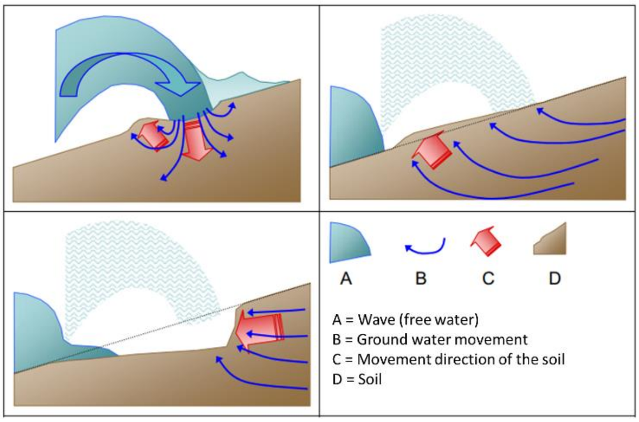

Figure 2: Schematic representation of wave impact

2.2. The simulator research

In January and February of 2020 Infram Hydren performed experiments on a section of the IJsseldijk Zwolle-Olst, with the wave overtopping simulator and the wave impact generator. At the test location, there is a grass cover on a substrate of sand (grass on sand). Sand can relatively easy be eroded by waves and running water compared to clay (Rijkswaterstaat, 2012). Therefore vegetation is of importance to ensure the strength of the top layer[5]. It is difficult to judge about the strength of a grass-on-sand cover without field tests. The goal of the experiments is to gain information about the strength of a grass cover on a sandy subsoil by performing representative experiments for the project specific wave load on the grass cover. The question was when the cover would erode as a result of these wave loads. The results of the tests could either avoid unnecessary investments in the dike reinforcements or say with sufficient certainty that the investments are justified (Overduin & Mom, Factual Report praktijkproeven IJsseldijk Zwolle-Olst, 2020). In Figure 3 an example of erosion caused by a different wave overtopping test is shown.

Figure 3: Erosion example caused by wave overtopping tests (Van der Meer, 2008)

2.2.1. Wave overtopping simulator

The wave overtopping simulator (WOS) in the IJsseldijk Zwolle Olst case is placed on the crest of the dike and it simulates individual volumes of overtopping waves, see Figure 4. The tests were performed in 4 different locations. The simulated waves had different overtopping discharges to simulate a more realistic storm. All sections were tested for 1, 10, 30 and 50 l/s per m. The width of the WOS is 4 m. After the tests the dimensions of the erosion were measured to check the severity.

Figure 4: Setup of the wave overtopping simulator

[5] Top layer refers to the outer cover of the dike with the roots of the grass and plants, existing of the substrate and the roots. The bottom layer is remaining part of the dike between the top layer and the core.

The expectation before the experiments was that a sandy top layer is less erosion proof against wave overtopping. The wave experiments on the Vechtdijk in 2010 seemed to confirm this, however the suspicion was based on a single experiment. Possibly the strength of grass on sand is sufficient to withstand an overtopping discharge bigger than 10 l/s per m for a storm of 5 hours (Mom, Overduin, & Wegman, Analyse en Duiding Golfoverslagproeven IJsseldijk, 2020). In 3 of the 4 locations, the top layer did not collapse after all different discharges were tested for 5 hours. Only the top layer in the second location collapsed after the last test with 50 l/s per m after 4.5 hours. The overtopping water got little to no grip on the rooted top layer. With these results the recommendation to WDOD was to find out where the circumstances are similar or better compared to the test locations. For these locations it can be stated that the gras cover withstands overtopping discharges of at least 10 l/s per m and not increasing the crest height can be considered.

2.2.2. Wave impact generator

For the wave impact experiments, the wave impact generator (WIG) was used. It was attached to a mobile crane to be able to switch locations, see Figure 5. Inside the generator is a 2 m wide double trap valve which is controlled hydraulically. The simulation is done by filling the generator with a constant discharge and by opening the valves, different volumes of waves are released. First the normal regime is applied. These are the 33% highest waves of the distribution representative for these locations, which need 467 hits to simulate one storm hour. If no significant damage occurred, the accelerated regime was used. The highest 10% waves of the distribution are simulated, which need only 121 hits (Overduin & Mom, Factual Report praktijkproeven IJsseldijk Zwolle-Olst, 2020).

Figure 5: Setup of the wave impact generator

The results show that the survival duration of the grass cover is limited with the performed tests. At the first section the top layer collapsed after 3.5 hours. The second section survived a bit longer but collapsed in between the 5th and 6th storm hour. These times are significantly smaller than the times from the erosion model. This can possibly be explained by the substrate of sand instead of clay. The top layer collapsed in both cases, however the bottom layer did not. The strength of this layer was not tested and remains unknown. If the strength of the bottom layer would be sufficient, then the current grass cover might still be sufficient (Mom & Wegman, 2020).

2.2.3. Results of the wave research

After the research it seems the grass cover is in a decent condition, however difficulties can occur on the outer slope of the dike. The top layer of the outer slope did collapsed within times that did not meet the standard. This is worrying, however it might not be needed to replace the grass cover if the bottom layer is strong enough. After discussion with the technical manager of the project it became clear that the outer slope will probably be replaced at every location (Van Dijk, 2020).

The inner slope is sufficiently safe according to the results. In most cases it did not collapse after a discharge which was 5 times higher than needed. The locations where the grass cover does not have to be replaced are currently still unknown, however 3 “what if” scenarios are created. In the first one, it is assumed that the dike cover is safe over the whole project site. In the second scenario, only the grass cover in the southern part, with the provincial road, does not have to be replaced. The last scenario assumes that the grass cover in the southern part does not have to be replaced, as well as every location where the slope is less steep than 1:3.

2.3. Life Cycle Analysis (LCA)

The LCA is a method to determine how environmentally friendly products or projects are (Liebsch, 2020). This question itself is difficult to answer as there are many different factors involved. The LCA provides a framework for measuring the environmental impact and to keep track of all important factors. The life cycle of a product includes emissions for raw material extraction, manufacturing & processing, transportation, usage & retail and waste disposal or recycling. The LCA can be interesting for different parties, especially in the decision making process.

By using the LCA, organisations get a better understanding of the environmental performance of their products. Based on that information companies can make better decisions when improving their products or processes. The LCA provides a framework for sustainability strategies as those decisions can be based on values which are measured and can be compared to other alternatives. Clients might choose a contractor based on how environmentally friendly the contractor can construct a project. The LCA will make an analysis of this.

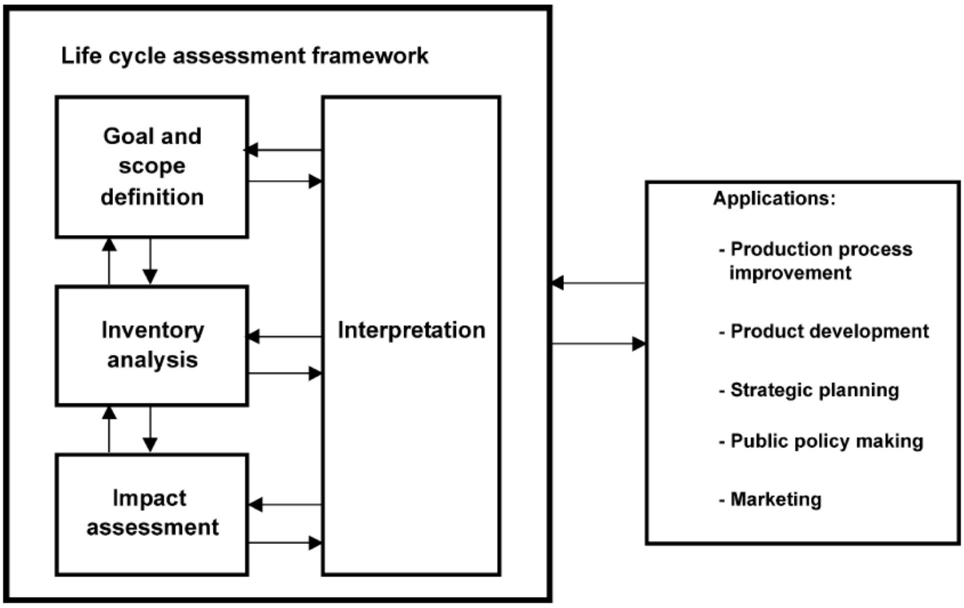

Figure 6: LCA phases (Mercado, Dominquez, Herrera, & Melgoza, 2017)

The LCA is carried out in four phases which will be performed in the separate sub-questions. These phases include the determination of the goals and scope of the LCA, the inventory analysis, impact assessment and the interpretation phase.

First it needs to be determined what will be assessed by setting the goal and scope. The LCA will be performed on a dike reinforcement project, but not on the full dike itself. The different aspects of the design which were influenced by the simulation results need to be specified here by setting the system boundaries. Next a decision has to be made on the system in which the environmental impact will be measured. To do this the impact categories need to be chosen and substantiated. The system boundaries are stated by determining the functions of a system. This is done by use of a functional or declared unit. A functional unit acts as a quantified performance of product system for use as a reference unit. This is specified to be able to compare the results between different alternatives. The declared unit is similar to the functional unit, however it is only used for partial carbon footprint analyses. The declared unit is usually used for the LCA of raw materials.

This second phase of the LCA is called the Life Cycle Inventory Analysis (LCI). This part determines all inputs and outputs of the system which could cause environmental harm. This is an essential step and needs to be performed carefully. Missing parts of the inventory would give a non-realistic view on the situation. The objective is to measure everything that goes in and out of the system. For example the amount of raw materials, the way and distance that the equipment and materials are transported etc.. This can get complex and takes a large part of the time for the LCA.

The third phase focusses on the third phase of the LCA. This will contain the life cycle impact analysis (LCIA). The environmental impacts are evaluated based on the results of the LCI. This is done for the chosen impact categories. The LCI will be sorted and is assigned to the different impact categories (Human toxicity, Global Warming Potential etc.). When finding the totals of the impact categories, the results can be determined. With these results, the reduced environmental emissions due to the simulator research can be determined.

The interpretation phase is a constant process as the results can be interpret at any moment during the assessment. Therefore, interpretation is done in every sub-question. When the conclusions are drawn, the important data should be known, so cautious statements can be made. What needs to be determined in the interpretation phase is stated in the ISO norms (ISO14040:2006, 2006). This includes identifying significant issues based on the inventory and impact assessment, but also about the evaluation of the LCA itself as well. This means determining how complete, sensitive and consistent the assessment has been performed. Data needs to be collected accurately in order to get to this stage and being able to make recommendations. This should answer questions like:

- What are the emissions of the project?
- How does this compare to other projects?
- What are the most important aspects of the project to be able to reduce the environmental impact?
- Can the project be constructed more efficiently?

In the case of this research, the first and third question are the most important.

2.4. DuboCalc

In GWW projects it was often difficult for Rijkswaterstaat to compare the sustainability performance of different contractors (Rijkswaterstaat, 2017). All parties have a different approach to build durable. Rijkswaterstaat wanted this comparison to be easier and enable sustainability to be calculated. DuboCalc is a software programme developed by Cenosco and Royal HaskoningDHV that makes this possible (Rijkswaterstaat, 2020). It calculates the environmental impact of materials in the design and realization phase of GWW-projects. This will be done for the full life cycle of the project, which makes it suitable to compare with the LCA. DuboCalc takes CO_2, as well as depletion of raw materials and 9 other environmental impacts into account. This all is based on EN15804[6] (SIST EN15804:2012, 2012). DuboCalc expresses these values into a monetary value called the environmental cost indicator (MKI). With the MKI value in DuboCalc it is possible to filter out the regular emissions for the CO_2-eq.

[6] EN15804:2012 provide international norms for environmental product declarations to determine the emissions of environmental impact categories.

DuboCalc uses a database called the "Nationale Milieu Database". This database contains data on LCA's of smaller components in projects. For example, it has pre-set values for the emissions of processing a cubic meter clay. These values are based on the "Bepalingsmethode Milieuprestatie gebouwen en GWW-werken" (Nationale Milieu Database, 2020) and the EN15804 (SIST EN15804:2012, 2012). LCA values for new products can be entered in the system as well, but these have to be tested by an external party to be approved by a third independent party for following the EN15804 norms. DuboCalc gives outputs for the carbon footprint and the MKI.

2.4.1. Carbon Footprint

The carbon footprint is the total of the greenhouse gases that are generated for a product or project (The Nature Conservancy, 2020). This represents the amount of CO_2-eq that is produced for the dike reinforcement project. The CO_2-eq represents all greenhouse gases in a single number so it is easy to compare the values of other projects. Other emissions that add to the global warming potential (such as CH_4) are quantified into its CO_2-eq. For example 1 kg CH_4 = 25 kg CO_2-eq (ISO14067:2018, 2018).

2.4.2. Environmental cost indicator (MKI)

The MKI summarizes all environmental impacts into one score that can be expressed in monetary values. It takes all categories during the lifecycle into account (Table 2). Therefore, it is an easy way to compare and communicate about a project's environmental performance. By calculating the emissions of all categories and multiplying them by their weight factor, a final monetary value is calculated. The lower this final amount, the better the project scores on sustainability.

Table 2: MKI categories assigned to values (Rijkswaterstaat, 2017)

Environmental impact categories	**Equivalent unit**	**Weight factor [€ / kg equivalent]**
Depletion of abiotic resources - elements	Sb eq	€ 0.16
Depletion of abiotic resources - fossil fuels	Sb eq	€ 0.16
Global warming	CO_2 eq	€ 0.05
Ozone depletion	CFC-11 eq	€ 30
Photochemical ozone creation	C_2H_4 eq	€ 2
Acidification of soil and water	SO_2 eq	€ 4
Eutrophication	PO_4 eq	€ 9
Human toxicity	1.4-DCB eq	€ 0.09
Fresh water aquatic ecotoxicity	1.4-DCB eq	€ 0.03
Marine aquatic ecotoxicity	1.4-DCB eq	€ 0.0001
terrestrial ecotoxicity	1.4-DCB eq	€ 0.06

3. Research Methodology

This research is based on the life cycle analysis. This structural approach to determine the environmental impact of products or projects, acts as a guideline to answer the sub-questions.

The first sub-question is aimed to find the goal and scope of the analysis. Here, a category from the DuboCalc outputs is chosen as environmental impact indicator. This study focuses on the CO_2-equivalent and the Environmental Cost Indicator (MKI). To determine the reduced emissions, two systems are created to perform the LCA on, namely the wave research and the dike cover replacement. The system boundaries are set based on the available data and literature. DuboCalc provides construction phases within the life cycle of GWW projects. The system boundaries are determined based on these phases. For the wave research system, the choice was made to only look at a single usage phase, as production of the simulators and experiments on other dikes do not influence this study. For the dike cover replacement, all phases in the next life cycle are within the boundaries. The system boundaries been specified with specific data and literature about the wave research and dike construction. As the design of the dike reinforcement is not final yet, three possible scenarios for replacement of the cover are determined in collaboration with WDOD (Van Dijk, 2020).

The second sub-question focusses on the life cycle inventory. The data relevant to complete the LCI is retrieved from different data sources. For the wave research system, the data is based on the script of the experiments, invoices of the companies and conversations with employees of Infram Hydren. For the dike cover reinforcement system, the manual for dike construction (Handboek Dijkenbouw, 2018) and conversations with a specialist in dike construction at Heijmans B.V. (Van den Heuvel, 2020) are used for the general construction approach of the dike reinforcement. Documents from WDOD, such as cross-sections, top views of the dike and reports based on the first exploration phases of the project, are used for the specific details of the IJsseldijk. The data for the emissions of activities is retrieved from the DuboCalc library (NMD versie 2.3 DuboCalc - 6.01.27092018, 2018) and Nationale Milieudatabase documents (Ten Bosch, Te Heijden, & Schipper, 2020).

The third question is answered by the life cycle impact analysis (LCIA). The environmental impacts are evaluated based on the results of the LCI. For this a framework in Microsoft Excel is used. When finding the totals of the impact categories, the carbon footprint and the MKI are calculated. It is necessary to evaluate both the dike reinforcement project and the wave research results. With these values, the reduced environmental impact due to the simulator research can be determined.

4. Q1. What will be the goal and scope of the LCA?

This step is based on the regulations for the LCA as described in NEN-EN-ISO 14067:2018 (ISO14067:2018, 2018). These norms offer a systematic way to evaluate the environmental impact of products and projects. This section describes the results of the first step of the LCA, where the goal, the wave research system and the dike cover replacement system are described. This frames the functions, functional unit, system boundaries, assumptions and limitations that are included in the LCI in the second phase of the LCA. As it is currently uncertain where the dike cover does not need a replacement, the specifics of three scenarios are described.

4.1. Goal of the LCA

The overall goal of conducting a LCA is to quantify the emissions of a product or project over its lifecycle. The goal is meant to inform Infram Hydren and WDOD about the environmental performance of the wave simulator research and its influence on the reduced emissions on the dike reinforcement project IJsseldijk Zwolle-Olst. With these insights, an estimate for the reduction of emissions at other dike reinforcements can be made. The sand makes this difficult to predict, therefore the standard calculation methods are very conservative. The simulator research can test the cover and make a more specific judgement about its performance. The results of this study help identify the environmental winnings of the gap between the conservative calculation methods and the actual cover performance, however they should not be taken as a certainty for other projects.

The intended audience of this research are mostly Infram Hydren and WDOD for reasons that are explained above. A third party for which this research might be interesting is Boskalis. Boskalis is the contractor that will carry out the reinforcement project. The results of this study can be interesting for them for similar reasons as WDOD as they will be part of determining the final design for the project. Other regional water authorities and international water authorities could be interested in the results as well. When there is a substantial benefit towards the environmental impact, it might be interesting for other water authorities to perform wave simulator research on their dike covers as well.

4.2. The systems

Two separate systems play a role in determining the reduced environmental impact due to wave simulator research. First, there is the wave research which itself has a certain impact. Secondly, there is the system of the dike cover reinforcement project. In this research, the LCA for both systems has to be determined and compared in the end. It is chosen to assess the systems separately and subtract them in the end. This was chosen as the wave research has already been performed and will have a single value for the kg CO_2-eq and MKI, while the dike cover replacement has yet to be carried out. Due to uncertainty in the final design for the dike cover replacement, it is not possible to express the results in a single value.

$$Reduced\ Environmental\ Impact = LCA_{dike\ cover\ reinforcement} - LCA_{wave\ research}$$

The scope for each system will be determined by defining the functions and functional unit of the system. The choice is made for the usage of a functional unit to be able to make a careful comparison, which does not fit a declared unit. When a comparison is made between systems, it should be made, based on the same functional unit (NEN-EN-ISO 14067, 2018).

4.2.1. LCA scope for the wave research

The wave experiments have already been described in the theoretical background, however this part will determine the aspects of the research that caused environmental emissions.

4.2.1.1. Functions and functional unit of the wave research system

The main functions of the wave research is to test strength and service time of the dike cover against wave impact erosion of the outer slope and against wave overtopping erosion of the dike crest and inner slope during a storm. It is chosen to make use of a functional unit to determine the basis of the LCA, which is described as follows:

"To be able to determine the service life of a mediocre, closed, grass cover on a dike with a top layer containing about 79.5% of sand based on wave overtopping erosion and wave impact erosion"

The tests were performed on the IJsseldijk, which has a high sand content in the top layer. According to the reports of Infram Hydren, the top layer consisted for about 79.5% of sand, 13% of silt and 7.6% of lutum. Besides the grass cover was tested on its actual strength[7]. From grass pulling tests it was determined that the cover was "mediocre" class. By visual inspection it was determined that the grass cover was a closed surface (Overduin & Mom, Factual Report praktijkproeven IJsseldijk Zwolle-Olst, 2020).

4.2.1.2. System boundaries of the wave research system

The lifecycle of the WIG and WOS exists of multiple phases, namely the production, construction, usage and demolition & processing phase (Figure 7). As the WIG and WOS are used for other experiments as well, the focus of this LCA will only be towards the usage phase at the IJsseldijk. Gathering of resources, construction and deconstruction of the simulators will not be taken into account as it has no relevance to this study. The different phases of a life cycle have been derived from DuboCalc (Rijkswaterstaat, 2017). The usage phase can been seen as a smaller system within the full life cycle of the WIG and WOS.

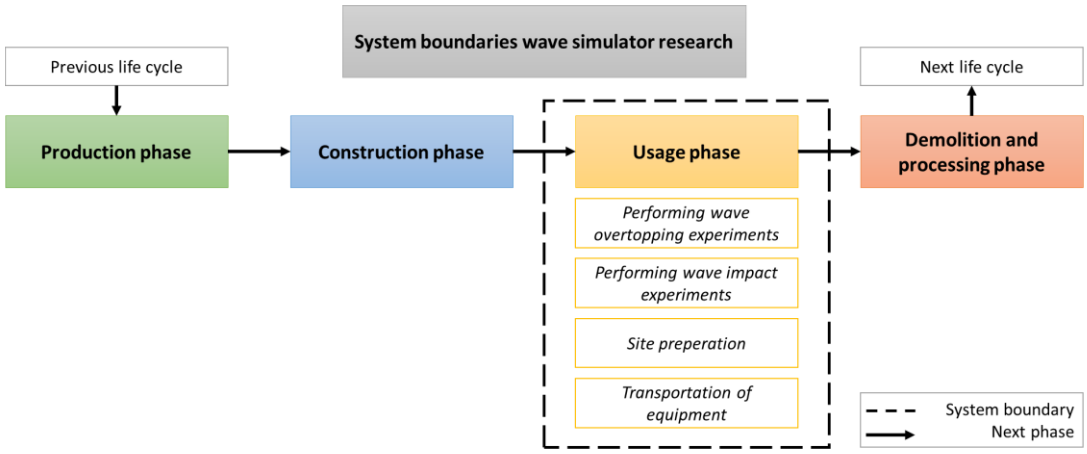

Figure 7: System boundaries wave research

The usage phase for the experiments on the IJsseldijk consist of different activities that play a role towards the emission of CO_2 (Table 3). The obvious activities are the usage of the WOS and WIG. These need power, pumps and a water supply to perform the experiments. Besides this, the setup, usage and deconstruction of the test site will cause emissions. This is taken into account during the site preparation, for example the excavation of a culvert for the needed water supply. The setup of a detour is excluded as the traffic on the test location exists of cyclers and hikers. Finally, the different transport movements have to be taken into account. This will contain data on truck kilometres for transporting equipment etc.. Transport of commuting personnel and materials for the traffic detour are excluded, as these are too time consuming to work out in the limited time of this research.

[7] Not the same as the service life against erosion, but the actual strength of the grass cover in N.

Table 3: Included and excluded aspects of the LCA of the wave research

Activity	Included	Excluded
Site preparation	Excavation of the culvert; Placement of the driving plates with a forklift; Cleaning of the trench; Placement of construction trailers	Setting up the detour for traffic
Performing experiments	Energy usage for electricity generators; Usage of a mobile crane; Movement of the WOS	
Transportation	Transportation of the WOS; Transportation of the WIG; Transportation of the container; Transportation of the driving plates, fencing and other needed materials on site.	Commuting of personnel; Transport of the signs and fences for rerouting traffic

4.2.1.3. Assumptions and limitations of the wave research system

The assumptions made in the following list are aimed overestimate the emissions of the included aspects in this system. Lower emission numbers would give a more positive result to this study. However, some activities that produce small emissions are excluded as mentioned before. As the emission results will be subtracted from the dike cover replacement system emissions, these emissions are assumed to balance out.

- Assumed that emissions for traffic diversions are non-existent. The experiments were performed on a cycling path of which only slow traffic makes uses. It is assumed that these types of traffic do not produce significant amount of emissions and are therefore not included in the calculation.
- Commuting to the test site is not considered, as this is too time consuming for this research. Besides, there are more commuting trips involved in a dike cover replacement system. After comparing the values of commuting for both systems, this would only underestimate the reduction of emissions.
- Water usage is assumed to be net even. Water for the experiments is pumped up from the pond and is put back into nature again.
- The production of the machines and equipment are not within the scope of this study.
- Safe values for different activities are used. For example, some extra hours for the use of the mobile crane. The actual emission numbers might therefore be slightly lower than the values calculated.
- All trucks that deliver equipment are assumed to return back empty. Other clients on the same route are neglected. This overestimates the emissions.

4.2.2. LCA scope for the dike cover reinforcement

This section will explain what aspects will be discussed for the LCA and what aspects will be excluded for replacement of the grass cover on the dike crest and inner slope.

4.2.2.1. Functions and functional unit of dike cover reinforcement

The main function of the dike cover reinforcement project is to keep the region Salland behind dike ring 53 safe for high water and waves from the Ijssel. The dike cover has another function being transportation, such as the provincial road. This road should still be there after the reinforcement. Other functions will be outside of the scope of the LCA. To be able to check the reduced emissions from the avoided reinforcements on the dike cover, different scenarios are created for renewal of the inner slope. To be able to compare these scenarios with each other, it has been chosen to make use of a functional unit, which is described as follows:

"To be able to protect the hinterland of 28.4 km IJsseldijk Zwolle-Olst against high water and waves from the IJssel for the next 50 years by reinforcing the grass cover, while replacing the 79.5% sand of the top layer by clay"

The dike section that needs reinforcement will be 28.4 km (Springer-Rouwette, 2019). Of this dike section, only the aspects of the dike cover that need reinforcement will be taken into account, as the wave research only tested the influence on the cover. In the reinforcement, the dike cover had a sand content of 79.5% will be replaced by clay. The dike cover should be designed for a lifecycle of 50 years (Springer-Rouwette, 2019).

The study will check the difference in kg CO_2-eq and MKI output between the activities around replacement of the dike cover and no replacement. This means that activities that need to happen in both cases will not be taken into account.

4.2.2.2. Description of the scenarios

The design for the dike reinforcements on the IJsseldijk Zwolle-Olst is still in the developing phase. The project has been awarded to Boskalis, which is currently working out the details of the reinforcements (Waterschap Drents Overijsselse Delta, 2020). Besides, the current plan is not socially responsible as the different stakeholder needs are not yet implemented. For these reasons, there is not a final design for the project yet. Therefore, three possible scenarios for dike reinforcement are determined with different solutions to withstand erosion of the dike cover.

These scenarios have been determined in cooperation with Maurits van Dijk, technical manager of the project at WDOD. It was decided that the outer slope cover should be replaced in all scenarios as the outer slope did not get sufficient results from the wave experiments. According to the test results, the inner slope should be safe for most locations. Therefore, the scenarios are varying where the inner slope should still be replaced. An assumption was made that the crest of the dike does not have to be replaced at sections where the inner slope does not have to replaced. This is due to the low velocity of water flowing over the crest during wave overtopping, as the surface is approximately horizontal. This was confirmed by the test results from the wave experiments. The transition between a road to the grass was not found to be problematic.

Scenario 1

Scenario 1 is the most optimistic scenario. Here, the inner slope and dike crest do not have to be replaced anywhere. This scenario will show the maximum potential impact that the wave research could have had.

Scenario 2

In scenario 2, the inner slope and crest will have to be replaced on most of the IJsseldijk. However, in the southern section there is a provincial road on top of the dike. Scenario 2 is aimed to see the avoided emissions that result from not reconstructing the provincial road and retaining the inner slope and crest as it is at these locations. As this provincial road makes the dike very wide at these locations, the flow velocity of overtopping water will decelerate. Besides this, the road provides extra strength to the dike cover by being less sensitive towards erosion. Also, it would be expensive to reconstruct this road. As the transition between a paved road and the grass cover was found to be not that harmful, it was decided that this scenario is a possibility. This scenario will show the minimum potential impact of the wave research.

Scenario 3

In scenario 3 the same reasoning as in scenario 2 is applied, which results in not having to replace the inner slope and crest cover at the locations of the provincial road. Additionality, it was decided that at all locations on the dike where the inner slope is less steep than 1:3, the inner slope and crest cover do not have to be replaced. The tests have been done on a slope of approximately 1:3 and have been determined to be safe. If the slope is less steep than 1:3, then less flow acceleration will occur and the flow velocity of overtopping water will be smaller, resulting in less erosion. If the slope is steeper than 1:3, the cover has to be replaced as it is uncertain how much erosion would occur. This scenario will show the potential impact of the wave research at the representative locations compared to the test site.

4.2.2.3. Visualisation and geographical data of the scenarios

The whole section IJsseldijk Zwolle-Olst is 28.4 km long. However, reinforcement is not needed everywhere. To make the project more structured, the whole section was divided into sub-sections. In Table 4, it is shown in which scenarios the inner slope and crest cover of the sub-sections should be replaced or not. A visualisation of this is shown in Figure 8.

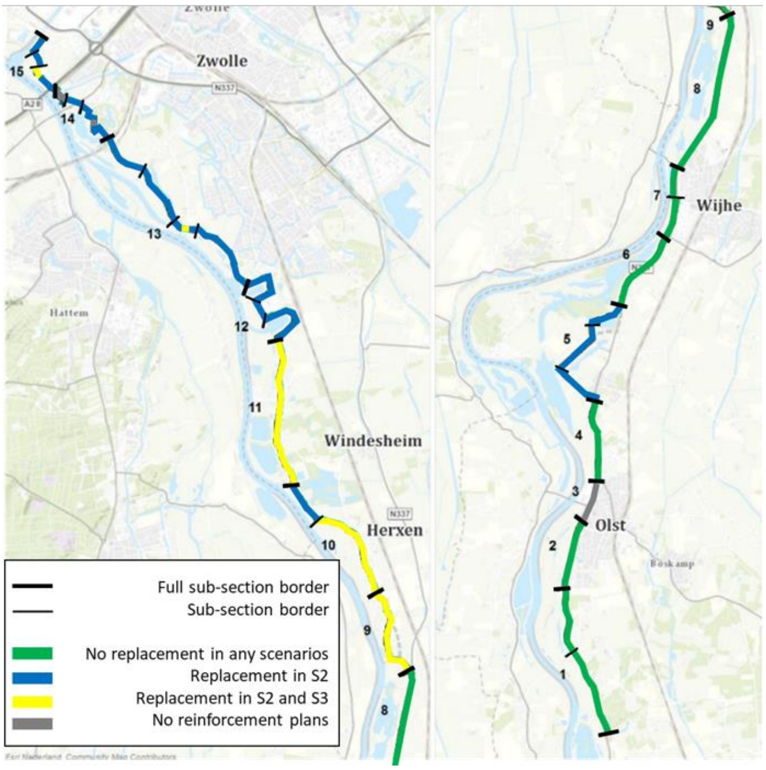

Figure 8: Visualisation for replacement of the dike cover in the different scenarios

Table 4: Dike cover replacement for scenarios per sub-section

Sub-section	From km	To km	#section	Provincial Road	Cross-section m/10	Slope	Replacement cover in Scenario 1	Replacement cover in Scenario 2	Replacement cover in Scenario 3
De Haere	17.8	19.3	1.1	Yes	1810	1:2.0	No	No	No
De Haere 2	19.3	20.4	1.2	Yes	1980	1:2.0	No	No	No
Olst-Zuid	20.4	21.6	2	Yes	2120	1:2.0	No	No	No
Olst-Dorp	21.6	22.3	3	Yes	No reinforcement				
Olst-Noord	22.3	23.7	4	Yes	2310	1:2.0	No	No	No
Den Nul (zuid)	23.7	24.5	5.1	No	2430	1:3.2	No	Yes	No
Den Nul (midden)	24.5	25.5	5.2	No	2500	1:3.2	No	Yes	No
Den Nul (noord)	25.5	26.1	5.3	No	2550	1:3.9	No	Yes	No
Duursche Waarden	26.1	27.5	6	Yes	2660	1:2.9	No	No	No
Wijhe Zuid	27.5	28.2	7.1	Yes	2790	1:2.6	No	No	No
Wijhe Dorp	28.2	28.7	7.2	Yes	2850	1:1.5	No	No	No
Wijhe Noord	28.7	31.4	8	Yes	3070	1:2.9	No	No	No
Paddenpol – Herxen	31.4	33.0	9	No	3170	1:2.7	No	Yes	Yes
Herxen Dorp	33.0	34.75	10.1	No	3380	1:2.7	No	Yes	Yes
Herxen tichelgaten	34.75	35.5	10.2	No	3530	1:3.5	No	Yes	No
Windesheim Noord Harculo (not complex)	35.5	36.9	11.1	No	3570	1:3.0	No	Yes	Yes
					3610	1:2.7	No	Yes	Yes
					3690	1:2.7	No	Yes	Yes
Windesheim Noord Harculo (complex)	36.9	38.05	11.2	No	3690	1:2.7	No	Yes	Yes
					3700	1:1.5	No	Yes	Yes
					3730	1:2.7	No	Yes	Yes
					3760	1:3.0	No	Yes	Yes
					3780	1:2.8	No	Yes	Yes
Centrale Harculo Zuid	38.05	39.05	12.1	No	3830	1:4.0	No	Yes	No
					3880	1:6.3	No	Yes	No
Centrale Harculo Midden	39.05	39.45	12.2	No	3930	1:6.6	No	Yes	No
Centrale Harculo Noord	39.45	40.3	12.3	No	3950	1:4.7	No	Yes	No
					4010	1:3.7	No	Yes	No
Schellerdijk	40.3	41.65	13.1	No	4070	1:3.6	No	Yes	No
					4100	1:3.0	No	Yes	No
					4130	1:3.7	No	Yes	No
Schellerdijk Oldeneel (complex)	41.65	42.1	13.2	No	4180	1:5.0	No	Yes	No
					4190	1:2.4	No	Yes	Yes
					4200	1:3.6	No	Yes	No
Schellerdijk Schellerwade	42.1	43.1	13.3	No	4250	1:5.1	No	Yes	No
					4290	1:3.5	No	Yes	No
Schellerdijk Vitens	43.1	43.95	13.4	No	4330	1:4.1	No	Yes	No
Engelse Werk	43.95	44.8	14.1	No	4400	1:3.4	No	Yes	No
					4410	1:5.4	No	Yes	No
					4420	No cover reinforcement			
					4460	1:16.7	No	Yes	No
					4470	1:6.9	No	Yes	No
Katerveerdijk	44.8	45.1	14.2	No	4500	1:3.0	No	Yes	No
Katerveercomplex	45.2	45.4	14.3	No	No cover reinforcement				
Spoolde 1	45.4	45.95	15.1	No	4570	1:4.1	No	Yes	No
Spoolde 2	45.95	46.2	15.2	No	4600	1:2.3	No	Yes	Yes
					4610	1:4.1	No	Yes	No
Spoolde kanaal 3	46.2	46.55	15.3	No	4630	1:4.1	No	Yes	No

4.2.2.4. System boundaries of dike cover reinforcement

The focus of this system is towards determining the environmental impact of the avoided dike cover reinforcements that were first planned on the IJsseldijk. This reinforcement project is seen as full new life cycle which is aimed to last for at least the coming 50 years. This is visualised in Figure 9. The different phases of a life cycle have been derived from DuboCalc (Rijkswaterstaat, 2017). Just the reinforcement of a dike could be seen as a part of maintenance and therefore a part of the usage phase. However, within this system, new raw materials are needed, which are processed in different construction activities. Also, the needed maintenance changes if the slope surface changes. These aspect make ensure that most phases of a life cycle should be taken into account. The only phase that is excluded is the demolition phase. Usually dikes will not see a demolition phase as they become part of the landscape (Reijn, 2016). After its designed life cycle the dike most often gets a new reinforcement and gets reused. Removal of unwanted parts that are constructed now will belong to the construction phase of the next life cycle. This means that removal of unwanted parts of the old design belong to the current life cycle.

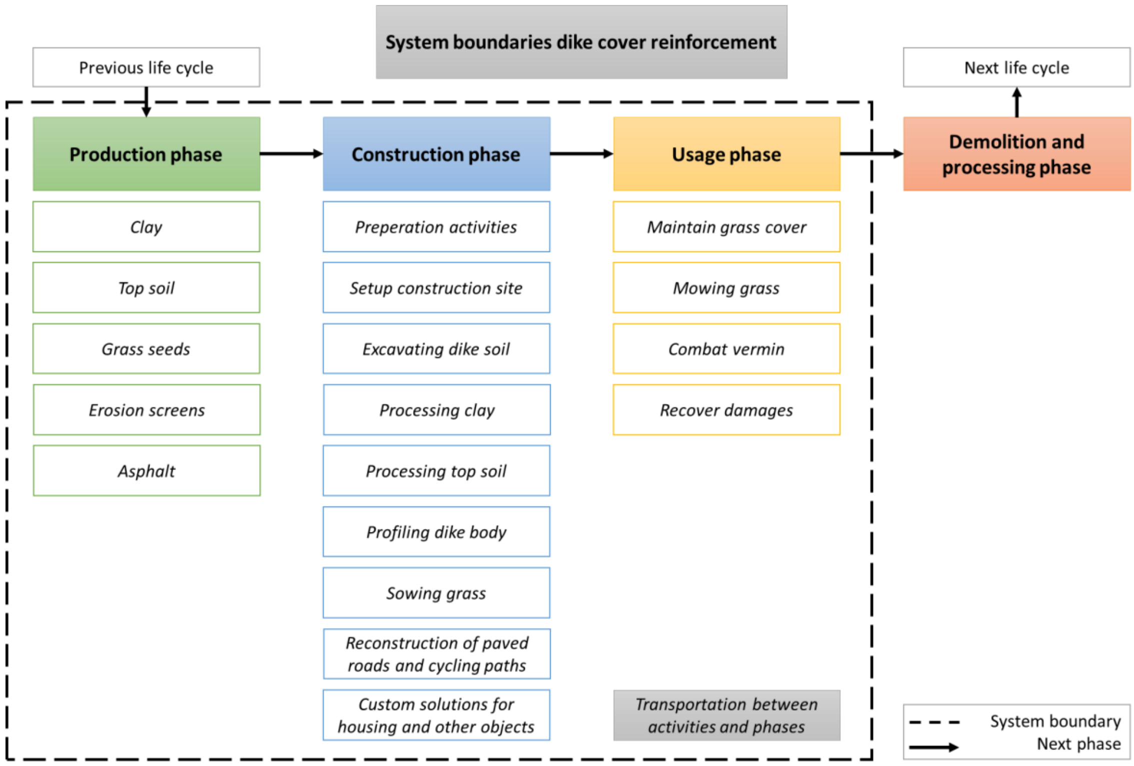

Figure 9: System boundaries dike cover reinforcement

The study is only aimed towards the reinforcement of the dike cover. This means that heightening of the core or stability berms will be out of the scope for this research. This choice is made, since the wave research only focuses on wave impact and overtopping erosion. As described before, no changes to the reinforcement plans of the outer slope will be made. In this system, only the crest and inner slope will be discussed. This means for the crest of the dike that the top layer should have been replaced by a meter of clay instead of the current sandy top layer. On top of the crest can be a paved section. For example in the southern section there is the provincial road and at other sections there is a cycling path. These need to be reconstructed if the cover needs to be replaced. On the inner slope 1 to 2 meter should be excavated to replace the sandy top layer by clay. Special attention should go towards custom solutions for objects on the dike such as houses. For this, sheet piles can be placed to prevent erosion due to overtopping or past flowing water. These sheet piles should only be accounted for when they have a function towards reducing erosion.

The production phase of the system is aimed towards the extraction of materials. For this the needed clay, grass seeds and top soil are included. However, on the crest the asphalt is needed for reconstruction of the roads. Road attributes and accessories are excluded as these have to be applied locally. This would be too time consuming for this study. Erosion screens will be seen as a raw material as conducting a separate LCA for the production of erosion screens is too time consuming for this study. In the construction phase all the separate processing activities are listed that need to take place to fulfil the reinforcement project. This includes the earth moving, sowing of the new grass cover, reconstruction of the road and placement of the erosion screens. The usage phase is taken into account as the surface of the dike cover could have changed. This influences the amount of maintenance hours needed. Transportation between activities and phases will be viewed per activity. Commuting is excluded as it is uncertain how much personnel the contractor will hire. Transportation of machinery is excluded as most machines, such as excavators, will most likely already be on the site for other reinforcements. An overview of the aspects that are included and excluded in this study are listed in Table 5. The remaining excluded aspects in this table are not taken into account due to the time constraint.

Table 5: Included and excluded aspects of the LCA of the dike cover reinforcement project

Activity	**Included**	**Excluded**
Raw material extraction	Clay; top soil; grass seeds; steel; concrete; asphalt; wood	Road attributes and accessories such as signs;
Excavating dike soil	Preparation activities such as mowing and milling; usage of machinery; disposal, cleaning and reuse of the soil	On and off ramps; separating of the contaminated and reusable soil
Processing new soil	Step wise profile; little and moderate erosion resistant clay; top soil;	On and off ramps
Profiling dike body and sowing grass	Usage of a roller and bulldozer; machinery for sowing the dike body	On and off ramps
Reconstruction of paved roads	Repair of the provincial road; reconstruction of the cycling paths	Road sings and attributes, except the lining; separate access roads; on and off ramps
Erosion screen placement	Placement of the steel erosion screens; placement of the cover gap	Clearing the surroundings; setting up the vibration system
Maintenance	Mowing and discharging;	Extra grass seeds for open spots in the future;
Transportation	Transportation of raw materials to the construction site; Transportation for the disposal of materials; transportation of materials to depot and the other way around	Commuting of personnel; Transportation of the machinery; Transportation of personnel on the construction site

4.2.2.5. Assumptions and limitations

The assumptions made in the following list are aimed underestimate the emissions of the included aspects in this system. Higher emission numbers would give a more positive result to this study. Some activities that produce small emissions are excluded as mentioned before. If these aspects were to be investigated, the result for the emission reduction would be higher.

- The current dike cover exists for 79.5% of sand. It is assumed that this is 100% when dealing with emissions. As sand has higher extraction emissions (Nationale Milieudatabase, 2018) the reusability of this soil will lower the emission reduction. This results in underestimating the potential emission reduction for a safe estimation.
- Sub-sections 3 and 14.3 do not see a replacement of the grass cover in the current reinforcement plans. The same accounts for cross section 4420 (Table 4).
- The soil that is used for backfilling will be clay with a 10 cm top soil layer for the grass to grow in.
- Transportation of equipment to the construction site will be out of the scope for this research. Some of this might already be there for other dike reinforcements.
- Calculations are based on optimal solutions, e.g. trucks are assumed to be fully loaded. This would result in a lower amount of emissions.
- Non-water retaining objects are not considered in this study, as their influence is difficult to predict. Considering this in a later stage can result in higher emissions.
- This study focuses on the direct impact of emissions. Electricity on the construction site for lighting and heating, machinery for fuelling the excavators and bulldozers and other indirect emissions will not be considered.
- The assumption is made that transport is done by use of the road network. Ships and other forms are discussed in the sensitivity analysis.
- Rerouting of traffic is not in the scope of this study. According to WDOD, the provincial road will not be closed fully during the construction. Traffic jams that could occur will be neglected.
- On and off ramps are all different and will therefore not be considered. This could only lead to higher emissions.
- For transport data, the default transport distance from DuboCalc is used, as it is unknown where the contractor will get the materials from.

5. Q2. What aspects of the wave research and dike cover replacement cause emissions?

The LCI is the second phase of the LCA, which involves the compilation and quantification of inputs and outputs for a product or project throughout its life cycle (NEN-EN-ISO 14067, 2018). This chapter will inventory all aspect within the scope of the LCA to and couple them to emissions. First the LCI is performed on the wave simulator research system, which is followed by the dike cover replacement system.

5.1. Wave simulator research

The first phase of the LCI is to inventory the aspects of the wave simulator research which have caused emissions. The main parts for this will be the fuel usage of the machinery, electricity generators and transport. The project had material and equipment coming from different companies in the surroundings of the test location. The data in this LCI is based on the script of the experiments, invoices of the companies and conversations with employees of Infram Hydren.

5.1.1. Energy usage

Under the energy usage of a LCI, there are three major components that have to be inventoried. These are water-usage, electricity-usage and fuel-usage (NEN, 2018). To perform the wave experiments, a lot of water is needed. For this the water from the pond at the inner side of the dike is used. Two electric submersible pumps are used for this with a capacity of 400m^3/h. The used water is discharged into the surroundings again. Therefore, the water is obtained from the surroundings and discharged in the surroundings. This results in a net water balance of zero. However, for the pumps electricity is needed.

The electricity that is used for the pumps is supplied a generator. This generator is used for the hydraulics and pumps. It is attached to an oil tank in which fuel is placed. The generator used for this is only active during the execution of the experiments. A second generator is used for the remainder of the needed electricity supply. This generator ran 24 hours per day with an internal fuel tank. The electricity is used for the lighting, heating and control equipment at the trial site. No electricity from the public electricity net is used, so all electricity is generated from the two generators. As all used electricity was generated on the site itself, the net electricity balance is equal to zero. However, the fuel usage has to be quantified to determine the emissions for the energy usage.

The fuel used for the generators is diesel and has been supplied by two different companies. After the experiments, the companies sent invoices which listed the fuel usage for these generators and some machinery. These diesel amounts on the invoices are listed in Table 6.

Table 6: Invoiced diesel volumes according to the invoices the companies

Invoice	**Date**	**Diesel L**
Filling generator fuel + activities crane and loader	22-4-2020	1112
Filling generator fuel + activities crane and loader	22-4-2020	1185
Fuel hydraulic excavator of cleaning of the trench	22-4-2020	85
Fuel for generators	27-2-20	2963
Total	-	**5343**

The total amount of used diesel is 5343L. This contains all fuel used for the generators and setup of the construction site. However, this excludes the usage of the hydraulic crane, placing and removing the driving plates and the transport of equipment to the location. The specifications for the emissions of diesel are listed in Table 7.

Table 7: Specifications of emission causing objects for the wave research system (NMD versie 2.3 DuboCalc - 6.01.27092018)

	Unit	kg CO_2-eq	MKI €
Fuel for generators - diesel	1 L	3.300 / L	0.58 / L
Hydraulic excavator	1 h	52.593 / h	9.22 / h
Truck with hydraulic crane on diesel	1 h	13.100 / h	1.75 / h
Vehicle kilometre transport truck	1 km	1.000 / km	0.12 / km

5.1.2. Usage of the hydraulic crane

The hydraulic crane was used for different small activities during the setup and break down of the trial location. The fuel used for this is included in the diesel invoices. The used fuel of the crane during the experiments is excluded from this. During the experiments with the WIG, the generator is attached to the hydraulic crane to be able to vary the location of the WIG relative to the slope. According to the script of the experiments, the crane is used for 5 full working days (Overduin & Mom, Draaiboek praktijkproeven ZwOlst, 2019). This would result in 40 active hours for the crane. In practice this was different. According to the test passports of the wave impact experiments, about 19 hours of storm were simulated. These tests were spread over 7 days. To be on the safe side, the 40 hours of the usage for the crane is assumed. The hydraulic crane was used during the experiments, but it was probably still active during the time between the experiments and for some small activities. The specifications of the hydraulic crane is listed in Table 7.

5.1.3. Placing and removing driving plates

The municipality indicated that the maximum allowed load on the cycling path on top of the dike is 5 ton. Because of that, steel driving plates were laid. The company laying the plates is responsible for the transportation, placement and removal of the plates. The transport part is discussed separately, however the emissions for the placement and removal is dealt with in this section. The truck used for this has an hydraulic crane on the back. For the placement of the plates, 1.5 working days were needed. The removal was quicker and only took 1 day. This results in a total of 20 active truck hours. The emissions for a truck with hydraulic crane are listed in Table 7.

5.1.4. Movement of WOS

The WOS is used at four different locations. The simulator therefore had to be moved, using a truck with hydraulic crane. The first time, the WOS was placed by company facilitating the generators. However, for the next 3 movements a different company was asked to move the simulator. The second company was located closer to the test location. After the experiments the simulator had to be picked up, to be moved to depot again. In total there were four full cycles for placing and picking up the WOS. These cycles lasted for about 2 hours (Mom, 2020). The emissions for a truck with hydraulic crane are listed in Table 7.

5.1.5. Transportation

The transport inventory contains all trips that have been made for delivering and picking up the needed equipment in order to be able to perform the experiments. Different companies have been involved in this process for different types of equipment. The companies with their roles and distances from the test site are listed in Table 8. It has to be noted that the company transporting the WOS and WIG have multiple depots for their trucks around the country. They had to transport the simulators from different places to the test site. Therefore, these distances are different for all transportation movements.

Table 8: The used equipment and their transportation distances (Overduin & Mom, Draaiboek praktijkproeven ZwOlst, 2019)

Equipment role	Distance km
Water pumps, diesel generators, connection water supply	121.0
Mobile crane, driving plates	22.3
Transport WOS, WIG and sea container	Different transportation distances, see appendix A
Security	86.5
Construction trailers and fencing	36.5
Driving plates	15.7
Movement of the WOS with hydraulic crane on a truck	10.3

The total distance travelled by loaded trucks is 1604.9km. However, these trucks had to return to the companies after delivering the equipment. Assumed is that the trucks were all empty and did not have other clients on their route. Therefore, the total distance of the trucks is doubled to get a slightly rough, but safe estimate of the travelled kilometres. The total transportation is therefore 3209.8km. Assumed is that all equipment is delivered by trucks. This allows for the standard DuboCalc value for transport of trucks per km to be used. The specifications of truck transportation per km are listed in Table 7. An overview of all transport movements are listed in Appendix A. “Overview of transport movements for the simulator research”.

5.2. Dike reinforcements for grass cover replacement

The second phase for the LCI is the system of the dike cover reinforcement. Within the system multiple activities need to be inventoried. The main part of this will be the earth moving, for example excavating and replacement of the top layer on the dike crest and inner slope. On the dike section, there will be multiple parts with a paved surface on the crest. For example the provincial road and cycling paths. If the crest has to be replaced, these paved surfaces need to be reconstructed. Lastly the erosion screens will be discussed as these are needed for custom solutions around houses and other not removable objects.

5.2.1. Earth moving

The earth moving will form the basis of the research. To determine the reduced environmental impact it is first needed to inventory what had to happen to the dike cover before the wave experiments. Therefore, WDOD supplied documents about the previous plans to reinforce the IJsseldijk. These included different cross sections of the dike, top views of the dike, reports on the promising design alternatives with its appendices on the dimensions of the reinforcement measurements and the substantiation of the preferred alternative per subsection.

5.2.1.1. Explanation of the earth moving activities

Before the wave overtopping research, the plans were to replace the dike cover on the inner slope and crest at most locations. This means that the existing top layer of grass on sand has to be excavated, new erosion resistant clay has to be placed and a new grass cover must be sown (Figure 10). The inner slope will be a clay cover in a tapered shape, being 1 meter thick at the crest and 2 meter thick at the toe of the dike. The soil on the inner slope will be little erosion resistant clay, previously named erosion resistance class 3. This clay has to be compacted and the slope must be shaved to steps in order to prevent the cover sliding of the dike body. On top of the clay a 10 cm thick top soil layer will be applied for the grass to grow in. This grass has to be sown in this layer to finish the cover. These dimensions have been extracted from the appendix on dimensions of the report on promising design alternatives (Frakking, 2018)..

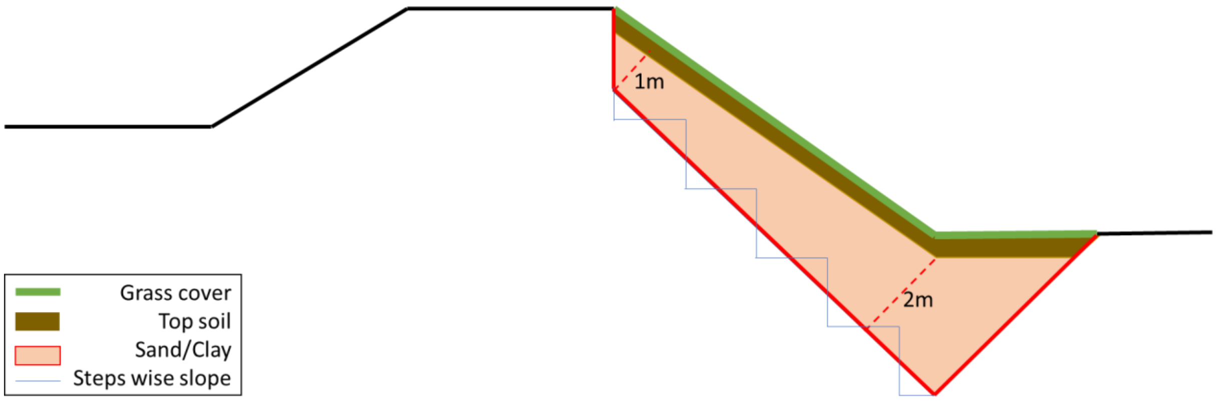

Figure 10: Schematic cross-section of an inner slope cover replacement

The crest of the dike has to be a clay layer of 1 meter thick. This soil will be moderate erosion resistant clay, previously named erosion resistance class 2. At locations where there will not be a paved road on top of the dike crest, there is a need for a 10 cm thick layer of top soil to sow the grass in (Frakking, 2018). The paved road will be discussed in a different section. A graphical explanation is shown in Figure 11.

Figure 11: Schematic cross-section of a crest cover replacement

WDOD provided data for different cross sections at the project site. These cross sections are used to determine the soil volumes that had to be excavated and placed. The cross sections are assigned to their corresponding sub-section and their representative length was determined based on the top views of the IJsseldijk. At transition locations, where it is unclear what cross section are representative, it is assumed to draw the line half way between the bordering cross sections. With the surfaces in the cross sections, the amount of soil is determined by multiplying that surface with the representative length of the cross section. An example of these surfaces are visualised in Figure 12 and Table 9. The data for the other locations and cross sections can be found in Appendix B.

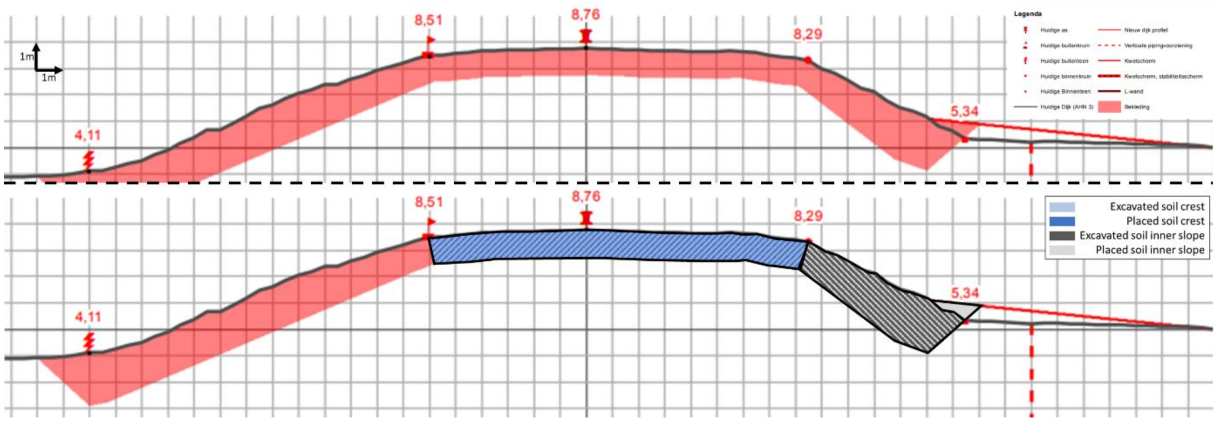

Figure 12: Example showing the amounts of soil to be processed. Cross section at location 1810 for alternative B

Table 9: Soil volumes to be placed and excavated at location 1810

Crest		Inner slope	
Excavated (Sand) m^2	Placed (Clay) m^2	Excavated (Sand) m^2	Placed (Clay) m^2
13,41	13,41	8,65	9,33
Multiplied by the representative length of this cross section: 1500 m			
Excavated (Sand) m^3	Placed (Clay) m^3	Excavated (Sand) m^3	Placed (Clay) m^3
20115	20115	12975	13995

5.2.1.2. *Excavation of the soil*

The first step in replacing the dike cover is the excavation of the soil. Before the excavation can start the dike cover needs to be prepared. The full surface of the dike crest and inner slope has to be mowed and milled before the excavation can start. This is needed to create a rough surface to connect to the old dike cover (Handboek Dijkenbouw, 2018). For this, tractors are used with a flail mowing or milling combination. The full data for the dike surface relevant for this study can be found in Appendix B. The specifications of the tractor can be found in Table 10. The sources for the values in this table are the DuboCalc library (NMD versie 2.3 DuboCalc - 6.01.27092018, 2018) and external reports of Nationale Milieudatabase (LCA Rapportage categorie 3 data Nationale Milieudatabase, 2020).

Table 10: Specifications of emission causing objects for the dike cover replacement system

	Capacity	kg CO_2-eq	MKI €
Tractor with mowing combination	1000 m^2 / h	34.4 / h	3.19 / h
Tractor with milling combination	600 m^2 / h	34.4 / h	3.19 / h
Hydraulic excavator (2000L)	100 m^3 / h	52.593 / h	9.22 / h
Transport truck bulk – land sand	1.7 m^3 / tkm	0.266 / tkm	0.04 / tkm
Cleaning process of the soil	1 m^3	16.62 / m^3	1.80 / m^3
Unnecessary extraction of sand	1 m^3	-4.62 / m^3	-0.41 / m^3
Unnecessary transport of sand	1.625 m^3/tkm	-0.266 / tkm	-0.04 / tkm

After the preparation the excavation process starts (Figure 13). The soil will be excavated from the dike body by an excavator, which will load the soil into a truck. It is assumed that the standard hydraulic excavator and transport truck for bulk materials from the DuboCalc library is used. This assumption is made, as it is unclear what types of machinery the contractor of the project will use. As most of the excavated soil will be sand, the specifications for the trucks loading capacity are based on sand extracted from land. The specifications of the excavator and truck can be is noted in Table 10.

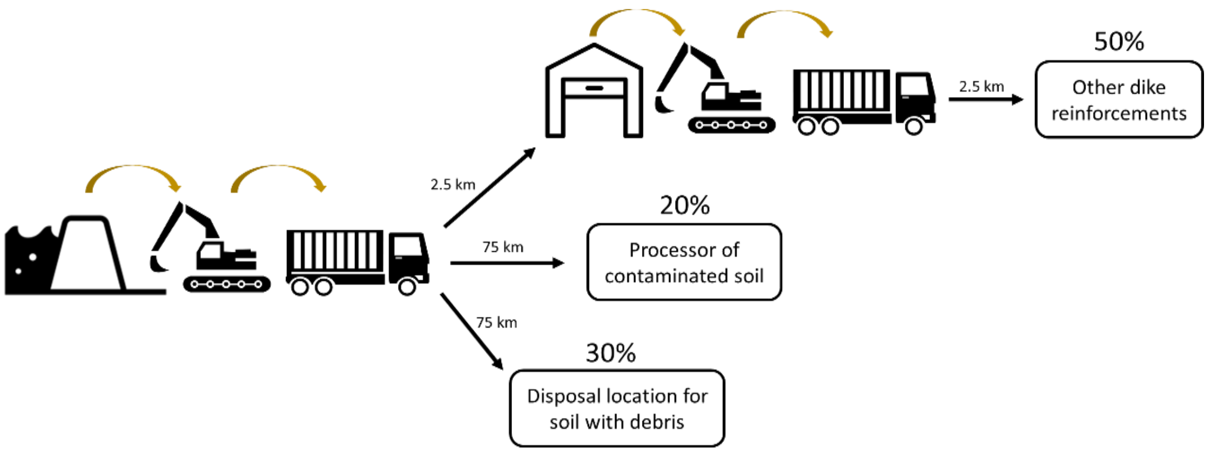

Figure 13: Schematic representation of the excavation process

There are three different paths to discharge the excavated soil (Frakking, 2018). About 50% of the soil will be available for reuse during the full reinforcement project. This usually means that the soil can be reused in the core or berm of the dike, however what will happen with it is currently unknown. About 30% of the soil will be disposed due to debris admixtures. The last 20% will be transported to a recognized processer of soil. This includes contaminated soil and soil that is exceeding intervention values for different substances like nitrogen or asbestos.

The truck will transport the soil to its destination. The soil containing debris will be transported to a disposal location at the DuboCalc default distance for bulk material of 75 km. This distance accounts for the contaminated soil which will be transported to a processer. The reusable soil will be transported to a depot near the construction site. For a dike stretch of 30 km usually 3 depots are used (Van den Heuvel, 2020). This results in an average transport distance of about 2.5 km between the construction site and nearest depot. When the soil is needed, an excavator loads up a truck to transport the soil from the depot to the new processing location. This process is visualized in.

It is important to note that there are two more factors which would influence the environmental emissions as an indirect consequence of the excavation process. First there is the cleaning process of the contaminated soil. It was decided that the disposal phase of the dike reinforcement would be part of the next lifecycle, which means that disposal of the previous lifecycle is within the scope of this study. DuboCalc already has the data on the emissions caused by this soil cleaning process. This can be found in Table 10.

The second consequence is that 50% of the soil is now available for reusability. This means that this surplus of soil can be placed in the core or a berm, reducing environmental emissions for other parts of the reinforcement. The extraction process of this soil and transportation to the construction site are not needed any more. This results into a negative value for the emissions of the dike cover reinforcement calculation. The specifications are listed in Table 10. The full calculation of the emissions for this process can be found in Appendix C.

5.2.1.3. Profiling the core stair wise

Creating a stair wise profile of the core material is an important step to make sure that a sliding plane between the dike core and the applied soil cannot occur (Figure 14). The stair wise profile can be created in phases, together with the phases of the soil backfill (Handboek Dijkenbouw, 2018).

Figure 14: Applying a stair wise profile on the slope

This will be done by use of an excavator. The same one that backfills the clay and excavated the old dike cover is used for this. The specifications for this excavator are listed in Table 11. As this is a time consuming activity, the capacity of processing the soil is lower than regular excavating or backfilling. This will be around 70 m^3/h (Van den Heuvel, 2020), the emissions are the same per hour.

Table 11: Specifications of the excavator used for stair wise profiling of the dike body

	Capacity	kg CO_2-eq	MKI €
Hydraulic excavator (2000L) – for stair wise profiling	70 m^3/h	52.593 / h	9.22 / h

The slope of the dike will be approximately 1:3 (Frakking, 2018). Therefore, the steps have to scale 1:3 as well. It is still unknown how big these steps will be and how much soil needs to be processed. However, it is usual in dike reinforcement projects to have steps with a width of 1 meter (Van den Heuvel, 2020). This results in the dimensions for the stair wise profiling of the slope as shown in Figure 15.

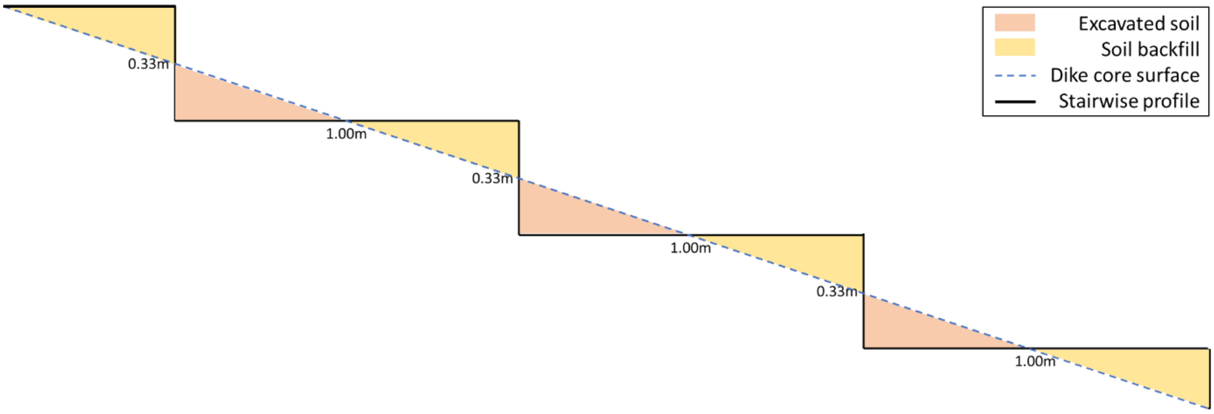

Figure 15: Schematic representation of the stair wise profiling of the dike body

To calculate the volume of soil that needs to be processed by the excavator in order to create this profile, the surfaces from Figure 15 can be taken. This results in the following:

$$Processed\ soil = excavated\ soil + backfilled\ soil \approx 0.082\ m^3/m^2{}_{core\ surface}$$

The full results on soil volumes per cross section to be profiled can be found in Appendix B.

5.2.1.4. Backfilling of the dike cover

Material extraction is the first step in the backfilling process of the dike cover (Figure 16). The new dike cover will exist of a clay layer as explained before which will get a 10 cm thick layer top soil layer on it. The clay coating has a water resistant function to protect the dike body against weathering and erosion. The top soil layer functions as the living layer for the roots of the grass to grow in. On the crest of the dike moderate erosion resistant clay will be placed. On the inner slope this will be little erosion resistant clay. The specifications for the extraction of these materials are listed in the DuboCalc library. For transport it is assumed that this soil will be moved by use of trucks over the default DuboCalc distance for bulk materials of 75 km. However, usually it is easier to get little erosion resistant clay from somewhere closer. A transport distance of 50 km is therefore applied. The specifications of the extraction of these materials are listed in Table 12.

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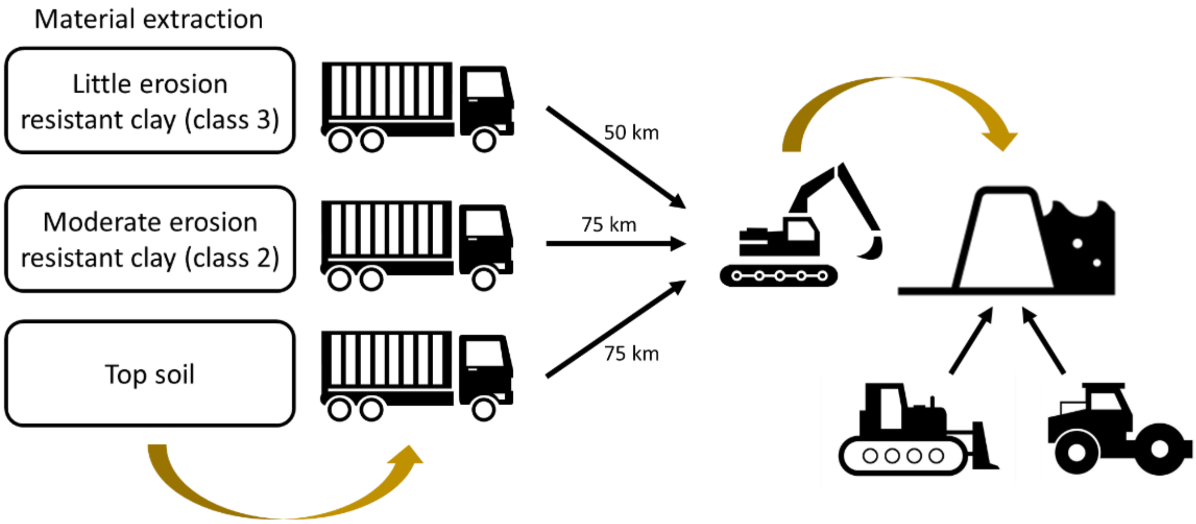

Figure 16: Schematic representation of the soil applying process

Table 12: Specifications for the extraction and transport of the materials

	Distance km	Capacity	kg CO_2-eq	MKI €
Moderate erosion resistant clay	75	1 m^3	0.6 / m^3	0.05 / m^3
Little erosion resistant clay	50	1 m^3	0.6 / m^3	0.05 / m^3
Top soil	75	1 m^3	0.6 / m^3	0.05 / m^3
Transport truck bulk – Clay	-	1.6 m^3/tkm	0.266 / tkm	0.04 / tkm
Transport truck bulk – Top soil	-	1.625 m^3/tkm	0.266 / tkm	0.04 / tkm

As clay will settle over time it is needed to apply extra material to make sure that the slope is straight in the future. Therefore a barrel round dike profile has to be applied. The clay is placed in a convex way, which creates a visual straight profile. According to Dutch standards all slopes need to be heightened by 2.5% at 2/3 of the slope length (Handboek Dijkenbouw, 2018). This barrel round profile is also needed at the crest, due to settling of the clay and drainage of rainwater. At the middle of the crest, the dike cover will be heightened by 1% of the crest width (Handboek Dijkenbouw, 2018). This is shown in Figure 17. The extra clay volumes have been accounted for in the total clay volume by use of goniometry and can be found in Appendix B.

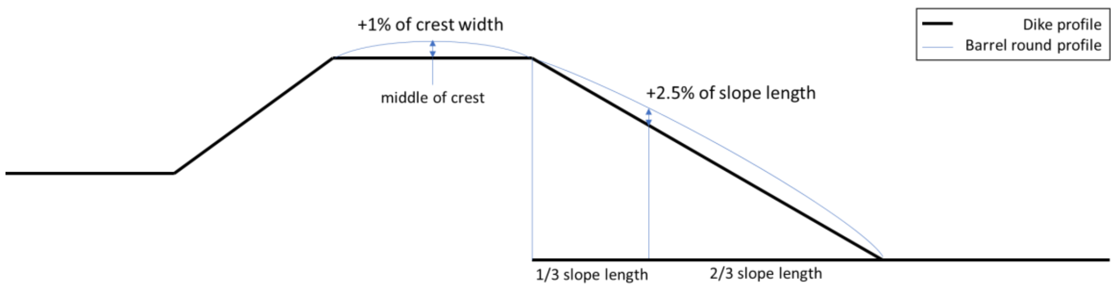

Figure 17: Schematic representation of the needed barrel round dike profile

When the materials arrive at the construction site, a hydraulic excavator with a volume of 2000L will place the clay on the dike cover. This cover needs to be profiled and compacted to close the pores in the clay as much as possible (Handreiking Dijkbekledingen, 2015). A bulldozer is used for profiling and levelling the soil. A sheep-foot roller is used for the compacting of the clay. The compacting and profiling is done in layers of 50cm (Frakking, 2018). The specifications these machines are listed in Table 13. These capacities per hour are the same as these machines work together and are therefore used for the same amount of hours. In a schematic representation of the backfilling process is shown. The full calculation of the emissions for this process can be found in Appendix D.

Table 13: Specifications for the machinery to backfill the soil according to the DuboCalc library

	Capacity m^3/h	kg CO_2-eq / h	MKI € / h
Hydraulic excavator (2000L) – placement of the soil	100	52.593	9.22
Bulldozer 12-35 t dry/wet	100	50.900	11.36
Sheep-foot roller	100	49.500	8.68

5.2.1.5. Sowing the dike body

The last phase of the earth moving is sowing the top soil layer with grass seeds. It is desired to wait with this until the clay lay for the first winter season (Frakking, 2018). In particular dike seed mixtures D1 and D2 are available on the market (Handreiking Dijkbekledingen - Deel 5: Grasbekledingen, 2015). For river dikes usually the seed mixture D1 is used as it has high resistance against setting foot on it, the grass grows and recovers faster and it is suitable for sheep (VisscherHolland, 2020). The emissions for the seed mixture production have been retrieved from ADAS Consulting Ltd (Bullard & Metcalfé, 2001). The grass seeds will be sowed by use of a tractor with sowing combination with a concentration of 150kg/ha. The tractor can sow about 400m^2/h (Van den Heuvel, 2020). The seeds will be transported for the default transport distance for bulk materials in the DuboCalc library, 75km. The specifications of the sowing elements can be found in Table 19. The full calculation of the emissions for this process can be found in Appendix E.

Table 14: Specifications of the elements in the grass sowing process

	Capacity	kg CO_2-eq	MKI €
Seed mixture D1 150kg/ha	0.015 kg / m^2	2.913 / kg	0.26 / kg
Tractor with sowing combination	400 m^2 / h	34.4 / h	3.19 / h
Transport truck bulk – 75 km	1000 kg / tkm	0.266 / tkm	0.04 / tkm

5.2.2. Erosion screens

At various locations on the dike section, it is not possible to replace the dike cover. This is usually the case when there are houses on the inner slope of the dike. For these situations, custom solutions are created. This will happen with stability, seepage and erosion screens. As piping and stability are not within the scope of this study, only erosion screens will be discussed. At the locations in Table 15, erosion screens would have been placed. The erosion screens will be placed over a length of 50m per location (Frakking, 2018).

Table 15: Number of locations where an erosion screen was needed

Sub-section	Locations	Sub-section	Locations
1.1	2	**13.2**	4
5.1	1	**13.3**	3
5.2	1	**14.1**	3
6	2	**14.2**	3
7.2	1	**15.1**	2
11.2	5	**15.3**	2
13.1	2		

The erosion screens will be unanchored sheet piles of type AZ 17-700 and they are assumed to have a length of 15m (Frakking, 2018). A length of 8m would have been sufficient, however by taking 15m it can have a double function as seepage screen. On top of the erosion screen, a concrete cover gap will be placed. This cover gap works as protection for the sheet pile and creates a straight surface to connect with the environment. The cover gap will have dimensions of 0.5x0.5m and has to be reinforced. A visual of this can be found in Figure 18.

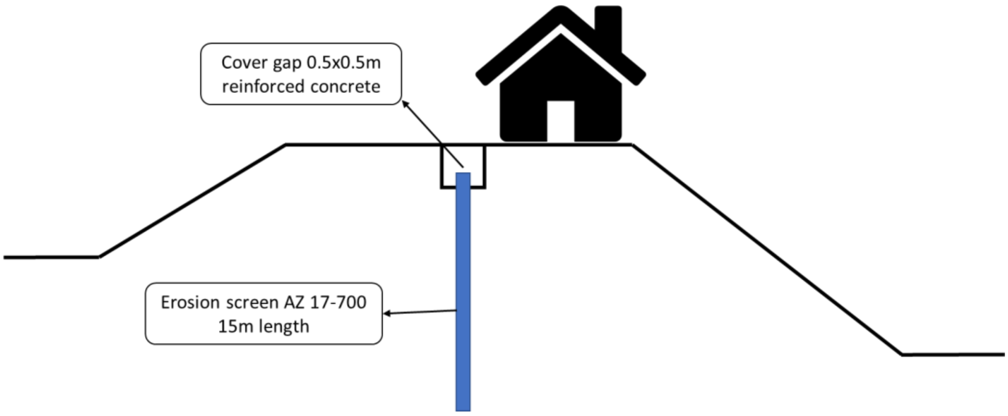

Figure 18: Schematic representation of the placement of an unanchored erosion screen

Placement of the sheet piles

The WDOD wants the erosions screens to be placed by use of high frequent vibrations. This method has the advantages of being simple and fast. Besides, this method results in less vibrations that could cause damage compared to using low frequency or a pile driver. The natural frequency of soil varies between 15 and 20 Hz. For placing the sheet piles, this frequency should be 50-75% higher. This prevents that the vibrations amplify to the surroundings, which results in a lower chance of damaging surrounding buildings (W-Dam, 2019). A dragline crane with a high-frequency vibratory hammer is needed to hold and place the erosion screens. This method can put about 12m^2/h of steel into the ground (DuboCalc, 2020). The sheet pile has a weight of 0.104t/m^2 (Grand Piling, 2020). The specifications for the materials and equipment are listed in Table 16.

Table 16: Specifications of the equipment needed for placing the erosion screens and the cover gap (NMD versie 2.3 DuboCalc - 6.01.27092018)

	Capacity	**kg CO_2-eq**	**MKI €**
AZ 17-700 sheet pile	0.104 t / m^2	908 / t	67.53 / t
Vibratory hammer	12 m^2 / h	0.667 / h	0.05 / h
Dragline	12 m^2 / h	79.750 / h	6.25 / h
Concrete C20/25 CEMIII	2.440 t / $m^3_{concrete}$	56.699 / t	5.37 / t
Steel reinforcement B500	0.056 t / $m^3_{concrete}$	908.000 / t	68.88 / t
Wood formwork	1.500 m^2 / m_{length}	1.529 / m^2	0.26 / m^2
Concrete pump + truck	105.042 m^3 / h	6.168 / h	0.48 / h
Hydraulic tele-crane	2.7 t_{steel} / h	79.750 / h	6.25 / h
Poker vibrator	2.5 m^3 / h	0.097 / h	0.01 / h
Transport truck concrete – 25 km	1 tkm	0.266 / tkm	0.04 / tkm
Transport truck steel – 50 km	1 tkm	0.266 / tkm	0.04 / tkm
Transport truck wood – 25 km	0.0104 tkm / m^2	0.266 / tkm	0.04 / tkm

Placement of the cover gap

The cover gap will act as a stabilizer for the sheet pile. It will form a straight surface on the ground level, such that the erosion screen does not poke out above (Vree, 2020). Usually a cover gap is not necessary for an unanchored sheet pile as there is no force transmission to the other panels or anchor. The only forces on the cover gap are loads from above such as traffic. As this force is relatively small, the choice is made to use a lower strength class of concrete, being C20/25 (CEMII) concrete. The concrete needs steel reinforcements, due to shrinkage stress. The amount of reinforcement should be at least 0.7% of B500 steel (Sman, Veenbergen, Verbraken, & Larsen, 2019).

First the wooden formwork will be put in place for the concrete to be poured into, after which the concrete is poured and reinforcement steel is placed. The concrete will be poured by use of a concrete pump attached to the cement truck. A tele-crane is used to handle the reinforcement material at the construction site, however the steel is placed by hand. At the end of the process, the concrete is compacted by use of a poker vibrator to reduce the pores. The specifications of this process are listed in Table 16. The full calculation of the emissions for this process can be found in Appendix F.

5.2.3. Paved dike crests

In addition to the protection against water, the IJsseldijk also has a transport function at different locations. On top of the dike crest there are different paved surfaces for traffic. During the reinforcement project, these can get damaged or they have to be reconstructed. Reconstruction and recovery works will increase the environmental emissions. An overview of the crest usage on the different sub-sections is given in Table 17.

Table 17: Overview of the crest usage per sub-section

Sub-section	#Section	Length cross sections m	Crest usage
De Haere	1.1	1500	Provincial road
De Haere 2	1.2	1100	Provincial road
Olst-Zuid	2	1200	Provincial road
Olst-Dorp	3	700	No reinforcements
Olst-Noord	4	1400	Provincial road
Den Nul (zuid)	5.1	800	Tichelstraat
Den Nul (midden)	5.2	1000	Grass
Den Nul (noord)	5.3	600	Grass
Duursche Waarden	6	1400	Provincial road
Wijhe Zuid	7.1	700	Provincial road
Wijhe Dorp	7.2	500	Provincial road
Wijhe Noord	8	2700	Provincial road
Paddenpol – Herxen	9	1600	Cycling path
Herxen Dorp	10.1	1750	Cycling path
Herxen tichelgaten	10.2	750	Grass
Windesheim Noord Harculo (not complex)	11.1	1400	Grass
Windesheim Noord Harculo (complex)	11.2	1150	Grass
Centrale Harculo Zuid	12.1	1000	Grass
Centrale Harculo Midden	12.2	400	Grass
Centrale Harculo Noord	12.3	850	Cycling path (Beekmanpad)
Schellerdijk	13.1	1350	Grass
Schellerdijk Oldeneel (complex)	13.2	450	Grass
Schellerdijk Schellerwade	13.3	1400	Cycling path
Schellerdijk Vitens	13.4	850	Cycling path
Engelse Werk	14.1	850	Grass
Katerveerdijk	14.2	300	Access road
Katerveercomplex	14.3	200	No reinforcements
Spoolde 1	15.1	550	Grass
Spoolde 2	15.2	250	Grass
Spoolde kanaal 3	15.3	350	Access road

In the next sections of this study, the different construction activities around these paved surfaces are discussed.

5.2.3.1. Provincial road

In the southern part of the project location, most of the times the provincial road is on the dike crest. In the preferred alternative, the provincial road stays on top of the dike without reconstructing it (Rapportage ontwerp kansrijke alternatieven verkenning Zwolle-Olst, 2019). It is wished to have no traffic disruption. Therefore, the provincial road does not have to be closed fully for reconstruction. However, during the replacement of the dike cover, damage could occur to this road. This is caused by carelessness of the machinery drivers or during the construction of the transition between the cover and the road. These damages have to be repaired. The repair work will be locally. This mostly exists of damage repair to the top layer of the asphalt. It is assumed that the no tar containing top layer has to be replaced over 50% of the road surface (Frakking, 2018). Repair work to local public transport facilities and other road equipment is not within the scope for this research. For the repairs, the guidelines from DuboCalc are used.

It is assumed that 50% of the road surface is renewed for this calculation. The width of a provincial road is 7.5m (CROW, 2016). The top layer has a thickness of 40 mm (DuboCalc, 2020). The density of asphalt is 2.5 t/m^3. With these values the amount of tonnes asphalt is calculated.

Removal of the old top layer

To repair the damages dealt to the asphalt, the old top layer has to be removed first. This is done by a cold milling machine, breaking up the old asphalt (Asfaltbedrijven, 2020). A sweep-suction car follows the milling machine to clean the debris off the terrain and puts this in a truck to be transported over the default distance of 30km. The specifications of the equipment used for this is listed in Table 18.

Table 18: Specifications for the removal of the old asphalt top layer according to the DuboCalc library

	Capacity	kg CO_2-eq	MKI €
Cold milling machine	28 t / h	91.953 / h	16.24 / kg
Sweep-suction truck	40 t / h	74.185 / h	13.02 / h
Transport truck bulk – 75 km	1 tkm	0.266 / tkm	0.04 / tkm

Applying the adhesive layer

For optimal durability, asphalt layers need to be connected well. If this connection is insufficient, different layers could slide due to the horizontal forces of traffic. To connect the existing foundation with the new top layer, an adhesive layer is applied (Latexfalt, 2020). This will be a layer of bitumen emulsion. The bitumen emulsion sub-layer is applied by use of a spraying car and it has to be transported over the default distance of 50km. The specifications of the material and equipment used in this process is listed in Table 19.

Table 19: Specifications of applying the adhesive layer according to the DuboCalc library

	Capacity	kg CO_2-eq	MKI €
Bitumen emulsion sub-layer	0.3 kg / m^2	277.318 / t	40.81 / t
Spraying car	750 m^2 / h	9.918 / h	1.74 / h
Transport truck bulk – 50km	1000 kg / tkm	0.266 / tkm	0.04 / tkm

Applying the top asphalt layer

It is assumed that the new top layer will consist of the asphalt type SMA. This asphalt has high durability with an average lifecycle of about 20 years. Besides it has a high resistance against deformation. SMA asphalt is economically attractive as it asks for little maintenance (CROW, 2014). This is placed by use of an asphalt truck with a paver behind it to lay it in place and divide it evenly over the surface. A roller is behind it to compact the asphalt. The asphalt is transported over the DuboCalc default distance of 30km. The specifications of this process are listed in Table 20.

Table 20: Specifications of the top layer paving process according to the DuboCalc library

	Capacity	**kg CO_2-eq**	**MKI €**
Asphalt SMA 0/11	2.5 t / m^3	80.893 / t	9.14 / t
Asphalt truck	75 t / h	74.185 / h	13.02 / h
Asphalt paver	75 t / h	49.500 / h	8.68 / h
Roller	75 t / h	46.143 / h	8.09 / h
Transport truck bulk – 30km	1 tkm	0.266 / tkm	0.04 / tkm

Applying road markings

For the road marks on SMA asphalt, thermoplastic marking material will be used. It is assumed that over the full section of the provincial road one uninterrupted stripe and one 3-3 interrupted stripe has to be placed (Handboek Ontwerpcriteria Wegen, 2014). The thermoplastic markings will be painted on the road surface by use of a stripe drawing machine. The stripes have a thickness of 3mm and are 20mm wide. The concentration of thermoplastic material is 10 kg/m^2 (DuboCalc, 2020). The material is transported over the DuboCalc default distance of 50 km. The specifications of this process are listed in Table 21. The full calculation of the emissions for this process can be found in Appendix G.

Table 21: Specifications for applying road markings

	Capacity	**kg CO_2-eq**	**MKI €**
Thermoplastic markings	2 t / km	2566.759 / t	270.32 / t
Marking machine	1.429 h / km	56.293 / h	6.07 / h
Transport truck bulk – 50km	1 tkm	0.266 / tkm	0.04 / tkm

5.2.3.2. Cycling paths

At different locations there is a cycling path on top of the dike crest. Due to the replacement of the dike cover at the crest, this cycling path has to be removed first. After the construction activities are finished, the cycling path needs to be reconstructed with the same dimensions (Frakking, 2018). The preference is a cycling path that can lay on the clay subsoil. This cycling path is made of prefab concrete slabs being 2m wide.

Figure 19: Cycling path at the start of sub-section 9 (Google Maps, 2016)

Removal of the old cycling path

The removal of the old concrete slabs is done by a wheel loader. The wheel loader places the concrete in a truck that will transport the slabs to a deposit location at the DuboCalc default transport distance of 50 km (DuboCalc, 2020). The deconstruction can be done with 40m^2/h. The specifications of the removal process is listed in Table 22.

Table 22: Specifications of the demolition process of the old cycling path according to the DuboCalc library

	Capacity	**kg CO_2-eq**	**MKI €**
Wheel loader	40 m^2 / h	43.494 / h	7.63 / h
Transport truck bulk – 50km	1 tkm	0.266 / tkm	0.04 / tkm

Placement of the sand sub-layer

To make sure that the new cycle path will not sag as much, a foundation of sand has to be made before placing the concrete. This sand layer will have a thickness of 30cm (BetonInfra, 2011). The sand is transported to location per truck over a distance of 75km. A wheel loader will place the sand at the right locations after which a roller compacts the sand layer. The specifications of the equipment used for placing the sand layer is listed in Table 23.

Table 23: Specifications of the material and equipment used to place the sand layer according to DuboCalc

	Capacity	**kg CO_2-eq**	**MKI €**
Sand	1.7 t / m^3	2.717 / t	0.24 / t
Wheel loader (2000L)	100 m^3 / h	43.494 / h	7.63 / h
Roller (average)	100 m^3 / h	49.500 / h	8.68 / h
Transport truck bulk – 75km	1 tkm	0.266 / tkm	0.04 / tkm

Placement of the concrete slabs

The last step to reconstruct the cycling path is placing the concrete slabs. The standard prefab concrete slabs in the DuboCalc library have a width and length of 2m. This matches the criteria for the cycling path according to WDOD. The slabs have a thickness of 140mm. The slabs are transported over a default distance of 50 km by a truck, after which a wheel loader lays them in place. This is done with a production standard of 24m^2/h. The specifications of this process are listed in Table 24. The full calculation of the emissions for this process can be found in Appendix H.

Table 24: Specifications of the concrete slab placement process according to the DuboCalc library

	Capacity	**kg CO_2-eq**	**MKI €**
Prefab concrete slabs – Concrete mortar C55/67	0.35 t / m^2	2.717 / t	0.24 / t
Wheel loader	24 m^2 / h	43.494 / h	7.63 / h
Transport truck bulk – 50km	1 tkm	0.266 / tkm	0.04 / tkm

5.2.4. Maintenance

WDOD is the responsible party for maintaining the dike cover. To keep the new dike cover in a good working condition a clear maintenance policy is needed. However this will not change much compared to the old dike cover. The important aspect in dike maintenance that are applicable to a dike cover are the following (Pilarczyk, 2003):

- Revetments
- Roads
- Buildings
- Fencing and road signs
- Vegetation
- Sheet piling and quay walls

The roads on the dike will remain the same as in the previous situation. Therefore, no change in the maintenance scheme is needed. It was discussed to widen the cycling paths on the dike, however nothing has been decided yet and the contractor was told to assume the same dimensions as before. The same applies to buildings, fencing and road signs on the dike. No new buildings and signs will be placed. For this reason, there are no significantly reduced environmental emissions to obtain in these aspects.

The design lifetime for the dike body and the sheet piles is at least 50 years as said before. That is why the chance for major damages should be low. However, if damage is done, this should be repaired. Damage to the revetments are usually due to a change of crest height. This reinforcement project ensures that this will not happen for the following years, however there is still a risk. It is assumed that this risk is similar to the risk of the previous reinforcement. The erosion screens are new, however they are designed for 50 years as well. There is a small risk that repairs or replacements have to be performed, however this cannot be said with certainty. Therefore, the safe assumption is made that no sheet piles will get damaged as there will not be an environmental benefit in this case.

The vegetation on the dike changes however. Maintenance for upkeep of the dike cover exist of re-sowing the grass cover when damages occur and mowing of the grass. As the surface of the grass cover gets bigger, there will be more spots on the surface with damage to the grass. Re-sowing these damaged spots will likely be done by hand which does not cause emissions and the amount of needed seeds for this will be insignificant if a good maintenance scheme is applied.

There is a change in the produced emissions of the mowing scheme before and after the dike cover replacement. All inner slopes have to be less steep than 1:3. To ensure this, the total cover surface changes. The maintenance scheme exists of mowing the dike surface twice a year while the remains will get discharged (Handreiking Dijkbekledingen, 2015). In a lifecycle of 50 years, this means that the surface has to be mowed 100 times. For the mowing, a tractor with a mow/suction combination is used. This shortens the grass and places the clippings in a trailing truck. When the truck is full, this grass is discharged over the default distance for grass of 25 km. The specifications of the mowing process are listed in Table 25. The weight of grass per mowing cycle is 0.488kg/m^2 (The Lawn Institute, 2020). The full calculation of the emissions for this process can be found in Appendix I.

Table 25: Specifications of the mowing process according to DuboCalc and NMD

	Capacity	**kg CO_2-eq**	**MKI €**
Tractor + mowing/suction combi	1000 m^2 / h	34.4 / h	3.19 / h
Transport truck bulk – 25km	0.00049 t / m2	0.266 / tkm	0.04 / tkm

6. Q3. What is the reduced environmental impact on the IJsseldijk based on literature values?

This phase of the LCA is aimed to evaluate the environmental impacts based on the data gathered in the LCI stage. As mentioned before, this is based on the kg CO_2-eq and the MKI of both the simulator research and the dike cover reinforcement project. The following data was retrieved by multiplying the emission factors with the quantity of different activities, for example the amount of hours that an excavator was active.

6.1. Environmental impact of the wave research

To determine the final LCA value of the wave research, all aspects previously discussed are evaluated. The quantities are coupled with the emission factors and the final results are calculated. The results are visualised in Table 26. The part most contributing to the final result is the fuel usage for the generators. This is because the generators were active during all of the experiments that were performed, while the other machinery was only made use of in smaller periods. Transport and the hydraulic crane for the WIG experiments are the next most emitting. The total amount of emissions for the wave research are 2.33E+04 kg CO_2-eq. The total MKI for the wave research is €3 902. The full calculation of the emissions for the wave research is stated in Appendix J.

Table 26: Environmental impact result of the wave research

Process/material	**kg CO2-eq**	*Percentage*	**MKI**	*Percentage*
Diesel	1,76E+04	75,63%	€ 3.098,94	79,42%
Mobile crane for using WIG	2,10E+03	9,02%	€ 368,80	9,45%
Truck with hydraulic crane for moving the WOS	1,05E+02	0,45%	€ 14,00	0,36%
Placement of the driving plates	1,57E+02	0,67%	€ 21,00	0,54%
Removing driving plates	1,05E+02	0,45%	€ 14,00	0,36%
Transport	3,21E+03	13,77%	€ 385,18	9,87%
Total emissions	**2,33E+04**	**kg CO2-eq**	**€ 3.902**	**MKI**

6.2. Reduced emissions of the scenarios for the dike cover reinforcement

The environmental emissions for the dike cover replacement project have been calculated for the three scenarios of the IJsseldijk. The results per construction activity are listed in this section. The results for excavating, backfilling, etc. are all calculated separately based on the specifications from the LCI. The scenarios are coupled to these cross-sections by checking the corresponding sub-sections in which the cover does not have to be replaced as shown in Table 4. When the cover of a sub-section does not need to be replaced in a scenario, then an emission reduction is noted. Finally, the total reduced emissions are calculated by subtracting the emissions from the wave simulator research from the emissions of the dike cover replacement. The results per cross-section are noted in Appendix K. “Kg CO2-eq results per cross-section” and Appendix L. “MKI results per cross-section”.

6.2.1. Reduced environmental impact dike reinforcement scenario 1

In the first scenario the full dike cover of the IJsseldijk Zwolle-Olst on the inner slope and crest does not have to be replaced. This results in reduced environmental emissions as the plans before the WOS research indicated that the dike cover had to be replaced at 27.35km. Table 27 shows the percentages per construction activity. These indicate the magnitude of the part that this activity played for the final result. The final results for the environmental impact analysis of scenario 1 are noted in Table 27 as well. The total amount of reduced emissions are 23.11 kton CO_2-eq. The MKI of the reduced emissions of scenario 1 is €3 269 525. The backfilling of soil contributes the most to the reduced emissions with

75.37% of the CO_2-eq. The sowing process contributes the least with 0.32%. The results show that the different processes do not contribute the same amount towards CO_2-eq and MKI emissions. This is the case as different activities cause different emissions. The MKI calculates this in a different ratio compared to the CO_2-eq.

Table 27: Environmental impact analysis results scenario 1

Construction activities	kton CO2-eq	*Percentage*	MKI	*Percentage*
Excavating process	1,52	6,57%	€ 237.179	7,25%
Backfilling of clay inner slope	10,51	45,42%	€ 1.600.185	48,88%
Backfilling of clay crest	4,82	20,83%	€ 732.722	22,38%
Backfilling of top soil	2,11	9,12%	€ 323.893	9,89%
Sowing process	0,07	0,32%	€ 6.861	0,21%
Erosion screens	2,47	10,66%	€ 188.450	5,76%
Provincial road	0,50	2,15%	€ 59.971	1,83%
Cycling paths	0,65	2,82%	€ 76.321	2,33%
Maintenance	0,49	2,11%	€ 47.844	1,46%
Sub-total emissions	***23,14***	100%	***€ 3.273.427***	100%
Emmissions simulator research	0,02		€ 3.902	
Total reduced emissions	**23,11**	**kton CO2-eq**	**€ 3.269.525**	**MKI**

6.2.2. Environmental impact dike reinforcement scenario 2

In the second scenario, the dike cover does not have to be replaced in the southern part of study area. This means all sub-sections on which the provincial road is placed. The sections where the current grass cover can remain in place have a total length of 10.5km. This is much less compared to scenario 1, where 27.35km of cover is replaced. Therefore the emissions for scenario 2 are lower. The results of the environmental impact analysis are noted in Table 28. The total amount of reduced emissions are 7.74 kton CO_2-eq. The MKI of the reduced emissions of scenario 2 is €1 120 533. The backfilling of soil contributes the most to the reduced emissions with 78.25% of the CO_2-eq. Due to the absence of cycling paths in this scenario, they contribute the least with 0%.

Table 28: Environmental impact analysis results scenario 2

Construction activities	kton CO2-eq	*Percentage*	MKI	*Percentage*
Excavating process	0,59	7,60%	€ 91.938	8,18%
Backfilling of clay inner slope	3,07	39,72%	€ 468.170	41,64%
Backfilling of clay crest	2,24	28,99%	€ 341.172	30,34%
Backfilling of top soil	0,74	9,54%	€ 113.301	10,08%
Sowing process	0,03	0,34%	€ 2.400	0,21%
Erosion screens	0,40	5,14%	€ 30.395	2,70%
Provincial road	0,50	6,42%	€ 59.971	5,33%
Cycling paths	0,00	0,00%	€ 0	0,00%
Maintenance	0,17	2,26%	€ 17.087	1,52%
Sub-total emissions	***7,74***	100%	***€ 1.124.435***	100%
Emmissions simulator research	0,02		€ 3.902	
Total reduced emissions	**7,72**	**kton CO2-eq**	**€ 1.120.533**	**MKI**

6.2.3. Environmental impact dike reinforcement scenario 3

In this scenario, the dike cover does not have to be replaced in the southern part with the provincial road, as well as the locations with a slope less steep than 1:3. This is the most realistic as the wave experiments have been performed on a slope with the same steepness. Therefore, the tests were representative for the locations discussed in this scenario. The total length of the sections on which the dike cover can remain in place is 21.9km. The results of scenario 3 are noted in Table 29. The total amount of reduced emissions are 17.87 kton CO_2-eq. The MKI of the reduced emissions of scenario 3 is €2 528 306. The backfilling of soil contributes the most to the reduced emissions with 76.08% of the CO_2-eq. The sowing process contributes the least with 0.33%.

Table 29: Environmental impact analysis results scenario 3

Construction activities	**kton CO2-eq**	*Percentage*	**MKI**	*Percentage*
Excavating process	1,16	6,51%	€ 181.416	7,16%
Backfilling of clay inner slope	8,00	44,78%	€ 1.218.199	48,11%
Backfilling of clay crest	3,93	21,97%	€ 596.733	23,57%
Backfilling of top soil	1,67	9,33%	€ 255.771	10,10%
Sowing process	0,06	0,33%	€ 5.418	0,21%
Erosion screens	1,91	10,69%	€ 145.897	5,76%
Provincial road	0,50	2,78%	€ 59.971	2,37%
Cycling paths	0,29	1,63%	€ 34.061	1,35%
Maintenance	0,36	1,99%	€ 34.742	1,37%
Sub-total emissions	***17,87***	100%	***€ 2.532.208***	100%
Emmissions simulator research	0,02		€ 3.902	
Total reduced emissions	**17,84**	**kton CO2-eq**	**€ 2.528.306**	**MKI**

6.2.4. Comparison of the scenarios

To be able to compare the results with other research on dike cover replacement studies, it is necessary to determine the reduced environmental impact per kilometre. This acts as a reference unit between the studies. Table 29 shows the reduced emissions of the IJsseldijk Zwolle-Olst case per kilometre for the scenarios. For every kilometre where the dike cover on the inner slope and crest does not have to be replaced, the emission reduction is 735 ton CO_2-eq on average in the worst-case scenario. In the best case, the emission reduction per kilometre is 845 ton CO_2-eq. In scenario 1 the value of not replacing the dike cover is the highest, followed by scenario 3. In scenario 2, the emission reduction is the lowest per kilometre.

Table 30: Reduced emissions of the scenarios per kilometre cover replacement

	ton CO_2-eq / km	**MKI / km**
Scenario 1	845	€119 544
Scenario 2	735	€106 717
Scenario 3	815	€115 448

The graphs in Figure 20 and Figure 21 show the difference in environmental emissions per scenario. They show how the emissions are build up, based on the different construction activities. It can be seen that the backfilling process is the biggest influence towards the emissions. This can be explained by the amount of clay that has to be transported and processed. As the volume of excavated soil is similar to the volume of newly placed clay, it was expected that the emissions would be similar. However, due to the reusability of the excavated soil at other parts of the dike reinforcement, the environmental impact is much lower for the excavating process.

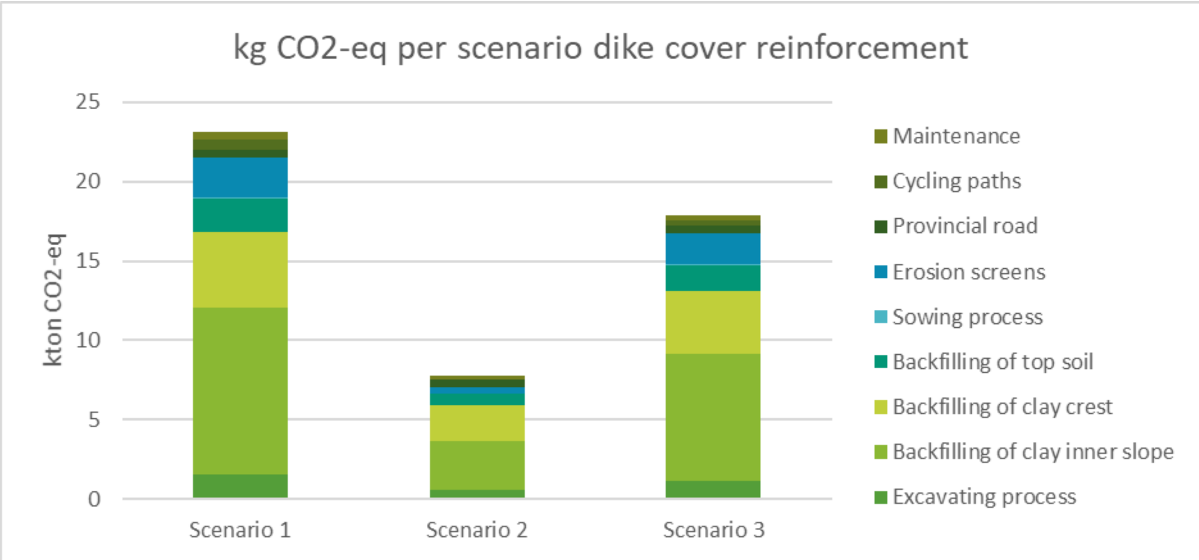

Figure 20: Comparison of the scenarios based on the kton CO_2-eq

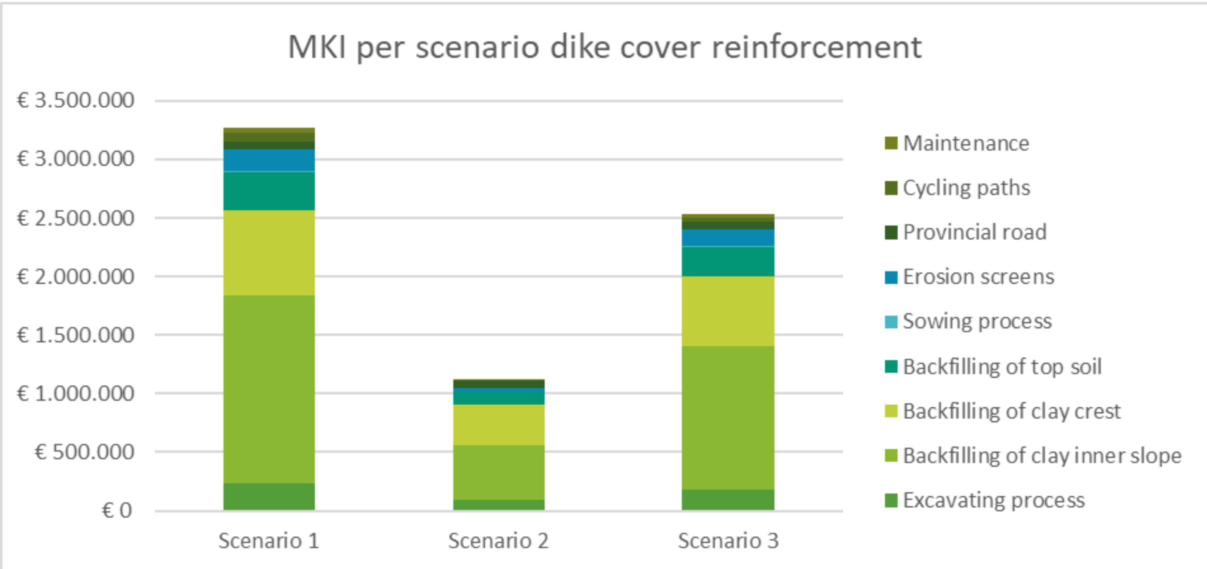

Figure 21: Comparison of the scenarios based on the MKI

Some construction activities have a bigger or smaller role in certain scenarios. Two things that stand out from Figure 22 are the percentages for backfilling of the crest and the inner slope of scenario 2. The relative emissions for backfilling of clay on the inner slope is significantly lower compared to scenario 1 and 3, while the relative emissions backfilling of clay on the crest is larger. The origin of the explanation for this has its roots in the average dimensions of the IJsseldijk in the scenarios. In the southern part, the provincial road is on top. Here, the crest is wider compared to the sections in the north. Due to the wider crest, there is a relatively larger volume of soil that is excavated and backfilled.

In the southern part of the IJsseldijk, the inner slope is shorter compared to other locations as well. The minimum dimensions for a provincial road were assumed to be on the safe side of the emissions for this rehabilitation. This results in a significant part of the dike crest for which the cover still has to be replaced. The influence of the rehabilitation of the provincial road has a bigger influence on the total emissions in scenario 2, as expected. Location specific emissions due to the placement of erosion screens and reconstruction of the cycling paths are much smaller in scenario 2. Scenario 1 and 3 achieve similar results based on the relative emissions per construction activity.

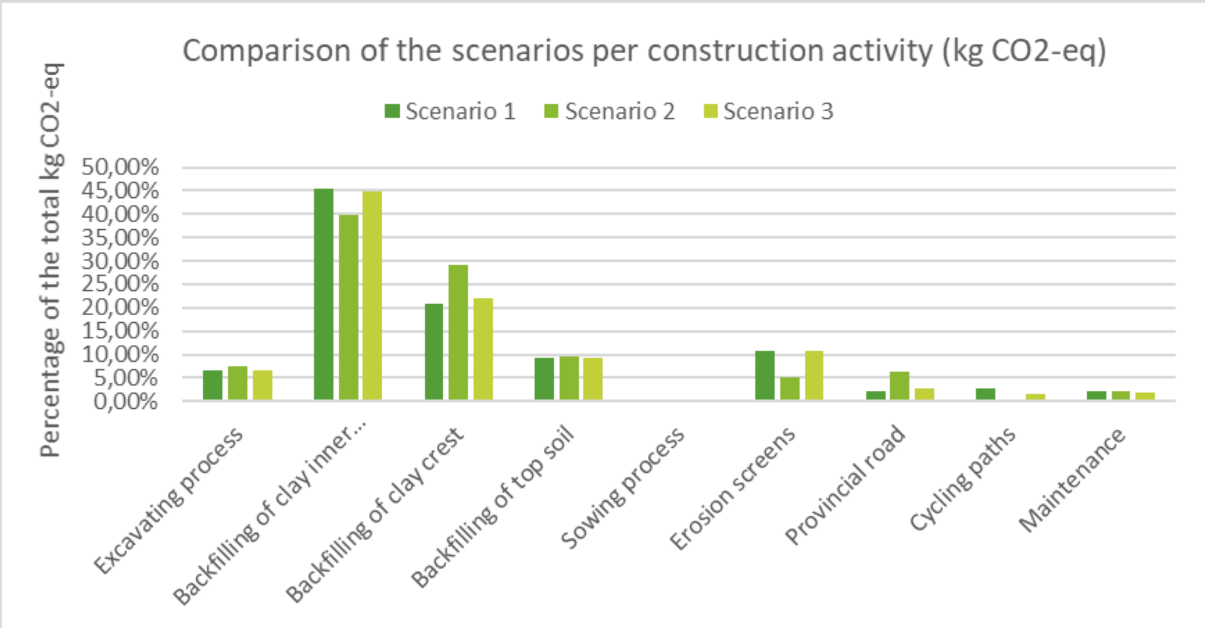

Figure 22: Comparison of the scenarios based on the relative amount of the total kg CO2-eq

6.2.5. Most influential aspects towards the results

During the research a difference was made between the simulator research and the dike cover replacement project. It became clear that the results for the wave simulator research are insignificant compared to the results of the dike cover replacement. In scenario 1 and 3 the emissions of the wave research compared to about 0.1% of the reduced emissions of the dike cover replacement (Table 31). In scenario 2 this compared to 0.3%.

Table 31: Wave research emissions compared to the dike cover replacement emissions per scenario

	CO_2-eq	MKI
Scenario 1	0.101 %	0.119 %
Scenario 2	0.301 %	0.347 %
Scenario 3	0.130 %	0.154 %

For the cover replacement, the emissions have been determined for the different construction activities. An overview of the average impact per construction activity is visualised in Figure 23. The data used for this figure is determined by taking the percentage kg CO_2-eq and MKI impacts of the reinforcement phases per scenario and taking the average of those six values.

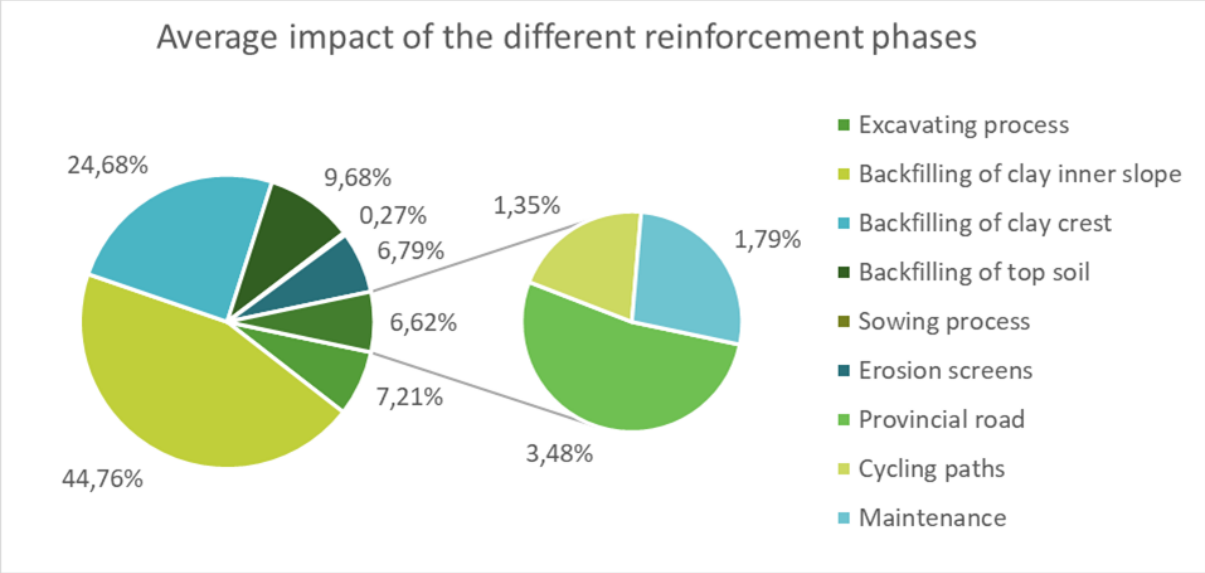

Figure 23: Average impact of the different construction activities in the dike cover replacement project

According to Figure 23, the construction activities for backfilling of soil on the inner slope has the biggest impact on the results with 44.76%. Followed by backfilling of the crest (24.68%) and backfilling of the top soil (9.68%). This difference is explained by the difference in soil volumes, as the construction process is similar. The total backfilling process combines for 79.1%. It should be noted that the influence of the excavation process is significantly lower than the backfilling process, contributing 7.2%. This is due to the reusability of the soil. The role of the other aspects, like erosion screens, maintenance and paved surfaces contributed for a combined 13.7%.

In Figure 24, it is visualised what the influence of machinery, transport and the production of materials are towards the final results for the kg CO_2-eq. According to this, it can be concluded that the largest influence towards the emissions is transport (76.2% average). Machinery contributed on average 9.8% and the production of materials contributed for 14.0%.

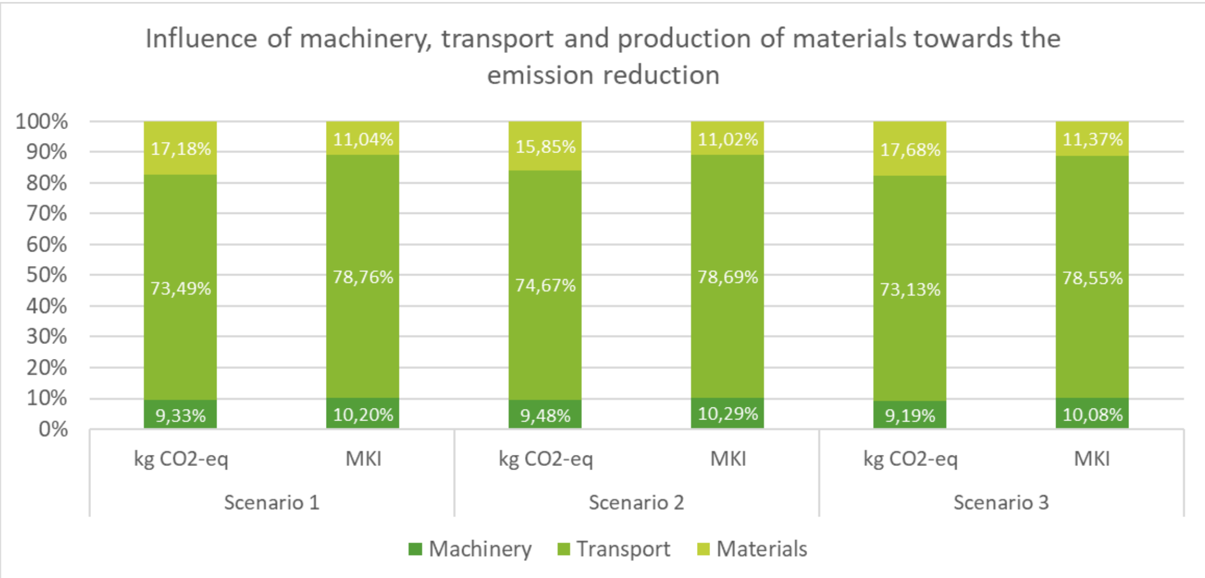

Figure 24: Overview of the emissions for machinery, transport and production of materials per scenario

6.3. Sensitivity analysis

In the previous section it was found that the biggest factor causing emissions is the backfilling process. Within the project, the largest number of emissions are reduced when lowering the environmental impact of transport. Also, reusability had a significant effect on the emission reduction of the excavation process. Therefore, the following points are discussed in the sensitivity analysis:

- Soil volumes
- Reusability of soil
- Different transport modes for soil
- Transport distances

6.3.1. Error margins soil volumes

During the de LCI phase, the soil volumes were determined based on the different cross-sections of the IJsseldijk. The surfaces for which the dike cover had to be replaced, were measured and multiplied by the representative length of the cross-section. In these results could be a slight error margin. Besides, the physical situation on the IJsseldijk could be slightly different compared to the cross-sections, as the cover might have some dents and bumps. Therefore, there might be an error margin in the soil volume.

For the sensitivity analysis, the soil volumes have been adjusted by error margins from -10% (10% less soil to be backfilled) to +10%. The results for the reduced emissions due to the wave research is plotted against these error margins (Figure 25 and Figure 26). These graphs show the difference of the effect of the wave research. The effect of the wave simulator towards the reduction of emissions is correlating with the soil volumes. For every 1% of extra soil, the emission reduction due to wave research is 0.87% bigger.

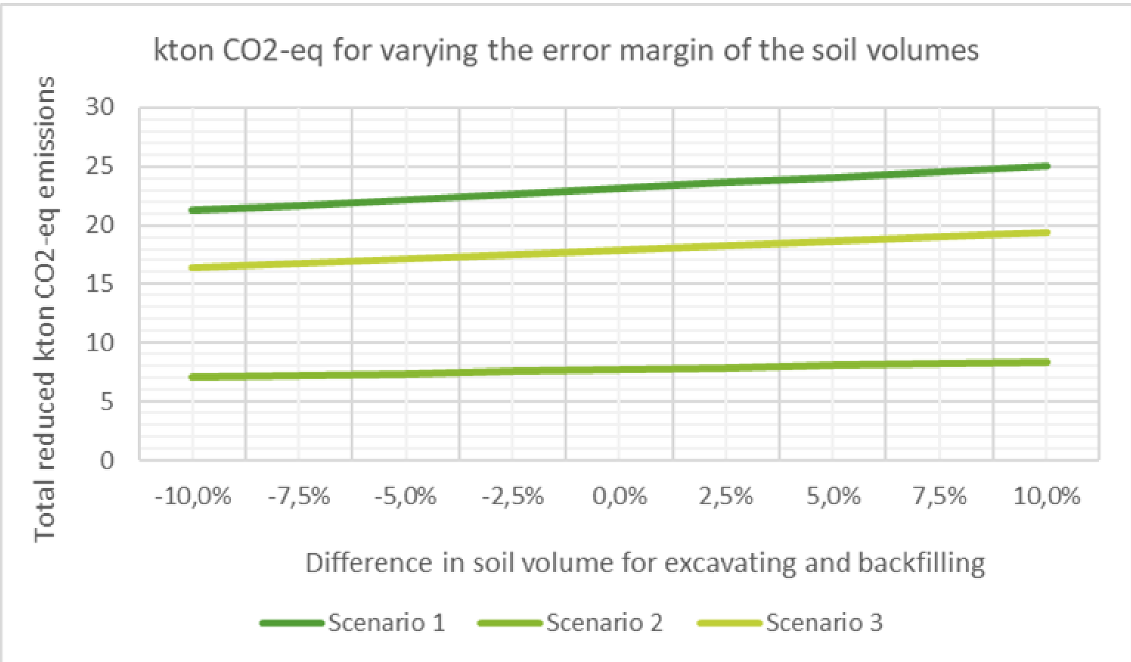

Figure 25: Reduced CO_2-eq emissions due to wave research for varying the error margin in soil volumes

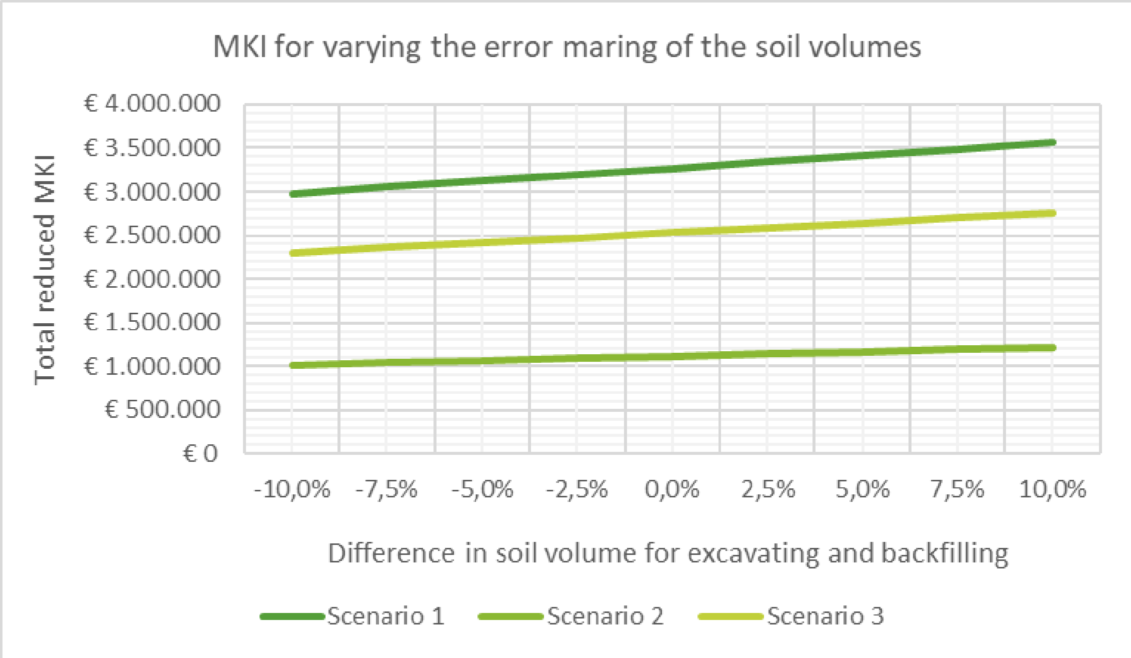

Figure 26: Reduced MKI due to wave research for varying the error margin in soil volumes

6.3.1. Percentage of reusable soil

During the LCA it was found that the excavation process contributed significantly less towards the emission reduction compared to the backfilling process. As discussed before, the reusability of soil influences the emissions for the excavation process. Reusability of the soil causes negative emissions as extracting and transporting new materials would be unnecessary. The reusability of soil is around 50% at the IJsseldijk project (Frakking, 2018), however this is not a certainty. Therefore the reusability percentage will be varied in the analysis.

As only 50% of the soil was reusable, the other soil had to dealt with separately. 40% of the remaining soil is assumed to be contaminated and has to be cleaned. The other 60% is containing debris and is disposed. The same ratios are used for the sensitivity analysis (Table 32). The reusability of the soil is plotted against the total emission reduction due to wave research (Figure 27 and Figure 28). These graphs show a significant effect. If the soil would not be reusable at all, the potential environmental reduction is almost doubled per scenario. However, when the soil would be fully reusable, the effects of the wave research are very little. For every 1% less reusability of the soil, the impact of the wave research would be 1.6% higher.

Table 32: Soil processing distribution used in the sensitivity analysis

Reusable soil	Soil with debris	Contaminated soil
100%	0%	0%
75%	15%	10%
50%	30%	20%
25%	45%	30%
0%	60%	40%

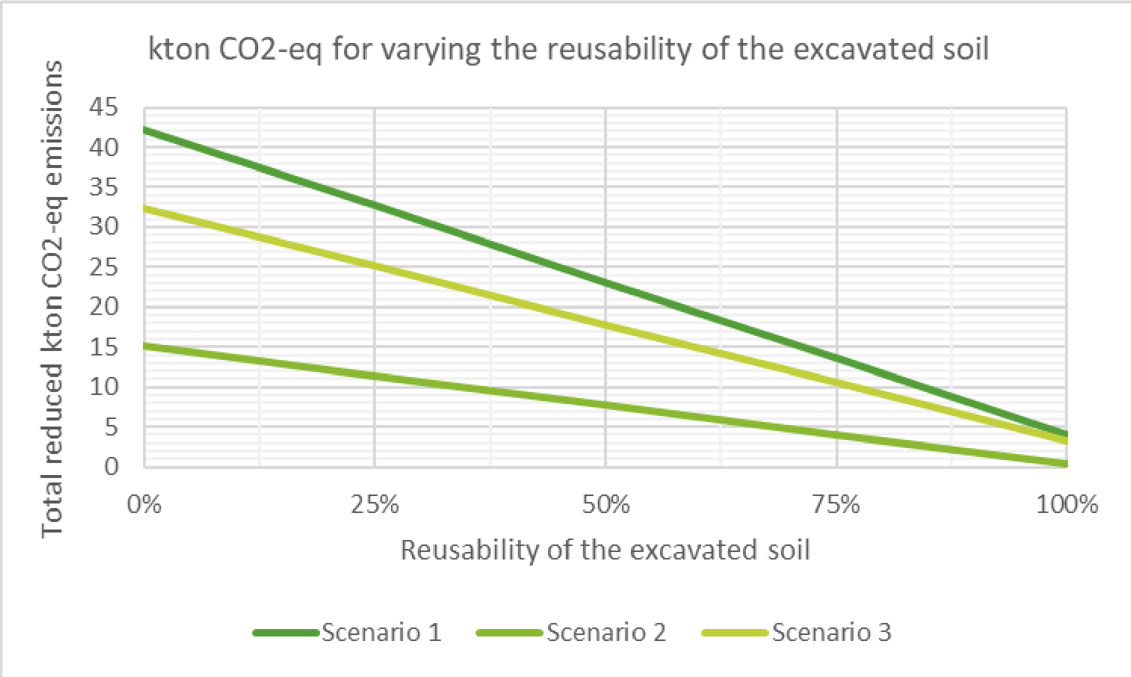

Figure 27: Reduced CO_2-eq emissions due to wave research for varying the reusability of soil

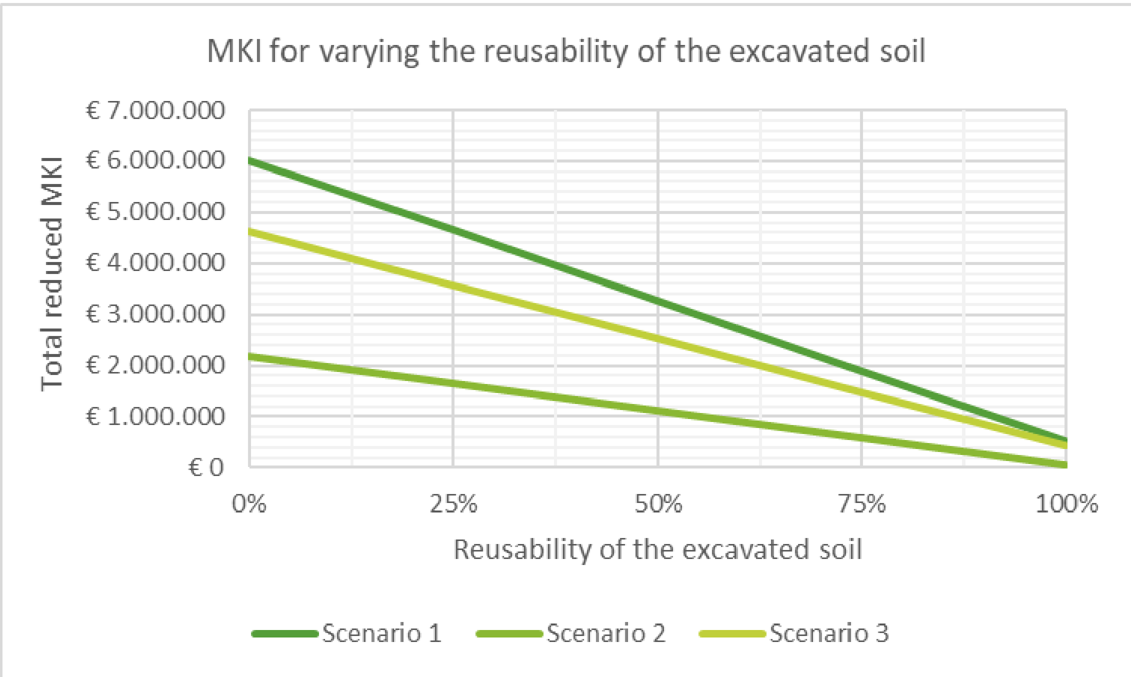

Figure 28: Reduced MKI due to wave research for varying the reusability of soil

6.3.2. Transport modes for soil

When performing the LCA trucks on diesel were used to make the calculations according to the standard method for clay in DuboCalc. However, the IJsseldijk is a river dike, which means that ships could transport the soil if the transport distance is significant (Van den Heuvel, 2020). Ships can transport more materials with less emissions per tkm. When using ships extra aspects contribute towards the transportation. For example, transport from extraction location to the ship by trucks, loading and unloading of the ships with a crane and transport of the ship to the IJsseldijk. Therefore, this process is much more extensive and will only be beneficial if the transport distance is sufficiently large.

Besides ships, different forms of fuel for trucks are taken into account in the calculation of the sensitivity analysis. This shows the reduction of emissions when the energy transition is fulfilled in the future. Biodiesel is an upcoming fuel type which can be used in most new diesel truck types (Ten Bosch, Te Heijden, & Schipper, 2020). It causes less emissions, however the costs for contractors are much higher. Trucks on hydrogen and electricity are considered as well. These trucks have to be produced differently and not many contractors work with them yet. However, the usage for these truck types will increase in the future (Baxter, 2020). For hydrogen and grey electricity trucks, the emissions are not equal to zero as the full life cycle of these fuels is taken into account. Currently, the production of these fuel types causes emissions, while the emissions from using the fuel are zero. To set a benchmark, trucks on green electricity will be considered as well. This fuel type has net emissions of zero. The emissions per tkm of the different transport modes are listed in Table 33. The calculations are only made for soil transport, as transporting little amounts of grass seeds would not happen with ships.

Table 33: Emissions of different transport modes and fuel types per tkm (LCA Rapportage categorie 3 data Nationale Milieudatabase, 2020)

	kg CO_2-eq / tkm	**MKI € / tkm**
Truck – diesel	0.266	0.0404
Ships	0.073	0.0096
Truck – biodiesel	0.039	0.0080
Truck – hydrogen	0.054	0.0076
Truck – grey electricity	0.093	0.0141
Truck – green electricity	0	0

These transport modes are applied to the calculation for the transportation of soil. The results of the reduced emissions due to the wave research haven been determined per transportation mode (Figure 29 and Figure 30). The results show that all options would be more environmental friendly and would cause a reduction for the emissions of a dike cover replacement project. Green electricity is the most beneficial to reduce the emissions. If this transport mode is implemented for soil transport, emissions are reduced by 66% compared to diesel.

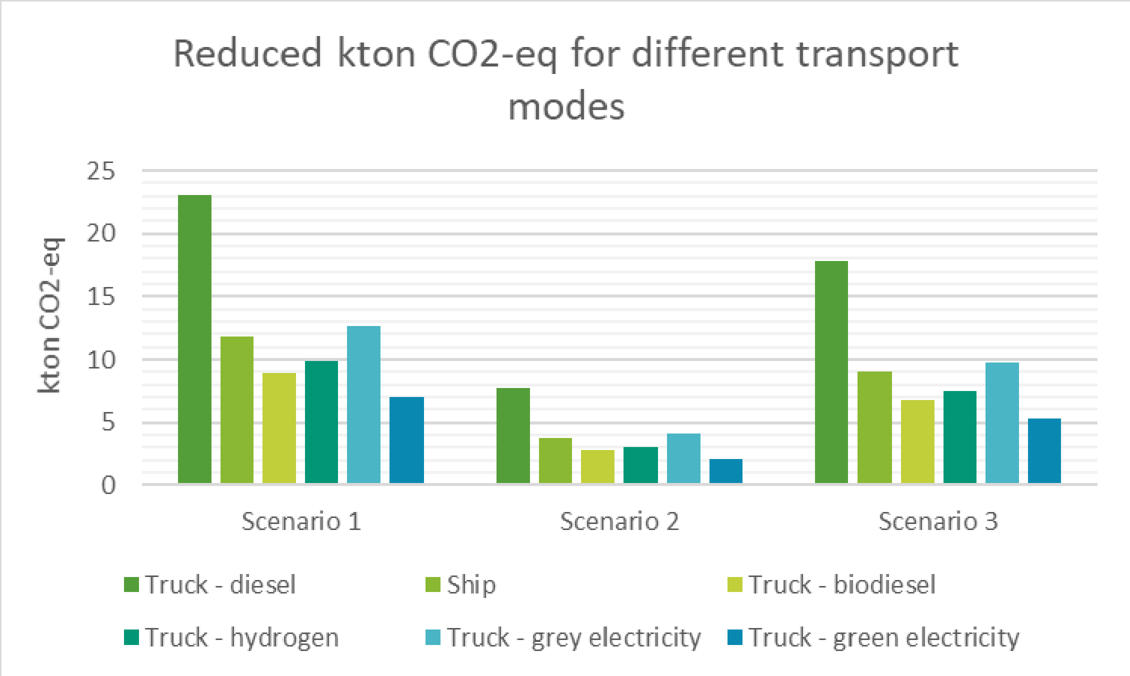

Figure 29: Reduced CO_2-eq emissions due to wave research for different transport modes

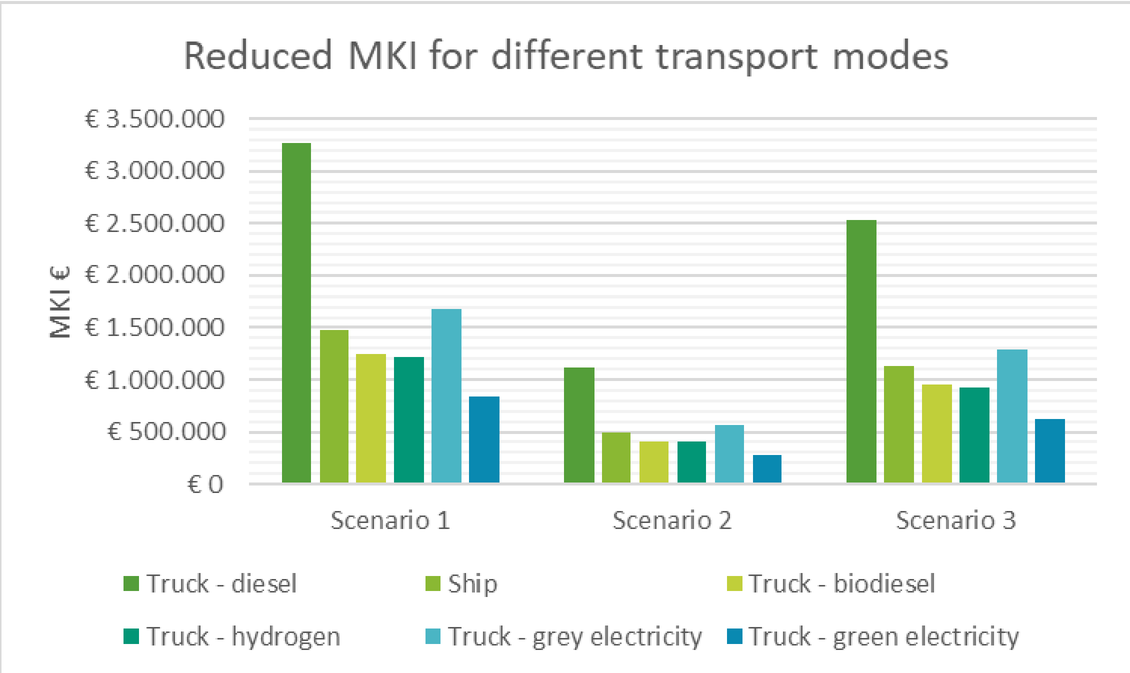

Figure 30: Reduced MKI due to wave research for different transport modes

6.3.3. Transport distances

In the LCA, the transport distance is assumed to be equal to the default distance given in DuboCalc. However, the contractor might extract the soil from a location nearby or further away. As, transport is the biggest emitting factor of the cover replacement project, the effect wave research is determined for different transportation distances. For the sensitivity analysis, the transport distances have been adjusted from -100%, meaning no transport is needed at all, to +100%, meaning double the DuboCalc default distance. The results for the reduced emissions due to the wave research is plotted against the difference in transport distance of soil (Figure 31 and Figure 32).

From the graphs it can be concluded that distance is an important factor towards the emissions. The transport distance should be limited as much as possible. This shows that gathering soil from the near surroundings is key in lowering the emissions. For every 1% extra transport distance, the effect of the wave research increases by 0.7%.

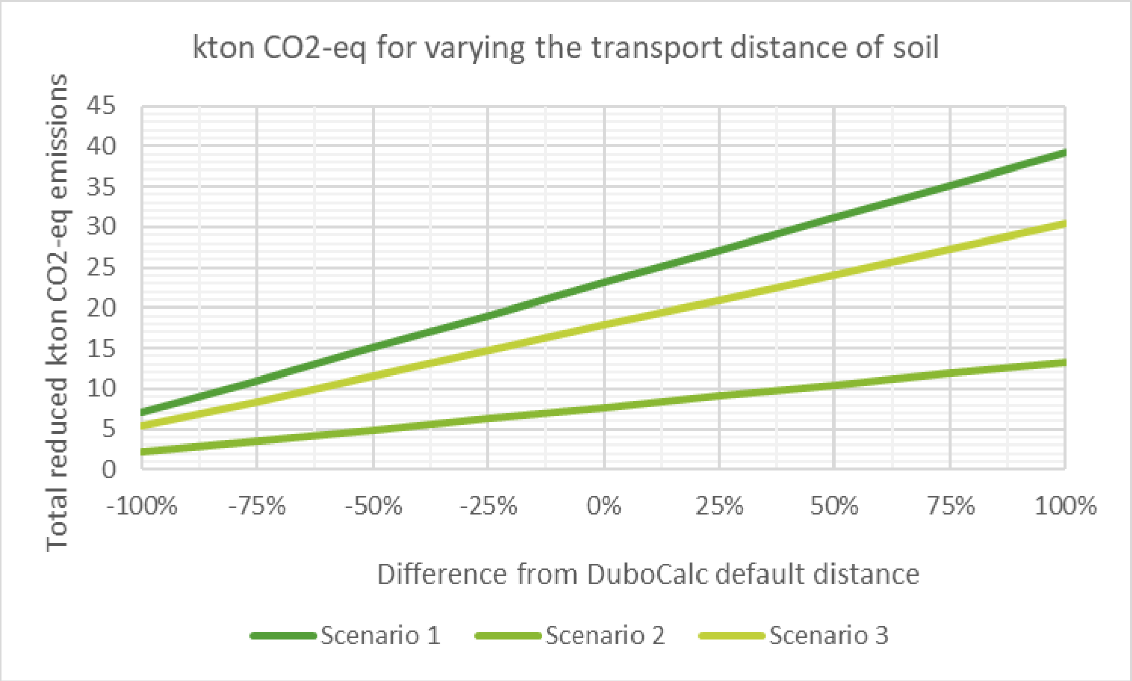

Figure 31: Reduced CO_2-eq emissions due to wave research for different transport distances

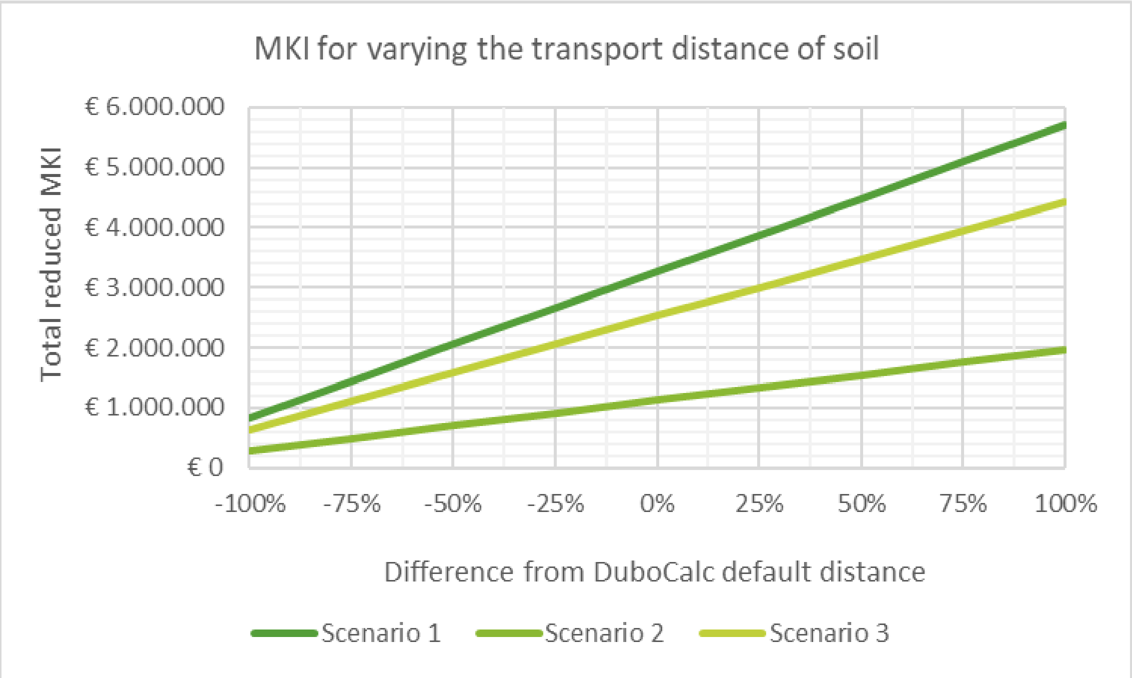

Figure 32: Reduced MKI due to wave research for different transport distances

7. Discussion

This research is one of the first studies to publicly discuss the reduced environmental impact of a dike cover replacement due to wave simulator research. After searching for other research about environmental impacts of wave research and regular dike reinforcement projects, no similar studies came forward. Therefore this study could act as a reference point for future research on dike cover replacements. Since the introduction of the Paris agreement, contractors and their clients have been aware of the environmental aspect within GWW projects. Over the past years this became a larger aspect during tenders. For example, DuboCalc was used for the reinforcement of the Afsluitdijk in the northern part of the Netherlands (Rijkswaterstaat, 2017). Information about the emissions of dike reinforcement projects from contractors is private. Therefore, making a comparison to other studies is difficult. The environmental assessments of dike reinforcements made by contractors probably contains less uncertainties. This study had to make assumptions on the type of machinery and the transport distances of different materials, while contractors exactly know what they are working with. When the contractor of the IJsseldijk would have finalised the design and could share more information, this study would be more accurate as well.

The results of this study are positive. When the wave research tests succeed the potential environmental benefits could be 300 to 1000 times larger compared to the emissions of the WIG and WOS tests. It has to be stated that the wave research does not always succeed. It is a risk to test the cover as both tests could fail. In this case the WIG experiments failed, while the WOS experiments succeeded. If the WIG would have succeeded, the results for not having to replace the cover on the outer slope could be similar to the results of the inner slope. This is the case when the slopes have similar dimensions. Looking at the results of Figure 23, the reduction of emissions could be about 55% higher if the WIG succeeded. This 55% only takes excavating and backfilling into account. The environmental benefits that that came forward from this research make this risk worth it. The tests should be performed whenever there is uncertainty about the strength of the grass cover. This could be, due to the cover laying or consisting mostly of sand. Also, when slopes are steeper than 1:2.7 in the case that the wave heights are bigger than the clay layer thickness (Rijkswaterstaat, 2012).

In this research different assumptions were made, which cause some limitations. Most of these assumptions were made due to the time restriction of this research. However, they could influence the results. The influence of different aspects have been determined in the sensitivity analysis. It turned out that an error margin in the measured soil volumes could cause a drop or increase of the results. The same applies for the reusability percentage of soil. This was given as an estimate by WDOD, however they thought it was a safe estimate. The transport distance could have a positive or negative influence on the results. The assumption was made that materials were transported over the DuboCalc default distance, but the exact distance is still unknown.

During the LCA of the wave research some aspects were excluded, for example rerouting of traffic. This could cause higher emissions of the wave research, however it was concluded that the emissions of the wave research were insignificant compared to the emissions of the cover replacement. Therefore, these extra emissions on the wave research will not make a significant difference. Aspects that were excluded in the research towards the emissions of the cover replacement would only give more positive results when they would be considered in a later stage. For example, indirect emissions caused by commuters, or energy usage on the construction site for lighting and heating.

This research could be translated to other locations or dike types, however this would mean that the data within the framework for the LCI and LCIA should be adjusted accordingly. The soil volumes of the different dike sections should be calculated. The calculation for excavating and backfilling of soil will then be similar. However external aspects should be recalculated as other locations or dike types might not include roads or erosion screens. Besides, the dimensions of these aspects would probably be different as well. Determining the emissions for the wave research at other locations would be translatable if the fuel amounts, transport and machinery numbers are known.

8. Conclusions & Recommendations

8.1. Conclusions

The goal of this study was to assess and quantify the potential reduction of the environmental impact on the dike reinforcement project IJsseldijk Zwolle-Olst due to the wave simulator research. This has been done for the greenhouse gas emissions in kg CO_2-eq and the environmental cost indicator (MKI) in euros.

The wave experiments showed that the inner slope of the IJsseldijk is strong enough to fulfil the legal requirements and therefore, does not need to be reinforced. This could be the case for the outer slope, if the sub-layer is strong enough. However, from talks with WDOD it turned out that this is not the case. Therefore, it is stated that the WIG experiments did not affect the results of this case in a positive way. In this case the WOS experiments are responsible for all reduced emissions. The total greenhouse gas emissions for the wave research was 23 ton CO_2-eq, which corresponds to a MKI of €3 902. The diesel for the generators had the biggest environmental footprint, contributing nearly 76% toward the total CO_2-eq emissions.

For the avoided replacement of the dike cover, it was chosen to take the full life cycle of 50 years into account. As the design for the IJsseldijk is not final yet, three possible scenarios for replacing the cover were created in collaboration with WDOD. The results showed that placement of erosion screens, reconstructing cycling paths and rehabilitation of the provincial road can be avoided if the cover is not replaced. The final results for the reduced emissions are calculated by subtracting the emissions of the wave research. The results are noted in Table 34. The biggest impact on these emissions is the backfilling process for both the crest and inner slope (79.1%). This is mostly due to the amount of clay that has to be transported by the trucks. On average, transport contributed 76.2% towards the CO_2-eq and MKI emission reduction of the scenarios. The excavating process contributed significantly less (7.2%), due to the reusability of the excavated soil. The role of the external aspects, such as erosion screens, maintenance and paved surfaces were small factors towards the final result (13.7% combined). Per kilometre, scenario 1 the is most beneficial, reducing emissions by 845 ton CO_2-eq per on average. Scenario 3 is the second best with a 815 ton CO_2-eq reduction. Scenario 2 is the least beneficial, reducing emissions by 735 ton CO_2-eq per kilometre. The sensitivity of the results was analysed. Here it became clear that the for every 1% of extra soil volume leads to a 0.87% increase in the reduction of the emissions due to the wave simulator. If 1% less soil is reusable, then the reduced emissions increase by 1.6%. An increase of 1% extra distance for transport results in a 0.7% increase of the reduced emissions.

Table 34: Results for the net reduced emissions per scenario

	Scenario 1		**Scenario 2**		**Scenario 3**	
	kg CO_2-eq	MKI €	kg CO_2-eq	MKI €	kg CO_2-eq	MKI €
Reduced emissions	2.31E+07	€ 3 269 525	7.72E+06	€ 1 120 533	1.78E+07	€ 2 528 306

Comparing the results of the two systems, it is concluded that the emissions of the wave experiments are insignificant. Even in worst-case scenario 2, the greenhouse gas emissions of the wave simulator research are about 0.3% of the potential reduction. In scenario 1 this is about 0.1%. For that reason, the wave experiments are valuable towards the reduction of environmental emissions. However, it has to be noted that the experiments are hit or miss. In this case, the reduction of emissions is due to the WOS experiments, while the WIG experiments did not lead to any reduced emissions.

8.2. Recommendations for further research

This study is aimed to estimate the reduced emissions of a dike cover replacement project, due to the influence of wave simulator research. However, one can argue that this study is not fully complete, due to the time constraint. Besides the earth moving, sowing, paved surfaces and erosion screens, different components that contribute to the emissions could be researched. Assumptions on what components were excluded have been discussed in Chapter 4. It is expected that the indirect emissions of the dike cover replacement project can contribute significantly to the results (Hong, Shen, Feng, Lau, & Mao, 2014). These indirect emissions include commuting of personnel, transportation of personnel around the construction site, a vehicle to fuel the machinery, heating, lighting and the construction trailers. Besides the time, this was difficult to determine, as the duration of the project is unknown. Other components to the dike such as on and off ramps and the separate access roads have been excluded as well. It is expected that the contribution of these components to the emission reduction is similar to the influence of the provincial road rehabilitation and the cycling path reconstructions. To get a complete overview of the emission reduction due to the wave research, these components should be included as well. After the contractor of the project has more information about the uncertainties within this study, the results of this study can be adapted to be more accurate. However, this will only work if the contractor allows this information to be public.

It would be interesting to see if the results of this study are similar compared to other locations and dikes. If this is the case, that would increase the certainty of the results for the emission reduction. This is the easiest on locations with a similar cover and dimensions, however it might be interesting to see the results of different types of dikes as well. The wave research could get different results when the tests are performed on a clay cover. If the research is performed on dike with bigger dimensions, the difference in results can be compared to see where they come from.

In the sensitivity analysis it was briefly discussed how the results of this study would hold up in the future. Currently contractors are starting to make investments in more environmental friendly machinery (Bouwmachines, 2020). The ambition is to aim for zero emission projects, however when is this possible? At that point there might not be a reduction of emissions due to wave research anymore, however the monetary aspect might be significant.

The WIG and WOS are used for the cover strength research. At first it is not expected to compare the results of the assessment to alternatives of testing cover strengths. However, this could be done in future research. A comparison could be made between different alternatives for cover strength research to see which alternative gets the results with the lowest emissions. However, when other LCAs for testing cover strength are performed, they should take the same functional unit to base their assessment of, or convert the results.

8.3. Recommendations for practice

The results of this study are positive for performing the wave research based on the emissions. When the wave research tests succeed the potential environmental benefits could be 300 to 1000 times larger compared to the emissions of the WIG and WOS tests. It has to be stated that the wave research does not always succeed. It is a risk to test the cover as both tests could fail. The environmental benefits that that came forward from this research are significantly large, making the tests worth it. The tests should be performed whenever there is uncertainty about the strength of the grass cover. This could be, due to the cover laying or consisting mostly of sand. Also, when slopes are steeper than 1:2.7 in the case that the wave heights are bigger than the clay layer thickness (Rijkswaterstaat, 2012).

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Appendices

A. Overview of transport movements for the simulator research

Table 35: Overview of the different transport movements during the wave simulator experiments

Equipment:	**Distance:**	**Number of trips:**	**Vehicle:**
WOS	55,4	1	Truck
Container with auxiliary material	55,4	1	Truck with crane
WIG	185	1	Truck
WOS + WIG	62,8	1	Truck
Container with auxiliary material	71,3	1	Truck with crane
WOS	74,3	1	Truck
Container with auxiliary material	74,3	1	Truck with crane
Security equipment	86,5	1	Van
Security equipment	86,5	1	Van
Construction trailers	36,5	1	Truck
Construction fences	36,5	1	Truck
Construction trailers	36,5	1	Truck
Construction fences	36,5	1	Truck
Pump, hydraulics, frequency inverter, generators and complementary equipment	121	2	Truck with crane
Pump, hydraulics, frequency inverter, generators and complementary equipment	121	2	Truck with crane
Mobile hydraulic crane	22,3	1	Truck
Mobile hydraulic crane	22,3	1	Truck
WIG	22,3	1	Truck
Steel driving plates	15,7	3	Truck with crane
Steel driving plates	15,7	3	Truck with crane
Dragline mats	15,7	1	Truck
Dragline mats	15,7	1	Truck
Truck with hydraulic crane for moving the WOS	10,3	3	Truck with crane
Total loaded km	*1604,9*		
Total + empty km	**3209,8**		

B. Soil volumes and grass cover surfaces per cross-section

Table 36: Soil volumes and surfaces for the earth moving activities

Cross-section	1810	1980	2120	no data	2310	2430	2500	2550	2660	2790	2850	3070	3170	3380	3530	3570	3610	3690	3690	3700	3730	3760	3780	3830
m3 excavated soil inner slope	1,30E+04	9,58E+03	1,64E+04	0,00E+00	1,85E+04	1,28E+04	1,87E+04	1,52E+04	1,38E+04	1,29E+04	3,25E+03	4,03E+04	2,74E+04	3,17E+04	3,11E+03	8,87E+03	1,44E+04	3,70E+03	4,63E+02	4,66E+03	7,52E+03	8,72E+03	3,28E+03	6,26E+03
m3 excavated soil crest	8,87E+03	4,27E+03	6,35E+03	0,00E+00	3,01E+03	1,24E+03	2,98E+03	2,08E+03	8,05E+03	4,46E+03	5,26E+03	2,60E+04	6,91E+03	8,54E+03	0,00E+00	2,09E+03	2,81E+03	5,44E+02	6,80E+01	5,42E+02	1,42E+03	1,60E+03	2,47E+03	1,45E+03
m3 excavated soil total	*2,18E+04*	*1,38E+04*	*2,27E+04*	*0,00E+00*	*2,15E+04*	*1,40E+04*	*2,17E+04*	*1,73E+04*	*2,19E+04*	*1,74E+04*	*8,51E+03*	*6,63E+04*	*3,43E+04*	*4,02E+04*	*3,11E+03*	*1,10E+04*	*1,72E+04*	*4,25E+03*	*5,31E+02*	*5,21E+03*	*8,94E+03*	*1,03E+04*	*5,75E+03*	*7,71E+03*
m3 placed clay inner slope	1,40E+04	1,01E+04	1,64E+04	0,00E+00	1,85E+04	1,35E+04	1,87E+04	1,52E+04	1,53E+04	1,29E+04	4,72E+03	4,03E+04	2,90E+04	3,32E+04	1,71E+04	8,87E+03	1,44E+04	1,24E+04	1,55E+03	3,93E+03	7,52E+03	8,72E+03	3,28E+03	6,58E+03
m3 placed clay crest	8,87E+03	4,27E+03	6,35E+03	0,00E+00	3,01E+03	1,24E+03	2,98E+03	2,08E+03	8,05E+03	4,46E+03	5,26E+03	2,60E+04	6,91E+03	8,54E+03	2,36E+03	2,09E+03	2,81E+03	1,75E+03	2,19E+02	1,48E+03	1,42E+03	1,60E+03	2,47E+03	1,45E+03
m3 placed clay total	*2,29E+04*	*1,43E+04*	*2,27E+04*	*0,00E+00*	*2,15E+04*	*1,47E+04*	*2,17E+04*	*1,73E+04*	*2,33E+04*	*1,74E+04*	*9,98E+03*	*6,63E+04*	*3,59E+04*	*4,18E+04*	*1,95E+04*	*1,10E+04*	*1,72E+04*	*1,41E+04*	*1,76E+03*	*5,41E+03*	*8,94E+03*	*1,03E+04*	*5,75E+03*	*8,03E+03*
m3 placed top soil inner slope	2,06E+03	2,78E+03	9,62E+02	0,00E+00	1,13E+03	1,64E+03	1,16E+03	8,47E+02	2,44E+03	7,02E+02	3,10E+02	3,16E+03	4,04E+03	3,45E+03	1,33E+03	5,88E+02	9,41E+02	4,84E+02	6,05E+01	2,46E+02	4,74E+02	4,28E+02	1,80E+02	1,08E+03
m3 placed top soil crest	8,87E+02	4,27E+02	6,35E+02	0,00E+00	3,01E+02	1,24E+02	2,98E+02	2,08E+02	8,05E+02	4,46E+02	5,26E+02	2,60E+03	3,71E+02	5,04E+02	2,36E+02	2,09E+02	2,81E+02	1,75E+02	2,19E+01	1,48E+02	1,42E+02	1,60E+02	2,47E+02	1,45E+02
m3 placed top soil total	2,95E+03	3,20E+03	1,60E+03	0,00E+00	1,43E+03	1,76E+03	1,46E+03	1,05E+03	3,24E+03	1,15E+03	8,35E+02	5,77E+03	4,41E+03	3,95E+03	1,57E+03	7,97E+02	1,22E+03	6,58E+02	8,23E+01	3,94E+02	6,16E+02	5,88E+02	4,27E+02	1,22E+03
m2 grass seeds inner slope	2,06E+04	2,78E+04	9,62E+03	0,00E+00	1,13E+04	1,64E+04	1,16E+04	8,47E+03	2,44E+04	7,02E+03	3,10E+03	3,16E+04	4,04E+04	3,45E+04	1,33E+04	5,88E+03	9,41E+03	4,84E+03	6,05E+02	2,46E+03	4,74E+03	4,28E+03	1,80E+03	1,08E+04
m2 grass seeds crest	8,87E+03	4,27E+03	6,35E+03	0,00E+00	3,01E+03	1,24E+03	2,98E+03	2,08E+03	8,05E+03	4,46E+03	5,26E+03	2,60E+04	3,71E+03	5,04E+03	2,36E+03	2,09E+03	2,81E+03	1,75E+03	2,19E+02	1,48E+03	1,42E+03	1,60E+03	2,47E+03	1,45E+03
m2 grass seeds total	*2,95E+04*	*3,20E+04*	*1,60E+04*	*0,00E+00*	*1,43E+04*	*1,76E+04*	*1,46E+04*	*1,05E+04*	*3,24E+04*	*1,15E+04*	*8,35E+03*	*5,77E+04*	*4,41E+04*	*3,95E+04*	*1,57E+04*	*7,97E+03*	*1,22E+04*	*6,58E+03*	*8,23E+02*	*3,94E+03*	*6,16E+03*	*5,88E+03*	*4,27E+03*	*1,22E+04*
m3 stair wise slope body	1,63E+03	2,20E+03	7,61E+02	0,00E+00	8,93E+02	1,30E+03	9,16E+02	6,70E+02	1,93E+03	5,55E+02	2,45E+02	2,50E+03	3,20E+03	2,73E+03	1,05E+03	4,65E+02	7,44E+02	3,82E+02	4,78E+01	1,95E+02	3,75E+02	3,39E+02	1,42E+02	8,50E+02

Cross-section	3880	3930	3950	4010	4070	4100	4130	4180	4190	4200	4250	4290	4330	4400	4410	4420	4460	4470	4500	no data	4570	4600	4610	4630
m3 excavated soil inner slope	1,61E+04	1,08E+04	7,25E+03	5,01E+03	9,61E+03	2,36E+03	6,29E+03	2,60E+01	8,63E+02	1,41E+03	2,78E+03	1,11E+03	4,57E+03	1,25E+03	5,57E+02	0,00E+00	1,50E+03	1,67E+03	3,90E+03	0,00E+00	2,92E+02	2,60E+02	2,30E+02	4,26E+03
m3 excavated soil crest	3,91E+03	1,70E+03	2,35E+03	1,69E+03	2,44E+03	1,05E+03	6,85E+02	9,00E+01	2,09E+02	3,18E+02	7,62E+02	3,12E+02	1,19E+03	3,90E+01	3,13E+02	0,00E+00	3,00E+01	1,82E+03	2,35E+03	0,00E+00	2,09E+02	0,00E+00	0,00E+00	4,69E+02
m3 excavated soil total	*2,00E+04*	*1,25E+04*	*9,60E+03*	*6,70E+03*	*1,21E+04*	*3,41E+03*	*6,98E+03*	*1,16E+02*	*1,07E+03*	*1,73E+03*	*3,54E+03*	*1,42E+03*	*5,76E+03*	*1,29E+03*	*8,69E+02*	*0,00E+00*	*1,53E+03*	*3,49E+03*	*6,24E+03*	*0,00E+00*	*5,01E+02*	*2,60E+02*	*2,30E+02*	*4,73E+03*
m3 placed clay inner slope	1,52E+04	1,08E+04	7,52E+03	5,10E+03	8,97E+03	5,59E+03	9,78E+03	1,09E+03	2,34E+03	3,43E+03	1,00E+04	6,66E+03	1,70E+04	1,46E+03	5,57E+02	0,00E+00	1,50E+03	1,67E+03	3,75E+03	0,00E+00	6,72E+03	3,89E+02	1,98E+03	4,37E+03
m3 placed clay crest	3,53E+03	1,70E+03	2,35E+03	1,69E+03	2,44E+03	9,72E+02	2,10E+03	8,46E+02	6,20E+02	8,52E+02	3,02E+03	2,15E+03	5,48E+03	4,05E+02	4,07E+02	0,00E+00	3,11E+02	2,02E+03	2,35E+03	0,00E+00	2,10E+03	1,94E+02	6,72E+02	4,69E+02
m3 placed clay total	*1,87E+04*	*1,25E+04*	*9,87E+03*	*6,79E+03*	*1,14E+04*	*6,56E+03*	*1,19E+04*	*1,93E+03*	*2,96E+03*	*4,28E+03*	*1,31E+04*	*8,80E+03*	*2,25E+04*	*1,87E+03*	*9,64E+02*	*0,00E+00*	*1,81E+03*	*3,69E+03*	*6,09E+03*	*0,00E+00*	*8,82E+03*	*5,83E+02*	*2,66E+03*	*4,84E+03*
m3 placed top soil inner slope	9,72E+02	8,58E+02	4,62E+02	1,42E+03	1,38E+03	4,03E+02	1,33E+03	4,62E+01	1,44E+02	1,97E+02	1,38E+03	1,06E+03	1,92E+03	1,04E+02	2,83E+01	0,00E+00	1,06E+02	1,11E+02	5,07E+02	0,00E+00	3,83E+02	1,37E+02	4,16E+02	7,89E+02
m3 placed top soil crest	3,53E+02	1,70E+02	1,30E+02	1,69E+02	2,44E+02	9,72E+01	2,10E+02	8,46E+01	6,20E+01	8,52E+01	1,82E+02	2,15E+02	3,78E+02	4,05E+01	4,07E+01	0,00E+00	3,11E+01	2,02E+02	8,46E+01	0,00E+00	2,10E+02	1,94E+01	6,72E+01	4,69E+01
m3 placed top soil total	*1,32E+03*	*1,03E+03*	*5,92E+02*	*1,59E+03*	*1,63E+03*	*5,00E+02*	*1,54E+03*	*1,31E+02*	*2,06E+02*	*2,82E+02*	*1,56E+03*	*1,28E+03*	*2,30E+03*	*1,44E+02*	*6,90E+01*	*0,00E+00*	*1,37E+02*	*3,14E+02*	*5,92E+02*	*0,00E+00*	*5,93E+02*	*1,56E+02*	*4,83E+02*	*8,36E+02*
m2 grass seeds inner slope	9,72E+03	8,58E+03	4,62E+03	1,42E+04	1,38E+04	4,03E+03	1,33E+04	4,62E+02	1,44E+03	1,97E+03	1,38E+04	1,06E+04	1,92E+04	1,04E+03	2,83E+02	0,00E+00	1,06E+03	1,11E+03	5,07E+03	0,00E+00	3,83E+03	1,37E+03	4,16E+03	7,89E+03
m2 grass seeds crest	3,53E+03	1,70E+03	1,30E+03	1,69E+03	2,44E+03	9,72E+02	2,10E+03	8,46E+02	6,20E+02	8,52E+02	1,82E+03	2,15E+03	3,78E+03	4,05E+02	4,07E+02	0,00E+00	3,11E+02	2,02E+03	8,46E+02	0,00E+00	2,10E+03	1,94E+02	6,72E+02	4,69E+02
m2 grass seeds total	*1,32E+04*	*1,03E+04*	*5,92E+03*	*1,59E+04*	*1,63E+04*	*5,00E+03*	*1,54E+04*	*1,31E+03*	*2,06E+03*	*2,82E+03*	*1,56E+04*	*1,28E+04*	*2,30E+04*	*1,44E+03*	*6,90E+02*	*0,00E+00*	*1,37E+03*	*3,14E+03*	*5,92E+03*	*0,00E+00*	*5,93E+03*	*1,56E+03*	*4,83E+03*	*8,36E+03*
m3 stair wise slope body	7,68E+02	6,79E+02	3,65E+02	1,13E+03	1,09E+03	3,19E+02	1,05E+03	3,65E+01	1,14E+02	1,56E+02	1,09E+03	8,40E+02	1,52E+03	8,21E+01	2,23E+01	0,00E+00	8,36E+01	8,79E+01	4,01E+02	0,00E+00	3,03E+02	1,08E+02	3,29E+02	6,24E+02

C. Calculation of the CO_2-eq and MKI for the excavation process

Table 37: Summary of specifications for the excavation process

Activity	Equipment/Material	Distance (km)	Capacity	Capacity unit	Source	kg CO2-eq / unit	Source	MKI euro / unit
Preperation activities								
mowing/maaien	tractor + mower combi		1000	m2/h	Dick van den Heuvel	34,4 / h	LCA Rapportage categorie 3 data Nationale Milieudatabase	3,19 / h
milling/frezen	tractor + mill combi		600	m2/h	Dick van den Heuvel	34,4 / h	LCA Rapportage categorie 3 data Nationale Milieudatabase	3,19 / h
excavating reusable soil transport and to	Hydraulic excavator (2000L)		100	m3/h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	52,593239 / h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	9,22 / h
depot - 50%	Transport truck bulk	2,5	0,588	m3/tonkm	DuboCalc - Transport bulk (over de weg)	0,26645608 / tonkm	DuboCalc - Transport bulk (over de weg)	0,0404 / tonkm
load soil from depot and transport to	Hydraulic excavator (2000L)		100	m3/h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	52,593239 / h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	9,22 / h
processing location	Transport truck bulk	2,5	0,588	m3/tonkm	DuboCalc - Transport bulk (over de weg)	0,26645608 / tonkm	DuboCalc - Transport bulk (over de weg)	0,0404 / tonkm
	Hydraulic excavator (2000L)		100	m3/h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	52,593239 / h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	9,22 / h
discharge soil - 30% + 20%	Transport truck bulk	75	0,588	m3/tonkm	DuboCalc - Transport bulk (over de weg)	0,26645608 / tonkm	DuboCalc - Transport bulk (over de weg)	0,0404 / tonkm
Cleeaning of the 20% excavated soil	Cleaning process		1	m3	DuboCalc - gereinigde grond	16,62 / m3	DuboCalc - gereinigde grond	1,8 / m3
	Sand		-1	m3	DuboCalc - Landzand (ophoogzand)	4,62 / m3	DuboCalc - Landzand (ophoogzand)	0,41 / m3
Reuse of excavated soil in crest - 50%	Transport truck bulk	-75	0,588	m3/tonkm	DuboCalc - Transport bulk (over de weg) - Zand	0,26645608 / tonkm	DuboCalc - Transport bulk (over de weg)	0,0404 / tonkm

Table 38: Results of the excavation process per unit

		Cross-section															
Equipment/Material	**Units**	**1810**	**1980**	**2120**	**no data**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
tractor + mower combi	h	2,95E+01	3,20E+01	1,60E+01	0,00E+00	1,43E+01	1,76E+01	1,46E+01	1,05E+01	3,24E+01	1,15E+01	8,35E+00	5,77E+01	4,41E+01	3,95E+01	1,57E+01	7,97E+00
tractor + mill combi	h	4,92E+01	5,34E+01	2,66E+01	0,00E+00	2,38E+01	2,94E+01	2,43E+01	1,76E+01	5,40E+01	1,91E+01	1,39E+01	9,61E+01	7,36E+01	6,59E+01	2,62E+01	1,33E+01
Hydraulic excavator (2000L)	h	1,09E+02	6,92E+01	1,14E+02	0,00E+00	1,08E+02	7,02E+01	1,08E+02	8,64E+01	1,09E+02	8,69E+01	4,25E+01	3,31E+02	1,72E+02	2,01E+02	1,56E+01	5,48E+01
Transport truck bulk	tonkm	4,64E+04	2,94E+04	4,83E+04	0,00E+00	4,58E+04	2,98E+04	4,61E+04	3,67E+04	4,65E+04	3,70E+04	1,81E+04	1,41E+05	7,29E+04	8,55E+04	6,62E+03	2,33E+04
Hydraulic excavator (2000L)	h	1,09E+02	6,92E+01	1,14E+02	0,00E+00	1,08E+02	7,02E+01	1,08E+02	8,64E+01	1,09E+02	8,69E+01	4,25E+01	3,31E+02	1,72E+02	2,01E+02	1,56E+01	5,48E+01
Transport truck bulk	tonkm	4,64E+04	2,94E+04	4,83E+04	0,00E+00	4,58E+04	2,98E+04	4,61E+04	3,67E+04	4,65E+04	3,70E+04	1,81E+04	1,41E+05	7,29E+04	8,55E+04	6,62E+03	2,33E+04
Hydraulic excavator (2000L)	h	1,09E+02	6,92E+01	1,14E+02	0,00E+00	1,08E+02	7,02E+01	1,08E+02	8,64E+01	1,09E+02	8,69E+01	4,25E+01	3,31E+02	1,72E+02	2,01E+02	1,56E+01	5,48E+01
Transport truck bulk	tonkm	1,39E+06	8,83E+05	1,45E+06	0,00E+00	1,37E+06	8,95E+05	1,38E+06	1,10E+06	1,40E+06	1,11E+06	5,42E+05	4,23E+06	2,19E+06	2,56E+06	1,99E+05	6,99E+05
Cleaning process	m3	4,37E+03	2,77E+03	4,54E+03	0,00E+00	4,31E+03	2,81E+03	4,33E+03	3,46E+03	4,38E+03	3,48E+03	1,70E+03	1,33E+04	6,86E+03	8,04E+03	6,23E+02	2,19E+03
Sand	m3	-1,09E+04	-6,92E+03	-1,14E+04	0,00E+00	-1,08E+04	-7,02E+03	-1,08E+04	-8,64E+03	-1,09E+04	-8,69E+03	-4,25E+03	-3,31E+04	-1,72E+04	-2,01E+04	-1,56E+03	-5,48E+03
Transport truck bulk	tonkm	-1,39E+06	-8,83E+05	-1,45E+06	0,00E+00	-1,37E+06	-8,95E+05	-1,38E+06	-1,10E+06	-1,40E+06	-1,11E+06	-5,42E+05	-4,23E+06	-2,19E+06	-2,56E+06	-1,99E+05	-6,99E+05
		Cross-section															
Equipment/Material	**Units**	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
tractor + mower combi	h	1,22E+01	6,58E+00	8,23E-01	3,94E+00	6,16E+00	5,88E+00	4,27E+00	1,22E+01	1,32E+01	1,03E+01	5,92E+00	1,59E+01	1,63E+01	5,00E+00	1,54E+01	1,31E+00
tractor + mill combi	h	2,04E+01	1,10E+01	1,37E+00	6,57E+00	1,03E+01	9,80E+00	7,12E+00	2,03E+01	2,21E+01	1,71E+01	9,86E+00	2,65E+01	2,71E+01	8,34E+00	2,57E+01	2,18E+00
Hydraulic excavator (2000L)	h	8,59E+01	2,12E+01	2,66E+00	2,60E+01	4,47E+01	5,16E+01	2,88E+01	3,86E+01	1,00E+02	6,24E+01	4,80E+01	3,35E+01	6,03E+01	1,71E+01	3,49E+01	5,80E-01
Transport truck bulk	tonkm	3,65E+04	9,03E+03	1,13E+03	1,11E+04	1,90E+04	2,19E+04	1,22E+04	1,64E+04	4,25E+04	2,65E+04	2,04E+04	1,42E+04	2,56E+04	7,25E+03	1,48E+04	2,47E+02
Hydraulic excavator (2000L)	h	8,59E+01	2,12E+01	2,66E+00	2,60E+01	4,47E+01	5,16E+01	2,88E+01	3,86E+01	1,00E+02	6,24E+01	4,80E+01	3,35E+01	6,03E+01	1,71E+01	3,49E+01	5,80E-01
Transport truck bulk	tonkm	3,65E+04	9,03E+03	1,13E+03	1,11E+04	1,90E+04	2,19E+04	1,22E+04	1,64E+04	4,25E+04	2,65E+04	2,04E+04	1,42E+04	2,56E+04	7,25E+03	1,48E+04	2,47E+02
Hydraulic excavator (2000L)	h	8,59E+01	2,12E+01	2,66E+00	2,60E+01	4,47E+01	5,16E+01	2,88E+01	3,86E+01	1,00E+02	6,24E+01	4,80E+01	3,35E+01	6,03E+01	1,71E+01	3,49E+01	5,80E-01
Transport truck bulk	tonkm	1,10E+06	2,71E+05	3,39E+04	3,32E+05	5,70E+05	6,58E+05	3,67E+05	4,92E+05	1,28E+06	7,96E+05	6,12E+05	4,27E+05	7,69E+05	2,18E+05	4,45E+05	7,40E+03
Cleaning process	m3	3,44E+03	8,50E+02	1,06E+02	1,04E+03	1,79E+03	2,06E+03	1,15E+03	1,54E+03	4,00E+03	2,50E+03	1,92E+03	1,34E+03	2,41E+03	6,82E+02	1,40E+03	2,32E+01
Sand	m3	-8,59E+03	-2,12E+03	-2,66E+02	-2,60E+03	-4,47E+03	-5,16E+03	-2,88E+03	-3,86E+03	-1,00E+04	-6,24E+03	-4,80E+03	-3,35E+03	-6,03E+03	-1,71E+03	-3,49E+03	-5,80E+01
Transport truck bulk	tonkm	-1,10E+06	-2,71E+05	-3,39E+04	-3,32E+05	-5,70E+05	-6,58E+05	-3,67E+05	-4,92E+05	-1,28E+06	-7,96E+05	-6,12E+05	-4,27E+05	-7,69E+05	-2,18E+05	-4,45E+05	-7,40E+03
		Cross-section															
Equipment/Material	**Units**	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**no data**	**4570**	**4600**	**4610**	**4630**
tractor + mower combi	h	2,06E+00	2,82E+00	1,56E+01	1,28E+01	2,30E+01	1,44E+00	6,90E-01	0,00E+00	1,37E+00	3,14E+00	5,92E+00	0,00E+00	5,93E+00	1,56E+00	4,83E+00	8,36E+00
tractor + mill combi	h	3,43E+00	4,70E+00	2,60E+01	2,13E+01	3,83E+01	2,41E+00	1,15E+00	0,00E+00	2,28E+00	5,23E+00	9,86E+00	0,00E+00	9,88E+00	2,60E+00	8,05E+00	1,39E+01
Hydraulic excavator (2000L)	h	5,36E+00	8,63E+00	1,77E+01	7,12E+00	2,88E+01	6,44E+00	4,35E+00	0,00E+00	7,64E+00	1,74E+01	3,12E+01	0,00E+00	2,50E+00	1,30E+00	1,15E+00	2,37E+01
Transport truck bulk	tonkm	2,28E+03	3,67E+03	7,53E+03	3,03E+03	1,23E+04	2,74E+03	1,85E+03	0,00E+00	3,25E+03	7,42E+03	1,33E+04	0,00E+00	1,06E+03	5,53E+02	4,88E+02	1,01E+04
Hydraulic excavator (2000L)	h	5,36E+00	8,63E+00	1,77E+01	7,12E+00	2,88E+01	6,44E+00	4,35E+00	0,00E+00	7,64E+00	1,74E+01	3,12E+01	0,00E+00	2,50E+00	1,30E+00	1,15E+00	2,37E+01
Transport truck bulk	tonkm	2,28E+03	3,67E+03	7,53E+03	3,03E+03	1,23E+04	2,74E+03	1,85E+03	0,00E+00	3,25E+03	7,42E+03	1,33E+04	0,00E+00	1,06E+03	5,53E+02	4,88E+02	1,01E+04
Hydraulic excavator (2000L)	h	5,36E+00	8,63E+00	1,77E+01	7,12E+00	2,88E+01	6,44E+00	4,35E+00	0,00E+00	7,64E+00	1,74E+01	3,12E+01	0,00E+00	2,50E+00	1,30E+00	1,15E+00	2,37E+01
Transport truck bulk	tonkm	6,84E+04	1,10E+05	2,26E+05	9,08E+04	3,68E+05	8,21E+04	5,54E+04	0,00E+00	9,75E+04	2,23E+05	3,98E+05	0,00E+00	3,19E+04	1,66E+04	1,46E+04	3,02E+05
Cleaning process	m3	2,14E+02	3,45E+02	7,08E+02	2,85E+02	1,15E+03	2,57E+02	1,74E+02	0,00E+00	3,06E+02	6,98E+02	1,25E+03	0,00E+00	1,00E+02	5,20E+01	4,59E+01	9,46E+02
Sand	m3	-5,36E+02	-8,63E+02	-1,77E+03	-7,12E+02	-2,88E+03	-6,44E+02	-4,35E+02	0,00E+00	-7,64E+02	-1,74E+03	-3,12E+03	0,00E+00	-2,50E+02	-1,30E+02	-1,15E+02	-2,37E+03
Transport truck bulk	tonkm	-6,84E+04	-1,10E+05	-2,26E+05	-9,08E+04	-3,68E+05	-8,21E+04	-5,54E+04	0,00E+00	-9,75E+04	-2,23E+05	-3,98E+05	0,00E+00	-3,19E+04	-1,66E+04	-1,46E+04	-3,02E+05

Table 39: kg CO_2-eq results per cross-section for the excavation process

	kg CO2-eq per Cross-section															
Equipment/Material	**1810**	**1980**	**2120**	**no data**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
tractor + mower combi	1,01E+03	1,10E+03	5,49E+02	0,00E+00	4,92E+02	6,07E+02	5,01E+02	3,63E+02	1,11E+03	3,95E+02	2,87E+02	1,98E+03	1,52E+03	1,36E+03	5,40E+02	2,74E+02
tractor + mill combi	1,69E+03	1,84E+03	9,16E+02	0,00E+00	8,20E+02	1,01E+03	8,35E+02	6,05E+02	1,86E+03	6,58E+02	4,79E+02	3,31E+03	2,53E+03	2,27E+03	9,00E+02	4,57E+02
Hydraulic excavator (2000L)	5,74E+03	3,64E+03	5,97E+03	0,00E+00	5,66E+03	3,69E+03	5,70E+03	4,55E+03	5,75E+03	4,57E+03	2,24E+03	1,74E+04	9,02E+03	1,06E+04	8,18E+02	2,88E+03
Transport truck bulk	1,24E+04	7,84E+03	1,29E+04	0,00E+00	1,22E+04	7,95E+03	1,23E+04	9,79E+03	1,24E+04	9,85E+03	4,82E+03	3,75E+04	1,94E+04	2,28E+04	1,76E+03	6,21E+03
Hydraulic excavator (2000L)	5,74E+03	3,64E+03	5,97E+03	0,00E+00	5,66E+03	3,69E+03	5,70E+03	4,55E+03	5,75E+03	4,57E+03	2,24E+03	1,74E+04	9,02E+03	1,06E+04	8,18E+02	2,88E+03
Transport truck bulk	1,24E+04	7,84E+03	1,29E+04	0,00E+00	1,22E+04	7,95E+03	1,23E+04	9,79E+03	1,24E+04	9,85E+03	4,82E+03	3,75E+04	1,94E+04	2,28E+04	1,76E+03	6,21E+03
Hydraulic excavator (2000L)	5,74E+03	3,64E+03	5,97E+03	0,00E+00	5,66E+03	3,69E+03	5,70E+03	4,55E+03	5,75E+03	4,57E+03	2,24E+03	1,74E+04	9,02E+03	1,06E+04	8,18E+02	2,88E+03
Transport truck bulk	3,71E+05	2,35E+05	3,86E+05	0,00E+00	3,66E+05	2,38E+05	3,68E+05	2,94E+05	3,72E+05	2,95E+05	1,45E+05	1,13E+06	5,83E+05	6,83E+05	5,29E+04	1,86E+05
Cleaning process	7,26E+04	4,60E+04	7,55E+04	0,00E+00	7,16E+04	4,66E+04	7,20E+04	5,75E+04	7,27E+04	5,78E+04	2,83E+04	2,20E+05	1,14E+05	1,34E+05	1,03E+04	3,64E+04
Sand	-5,05E+04	-3,20E+04	-5,25E+04	0,00E+00	-4,97E+04	-3,24E+04	-5,01E+04	-3,99E+04	-5,05E+04	-4,02E+04	-1,96E+04	-1,53E+05	-7,92E+04	-9,29E+04	-7,19E+03	-2,53E+04
Transport truck bulk	-3,71E+05	-2,35E+05	-3,86E+05	0,00E+00	-3,66E+05	-2,38E+05	-3,68E+05	-2,94E+05	-3,72E+05	-2,95E+05	-1,45E+05	-1,13E+06	-5,83E+05	-6,83E+05	-5,29E+04	-1,86E+05
	kg CO2-eq per Cross-section															
Equipment/Material	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
tractor + mower combi	4,21E+02	2,26E+02	2,83E+01	1,36E+02	2,12E+02	2,02E+02	1,47E+02	4,20E+02	4,56E+02	3,54E+02	2,04E+02	5,48E+02	5,59E+02	1,72E+02	5,30E+02	4,50E+01
tractor + mill combi	7,01E+02	3,77E+02	4,72E+01	2,26E+02	3,53E+02	3,37E+02	2,45E+02	6,99E+02	7,59E+02	5,89E+02	3,39E+02	9,13E+02	9,32E+02	2,87E+02	8,83E+02	7,50E+01
Hydraulic excavator (2000L)	4,52E+03	1,12E+03	1,40E+02	1,37E+03	2,35E+03	2,71E+03	1,51E+03	2,03E+03	5,26E+03	3,28E+03	2,52E+03	1,76E+03	3,17E+03	8,97E+02	1,83E+03	3,05E+01
Transport truck bulk	9,73E+03	2,41E+03	3,01E+02	2,95E+03	5,06E+03	5,84E+03	3,26E+03	4,37E+03	1,13E+04	7,07E+03	5,44E+03	3,79E+03	6,83E+03	1,93E+03	3,95E+03	6,57E+01
Hydraulic excavator (2000L)	4,52E+03	1,12E+03	1,40E+02	1,37E+03	2,35E+03	2,71E+03	1,51E+03	2,03E+03	5,26E+03	3,28E+03	2,52E+03	1,76E+03	3,17E+03	8,97E+02	1,83E+03	3,05E+01
Transport truck bulk	9,73E+03	2,41E+03	3,01E+02	2,95E+03	5,06E+03	5,84E+03	3,26E+03	4,37E+03	1,13E+04	7,07E+03	5,44E+03	3,79E+03	6,83E+03	1,93E+03	3,95E+03	6,57E+01
Hydraulic excavator (2000L)	4,52E+03	1,12E+03	1,40E+02	1,37E+03	2,35E+03	2,71E+03	1,51E+03	2,03E+03	5,26E+03	3,28E+03	2,52E+03	1,76E+03	3,17E+03	8,97E+02	1,83E+03	3,05E+01
Transport truck bulk	2,92E+05	7,22E+04	9,02E+03	8,85E+04	1,52E+05	1,75E+05	9,77E+04	1,31E+05	3,40E+05	2,12E+05	1,63E+05	1,14E+05	2,05E+05	5,80E+04	1,19E+05	1,97E+03
Cleaning process	5,71E+04	1,41E+04	1,77E+03	1,73E+04	2,97E+04	3,43E+04	1,91E+04	2,56E+04	6,65E+04	4,15E+04	3,19E+04	2,23E+04	4,01E+04	1,13E+04	2,32E+04	3,86E+02
Sand	-3,97E+04	-9,81E+03	-1,23E+03	-1,20E+04	-2,06E+04	-2,38E+04	-1,33E+04	-1,78E+04	-4,62E+04	-2,88E+04	-2,22E+04	-1,55E+04	-2,78E+04	-7,88E+03	-1,61E+04	-2,68E+02
Transport truck bulk	-2,92E+05	-7,22E+04	-9,02E+03	-8,85E+04	-1,52E+05	-1,75E+05	-9,77E+04	-1,31E+05	-3,40E+05	-2,12E+05	-1,63E+05	-1,14E+05	-2,05E+05	-5,80E+04	-1,19E+05	-1,97E+03
	kg CO2-eq per Cross-section															
Equipment/Material	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**no data**	**4570**	**4600**	**4610**	**4630**
tractor + mower combi	7,08E+01	9,70E+01	5,37E+02	4,39E+02	7,89E+02	4,97E+01	2,37E+01	0,00E+00	4,71E+01	1,08E+02	2,04E+02	0,00E+00	2,04E+02	5,37E+01	1,66E+02	2,88E+02
tractor + mill combi	1,18E+02	1,62E+02	8,95E+02	7,32E+02	1,32E+03	8,28E+01	3,95E+01	0,00E+00	7,84E+01	1,80E+02	3,39E+02	0,00E+00	3,40E+02	8,94E+01	2,77E+02	4,79E+02
Hydraulic excavator (2000L)	2,82E+02	4,54E+02	9,31E+02	3,74E+02	1,52E+03	3,38E+02	2,29E+02	0,00E+00	4,02E+02	9,17E+02	1,64E+03	0,00E+00	1,32E+02	6,84E+01	6,04E+01	1,24E+03
Transport truck bulk	6,07E+02	9,78E+02	2,01E+03	8,07E+02	3,26E+03	7,29E+02	4,92E+02	0,00E+00	8,66E+02	1,98E+03	3,54E+03	0,00E+00	2,84E+02	1,47E+02	1,30E+02	2,68E+03
Hydraulic excavator (2000L)	2,82E+02	4,54E+02	9,31E+02	3,74E+02	1,52E+03	3,38E+02	2,29E+02	0,00E+00	4,02E+02	9,17E+02	1,64E+03	0,00E+00	1,32E+02	6,84E+01	6,04E+01	1,24E+03
Transport truck bulk	6,07E+02	9,78E+02	2,01E+03	8,07E+02	3,26E+03	7,29E+02	4,92E+02	0,00E+00	8,66E+02	1,98E+03	3,54E+03	0,00E+00	2,84E+02	1,47E+02	1,30E+02	2,68E+03
Hydraulic excavator (2000L)	2,82E+02	4,54E+02	9,31E+02	3,74E+02	1,52E+03	3,38E+02	2,29E+02	0,00E+00	4,02E+02	9,17E+02	1,64E+03	0,00E+00	1,32E+02	6,84E+01	6,04E+01	1,24E+03
Transport truck bulk	1,82E+04	2,93E+04	6,02E+04	2,42E+04	9,79E+04	2,19E+04	1,48E+04	0,00E+00	2,60E+04	5,93E+04	1,06E+05	0,00E+00	8,51E+03	4,42E+03	3,90E+03	8,04E+04
Cleaning process	3,56E+03	5,74E+03	1,18E+04	4,73E+03	1,92E+04	4,28E+03	2,89E+03	0,00E+00	5,08E+03	1,16E+04	2,08E+04	0,00E+00	1,66E+03	8,64E+02	7,63E+02	1,57E+04
Sand	-2,48E+03	-3,99E+03	-8,18E+03	-3,29E+03	-1,33E+04	-2,97E+03	-2,01E+03	0,00E+00	-3,53E+03	-8,06E+03	-1,44E+04	0,00E+00	-1,16E+03	-6,01E+02	-5,30E+02	-1,09E+04
Transport truck bulk	-1,82E+04	-2,93E+04	-6,02E+04	-2,42E+04	-9,79E+04	-2,19E+04	-1,48E+04	0,00E+00	-2,60E+04	-5,93E+04	-1,06E+05	0,00E+00	-8,51E+03	-4,42E+03	-3,90E+03	-8,04E+04

Table 40: MKI results per cross-section for the excavation process

								kg CO_2-eq per Cross-section								
Equipment/Material	**1810**	**1980**	**2120**	**no data**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
tractor + mower combi	€ 94,07	€ 102,22	€ 50,95	€ 0,00	€ 45,64	€ 56,27	€ 46,48	€ 33,65	€ 103,39	€ 36,62	€ 26,64	€ 183,97	€ 140,82	€ 126,05	€ 50,05	€ 25,43
tractor + mill combi	€ 156,79	€ 170,36	€ 84,92	€ 0,00	€ 76,07	€ 93,79	€ 77,46	€ 56,08	€ 172,31	€ 61,04	€ 44,39	€ 306,62	€ 234,70	€ 210,09	€ 83,42	€ 42,38
Hydraulic excavator (2000L)	€ 1.006,82	€ 638,44	€ 1.047,21	€ 0,00	€ 992,63	€ 646,88	€ 998,99	€ 796,88	€ 1.008,76	€ 801,59	€ 392,08	€ 3.055,74	€ 1.581,41	€ 1.853,10	€ 143,49	€ 505,44
Transport truck bulk	€ 1.875,71	€ 1.189,41	€ 1.950,95	€ 0,00	€ 1.849,26	€ 1.205,13	€ 1.861,11	€ 1.484,60	€ 1.879,32	€ 1.493,36	€ 730,45	€ 5.692,84	€ 2.946,18	€ 3.452,34	€ 267,32	€ 941,64
Hydraulic excavator (2000L)	€ 1.006,82	€ 638,44	€ 1.047,21	€ 0,00	€ 992,63	€ 646,88	€ 998,99	€ 796,88	€ 1.008,76	€ 801,59	€ 392,08	€ 3.055,74	€ 1.581,41	€ 1.853,10	€ 143,49	€ 505,44
Transport truck bulk	€ 1.875,71	€ 1.189,41	€ 1.950,95	€ 0,00	€ 1.849,26	€ 1.205,13	€ 1.861,11	€ 1.484,60	€ 1.879,32	€ 1.493,36	€ 730,45	€ 5.692,84	€ 2.946,18	€ 3.452,34	€ 267,32	€ 941,64
Hydraulic excavator (2000L)	€ 1.006,82	€ 638,44	€ 1.047,21	€ 0,00	€ 992,63	€ 646,88	€ 998,99	€ 796,88	€ 1.008,76	€ 801,59	€ 392,08	€ 3.055,74	€ 1.581,41	€ 1.853,10	€ 143,49	€ 505,44
Transport truck bulk	€ 56.271,43	€ 35.682,37	€ 58.528,47	€ 0,00	€ 55.477,86	€ 36.153,88	€ 55.833,42	€ 44.537,91	€ 56.379,64	€ 44.800,71	€ 21.913,39	€ 170.785,33	€ 88.385,31	€ 103.570,09	€ 8.019,45	€ 28.249,08
Cleaning process	€ 7.862,40	€ 4.985,64	€ 8.177,76	€ 0,00	€ 7.751,52	€ 5.051,52	€ 7.801,20	€ 6.222,96	€ 7.877,52	€ 6.259,68	€ 3.061,80	€ 23.862,60	€ 12.349,44	€ 14.471,10	€ 1.120,50	€ 3.947,04
Sand	-€ 4.477,20	-€ 2.839,05	-€ 4.656,78	€ 0,00	-€ 4.414,06	-€ 2.876,56	-€ 4.442,35	-€ 3.543,63	-€ 4.485,81	-€ 3.564,54	-€ 1.743,53	-€ 13.588,43	-€ 7.032,32	-€ 8.240,49	-€ 638,06	-€ 2.247,62
Transport truck bulk	-€ 56.271,43	-€ 35.682,37	-€ 58.528,47	€ 0,00	-€ 55.477,86	-€ 36.153,88	-€ 55.833,42	-€ 44.537,91	-€ 56.379,64	-€ 44.800,71	-€ 21.913,39	-€ 170.785,33	-€ 88.385,31	-€ 103.570,09	-€ 8.019,45	-€ 28.249,08
								kg CO_2-eq per Cross-section								
Equipment/Material	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
tractor + mower combi	€ 39,01	€ 21,00	€ 2,63	€ 12,57	€ 19,65	€ 18,75	€ 13,63	€ 38,92	€ 42,25	€ 32,79	€ 18,88	€ 50,80	€ 51,86	€ 15,95	€ 49,13	€ 4,17
tractor + mill combi	€ 65,01	€ 35,00	€ 4,38	€ 20,96	€ 32,75	€ 31,25	€ 22,72	€ 64,86	€ 70,42	€ 54,66	€ 31,47	€ 84,67	€ 86,44	€ 26,59	€ 81,88	€ 6,95
Hydraulic excavator (2000L)	€ 791,91	€ 195,83	€ 24,48	€ 240,00	€ 412,00	€ 475,52	€ 265,10	€ 355,43	€ 922,00	€ 575,70	€ 442,58	€ 308,64	€ 555,53	€ 157,25	€ 321,55	€ 5,35
Transport truck bulk	€ 1.475,32	€ 364,84	€ 45,60	€ 447,11	€ 767,55	€ 885,90	€ 493,88	€ 662,17	€ 1.717,69	€ 1.072,52	€ 824,53	€ 575,00	€ 1.034,95	€ 292,95	€ 599,04	€ 9,96
Hydraulic excavator (2000L)	€ 791,91	€ 195,83	€ 24,48	€ 240,00	€ 412,00	€ 475,52	€ 265,10	€ 355,43	€ 922,00	€ 575,70	€ 442,58	€ 308,64	€ 555,53	€ 157,25	€ 321,55	€ 5,35
Transport truck bulk	€ 1.475,32	€ 364,84	€ 45,60	€ 447,11	€ 767,55	€ 885,90	€ 493,88	€ 662,17	€ 1.717,69	€ 1.072,52	€ 824,53	€ 575,00	€ 1.034,95	€ 292,95	€ 599,04	€ 9,96
Hydraulic excavator (2000L)	€ 791,91	€ 195,83	€ 24,48	€ 240,00	€ 412,00	€ 475,52	€ 265,10	€ 355,43	€ 922,00	€ 575,70	€ 442,58	€ 308,64	€ 555,53	€ 157,25	€ 321,55	€ 5,35
Transport truck bulk	€ 44.259,64	€ 10.945,10	€ 1.368,14	€ 13.413,42	€ 23.026,45	€ 26.576,91	€ 14.816,34	€ 19.865,05	€ 51.530,61	€ 32.175,71	€ 24.735,98	€ 17.249,87	€ 31.048,48	€ 8.788,55	€ 17.971,30	€ 298,88
Cleaning process	€ 6.184,08	€ 1.529,28	€ 191,16	€ 1.874,16	€ 3.217,32	€ 3.713,40	€ 2.070,18	€ 2.775,60	€ 7.200,00	€ 4.495,68	€ 3.456,18	€ 2.410,20	€ 4.338,18	€ 1.227,96	€ 2.511,00	€ 41,76
Sand	-€ 3.521,49	-€ 870,84	-€ 108,86	-€ 1.067,23	-€ 1.832,09	-€ 2.114,58	-€ 1.178,85	-€ 1.580,55	-€ 4.100,00	-€ 2.560,04	-€ 1.968,10	-€ 1.372,48	-€ 2.470,35	-€ 699,26	-€ 1.429,88	-€ 23,78
Transport truck bulk	-€ 44.259,64	-€ 10.945,10	-€ 1.368,14	-€ 13.413,42	-€ 23.026,45	-€ 26.576,91	-€ 14.816,34	-€ 19.865,05	-€ 51.530,61	-€ 32.175,71	-€ 24.735,98	-€ 17.249,87	-€ 31.048,48	-€ 8.788,55	-€ 17.971,30	-€ 298,88
								kg CO_2-eq per Cross-section								
Equipment/Material	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**no data**	**4570**	**4600**	**4610**	**4630**
tractor + mower combi	€ 6,57	€ 9,00	€ 49,80	€ 40,73	€ 73,21	€ 4,61	€ 2,20	€ 0,00	€ 4,36	€ 10,00	€ 18,87	€ 0,00	€ 18,91	€ 4,98	€ 15,41	€ 26,67
tractor + mill combi	€ 10,95	€ 14,99	€ 83,00	€ 67,88	€ 122,02	€ 7,68	€ 3,67	€ 0,00	€ 7,27	€ 16,67	€ 31,45	€ 0,00	€ 31,52	€ 8,29	€ 25,68	€ 44,46
Hydraulic excavator (2000L)	€ 49,42	€ 79,59	€ 163,19	€ 65,65	€ 265,67	€ 59,33	€ 40,06	€ 0,00	€ 70,46	€ 160,84	€ 287,80	€ 0,00	€ 23,07	€ 11,99	€ 10,58	€ 218,15
Transport truck bulk	€ 92,07	€ 148,28	€ 304,03	€ 122,30	€ 494,95	€ 110,53	€ 74,63	€ 0,00	€ 131,27	€ 299,65	€ 536,18	€ 0,00	€ 42,99	€ 22,33	€ 19,71	€ 406,40
Hydraulic excavator (2000L)	€ 49,42	€ 79,59	€ 163,19	€ 65,65	€ 265,67	€ 59,33	€ 40,06	€ 0,00	€ 70,46	€ 160,84	€ 287,80	€ 0,00	€ 23,07	€ 11,99	€ 10,58	€ 218,15
Transport truck bulk	€ 92,07	€ 148,28	€ 304,03	€ 122,30	€ 494,95	€ 110,53	€ 74,63	€ 0,00	€ 131,27	€ 299,65	€ 536,18	€ 0,00	€ 42,99	€ 22,33	€ 19,71	€ 406,40
Hydraulic excavator (2000L)	€ 49,42	€ 79,59	€ 163,19	€ 65,65	€ 265,67	€ 59,33	€ 40,06	€ 0,00	€ 70,46	€ 160,84	€ 287,80	€ 0,00	€ 23,07	€ 11,99	€ 10,58	€ 218,15
Transport truck bulk	€ 2.762,04	€ 4.448,38	€ 9.120,92	€ 3.668,98	€ 14.848,55	€ 3.315,99	€ 2.239,01	€ 0,00	€ 3.938,23	€ 8.989,52	€ 16.085,28	€ 0,00	€ 1.289,55	€ 669,90	€ 591,31	€ 12.192,14
Cleaning process	€ 385,92	€ 621,54	€ 1.274,40	€ 512,64	€ 2.074,68	€ 463,32	€ 312,84	€ 0,00	€ 550,26	€ 1.256,04	€ 2.247,48	€ 0,00	€ 180,18	€ 93,60	€ 82,62	€ 1.703,52
Sand	-€ 219,76	-€ 353,93	-€ 725,70	-€ 291,92	-€ 1.181,42	-€ 263,84	-€ 178,15	€ 0,00	-€ 313,34	-€ 715,25	-€ 1.279,82	€ 0,00	-€ 102,60	-€ 53,30	-€ 47,05	-€ 970,06
Transport truck bulk	-€ 2.762,04	-€ 4.448,38	-€ 9.120,92	-€ 3.668,98	-€ 14.848,55	-€ 3.315,99	-€ 2.239,01	€ 0,00	-€ 3.938,23	-€ 8.989,52	-€ 16.085,28	€ 0,00	-€ 1.289,55	-€ 669,90	-€ 591,31	-€ 12.192,14

D. Calculation of the CO_2-eq and MKI for the backfilling process

Table 41: Summary of specifications for the backfilling process

Activity	Equipment/Material	Distance (km)	Capacity	Capacity unit	Source	kg CO2-eq /	unit	Source	MKI euro /	unit
Gathering clay inner slope										
extraction	Clay, erosion class 3		1	m3	DuboCalc - Klei (gemiddeld)	0,6 /	m3	DuboCalc - Klei (gemiddeld)	0,05 /	m3
transport	Transport truck bulk	50	0,625	m3/tonkm	DuboCalc - Transport bulk (over de weg) - Klei	0,26645608 /	tonkm	DuboCalc - Transport bulk (over de weg)	0,0404 /	tonkm
processing clay (placing and compacting)										
stepwise slope	Hydraulic excavator (2000L)		70	m3/h	Dick van den Heuvel	52,593239 /	h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	9,22 /	h
processing	Hydraulic excavator (2000L)		100	m3/h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	52,593239 /	h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	9,22 /	h
profiling	Bulldozer 12-35 t dry/wet		100	m3/h	DuboCalc- Bulldozer 12-35 t droog/nat	50,9 /	h	DuboCalc - Bulldozer 12-35 t droog/nat	11,36 /	h
compacting	sheep-foot roller		200	m2/h	Dick van den Heuvel	49,49952 /	h	DuboCalc - Wals (gemiddeld)	8,68 /	h
Activity	**Equipment/Material**	**Distance (km)**	**Capacity**	**Capacity unit**	**Source**	**kg CO2-eq /**	**unit**	**Source**	**MKI euro /**	**unit**
Gathering clay crest										
delivering	Clay, erosion class 2		1	m3	DuboCalc - Klei (gemiddeld)	0,6 /	m3	DuboCalc - Klei (gemiddeld)	0,05 /	m3
transport	Transport truck bulk	75	0,625	m3/tonkm	DuboCalc - Transport bulk (over de weg) - Klei	0,26645608 /	tonkm	DuboCalc - Transport bulk (over de weg)	0,0404 /	tonkm
processing clay (placing and compacting)										
processing	Hydraulic excavator (2000L)		100	m3/h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	52,593239 /	h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	9,22 /	h
profiling	Bulldozer 12-35 t dry/wet		100	m3/h	DuboCalc- Bulldozer 12-35 t droog/nat	50,9 /	h	DuboCalc - Bulldozer 12-35 t droog/nat	11,36 /	h
compacting	sheep-foot roller		200	m2/h	Dick van den Heuvel	49,49952 /	h	DuboCalc - Wals (gemiddeld)	8,68 /	h
Activity	**Equipment/Material**	**Distance (km)**	**Capacity**	**Capacity unit**	**Source**	**kg CO2-eq /**	**unit**	**Source**	**MKI euro /**	**unit**
applying top soil / teelaarde										
delivering	top soil		1	m3	10 cm top soil layer	0,6 /	m3	DuboCalc - Grond	0,05 /	m3
transport	Transport truck bulk	75	0,615	m3/tonkm	DuboCalc - Transport bulk (over de weg) - Grond (pei	0,26645608 /	tonkm	DuboCalc - Transport bulk (over de weg)	0,0404 /	tonkm
processing top soil										
processing	Hydraulic excavator (2000L)		100	m3/h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	52,593239 /	h	DuboCalc - Gr.mach.Hydr. (gemiddeld)	9,22 /	h
profiling	Bulldozer 12-35 t dry/wet		100	m3/h	DuboCalc- Bulldozer 12-35 t droog/nat	50,9 /	h	DuboCalc - Bulldozer 12-35 t droog/nat	11,36 /	h
compacting	sheep-foot roller		200	m2/h	Dick van den Heuvel	49,49952 /	h	DuboCalc - Wals (gemiddeld)	8,68 /	h

In the following tables, the next colours indicate the material; moderate erosion resistant clay, little erosion resistant clay or top soil.

Little erosion resistant clay
Moderate erosion resistant clay
Top Soil

		Cross-section															
Equipment/Material	**Units**	**1810**	**1980**	**2120**	**no data**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
Applying clay class 3																	
Clay, erosion class 3	m3	1,40E+04	1,01E+04	1,64E+04	0,00E+00	1,85E+04	1,35E+04	1,87E+04	1,52E+04	1,53E+04	1,29E+04	4,72E+03	4,03E+04	2,90E+04	3,32E+04	1,71E+04	8,87E+03
Transport truck bulk	tonkm	1,12E+06	8,06E+05	1,31E+06	0,00E+00	1,48E+06	1,08E+06	1,50E+06	1,22E+06	1,22E+06	1,03E+06	3,78E+05	3,22E+06	2,32E+06	2,66E+06	1,37E+06	7,10E+05
Processing																	
Hydraulic excavator (2000L)	h	2,33E+01	3,14E+01	1,09E+01	0,00E+00	1,28E+01	1,85E+01	1,31E+01	9,57E+00	2,75E+01	7,93E+00	3,50E+00	3,57E+01	4,57E+01	3,89E+01	1,51E+01	6,64E+00
Hydraulic excavator (2000L)	h	1,40E+02	1,01E+02	1,64E+02	0,00E+00	1,85E+02	1,35E+02	1,87E+02	1,52E+02	1,53E+02	1,29E+02	4,72E+01	4,03E+02	2,90E+02	3,32E+02	1,71E+02	8,87E+01
Bulldozer 12-35 t dry/wet	h	1,40E+02	1,01E+02	1,64E+02	0,00E+00	1,85E+02	1,35E+02	1,87E+02	1,52E+02	1,53E+02	1,29E+02	4,72E+01	4,03E+02	2,90E+02	3,32E+02	1,71E+02	8,87E+01
sheep-foot roller	h	1,03E+02	1,39E+02	4,81E+01	0,00E+00	5,65E+01	8,20E+01	5,80E+01	4,24E+01	1,22E+02	3,51E+01	1,55E+01	1,58E+02	2,02E+02	1,72E+02	6,66E+01	2,94E+01
Applying clay class 2																	
Clay, erosion class 2	m3	8,87E+03	4,27E+03	6,35E+03	0,00E+00	3,01E+03	1,24E+03	2,98E+03	2,08E+03	8,05E+03	4,46E+03	5,26E+03	2,60E+04	6,91E+03	8,54E+03	2,36E+03	2,09E+03
Transport truck bulk	tonkm	1,06E+06	5,12E+05	7,62E+05	0,00E+00	3,61E+05	1,49E+05	3,58E+05	2,49E+05	9,66E+05	5,35E+05	6,31E+05	3,12E+06	8,29E+05	1,02E+06	2,84E+05	2,51E+05
Processing																	
Hydraulic excavator (2000L)	h	8,87E+01	4,27E+01	6,35E+01	0,00E+00	3,01E+01	1,24E+01	2,98E+01	2,08E+01	8,05E+01	4,46E+01	5,26E+01	2,60E+02	6,91E+01	8,54E+01	2,36E+01	2,09E+01
Bulldozer 12-35 t dry/wet	h	8,87E+01	4,27E+01	6,35E+01	0,00E+00	3,01E+01	1,24E+01	2,98E+01	2,08E+01	8,05E+01	4,46E+01	5,26E+01	2,60E+02	6,91E+01	8,54E+01	2,36E+01	2,09E+01
sheep-foot roller	h	4,43E+01	2,13E+01	3,17E+01	0,00E+00	1,51E+01	6,20E+00	1,49E+01	1,04E+01	4,03E+01	2,23E+01	2,63E+01	1,30E+02	3,46E+01	4,27E+01	1,18E+01	1,05E+01
Applying top soil																	
top soil	m3	2,95E+03	3,20E+03	1,60E+03	0,00E+00	1,43E+03	1,76E+03	1,46E+03	1,05E+03	3,24E+03	1,15E+03	8,35E+02	5,77E+03	4,41E+03	3,95E+03	1,57E+03	7,97E+02
Transport truck bulk	tonkm	3,60E+05	3,91E+05	1,95E+05	0,00E+00	1,74E+05	2,15E+05	1,78E+05	1,29E+05	3,95E+05	1,40E+05	1,02E+05	7,03E+05	5,38E+05	4,82E+05	1,91E+05	9,72E+04
Processing																	
Hydraulic excavator (2000L)	h	2,95E+01	3,20E+01	1,60E+01	0,00E+00	1,43E+01	1,76E+01	1,46E+01	1,05E+01	3,24E+01	1,15E+01	8,35E+00	5,77E+01	4,41E+01	3,95E+01	1,57E+01	7,97E+00
Bulldozer 12-35 t dry/wet	h	2,95E+01	3,20E+01	1,60E+01	0,00E+00	1,43E+01	1,76E+01	1,46E+01	1,05E+01	3,24E+01	1,15E+01	8,35E+00	5,77E+01	4,41E+01	3,95E+01	1,57E+01	7,97E+00
sheep-foot roller	h	1,47E+02	1,60E+02	7,99E+01	0,00E+00	7,15E+01	8,82E+01	7,29E+01	5,27E+01	1,62E+02	5,74E+01	4,18E+01	2,88E+02	2,21E+02	1,98E+02	7,85E+01	3,99E+01

									Cross-section								
Equipment/Material	**Units**	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
Applying clay class 3																	
Clay, erosion class 3	m3	1,44E+04	1,24E+04	1,55E+03	3,93E+03	7,52E+03	8,72E+03	3,28E+03	6,58E+03	1,52E+04	1,08E+04	7,52E+03	5,10E+03	8,97E+03	5,59E+03	9,78E+03	1,09E+03
Transport truck bulk	tonkm	1,15E+06	9,89E+05	1,24E+05	3,14E+05	6,01E+05	6,98E+05	2,62E+05	5,26E+05	1,22E+06	8,63E+05	6,02E+05	4,08E+05	7,18E+05	4,47E+05	7,82E+05	8,69E+04
Processing																	
Hydraulic excavator (2000L)	h	1,06E+01	5,46E+00	6,83E-01	2,78E+00	5,35E+00	4,84E+00	2,03E+00	1,21E+01	1,10E+01	9,69E+00	5,22E+00	1,61E+01	1,56E+01	4,55E+00	1,50E+01	5,22E-01
Hydraulic excavator (2000L)	h	1,44E+02	1,24E+02	1,55E+01	3,93E+01	7,52E+01	8,72E+01	3,28E+01	6,58E+01	1,52E+02	1,08E+02	7,52E+01	5,10E+01	8,97E+01	5,59E+01	9,78E+01	1,09E+01
Bulldozer 12-35 t dry/wet	h	1,44E+02	1,24E+02	1,55E+01	3,93E+01	7,52E+01	8,72E+01	3,28E+01	6,58E+01	1,52E+02	1,08E+02	7,52E+01	5,10E+01	8,97E+01	5,59E+01	9,78E+01	1,09E+01
sheep-foot roller	h	4,71E+01	2,42E+01	3,02E+00	1,23E+01	2,37E+01	2,14E+01	9,00E+00	5,38E+01	4,86E+01	4,29E+01	2,31E+01	7,12E+01	6,91E+01	2,01E+01	6,65E+01	2,31E+00
Applying clay class 2																	
Clay, erosion class 2	m3	2,81E+03	1,75E+03	2,19E+02	1,48E+03	1,42E+03	1,60E+03	2,47E+03	1,45E+03	3,53E+03	1,70E+03	2,35E+03	1,69E+03	2,44E+03	9,72E+02	2,10E+03	8,46E+02
Transport truck bulk	tonkm	3,38E+05	2,10E+05	2,62E+04	1,78E+05	1,70E+05	1,91E+05	2,97E+05	1,74E+05	4,23E+05	2,04E+05	2,82E+05	2,02E+05	2,93E+05	1,17E+05	2,52E+05	1,02E+05
Processing																	
Hydraulic excavator (2000L)	h	2,81E+01	1,75E+01	2,19E+00	1,48E+01	1,42E+01	1,60E+01	2,47E+01	1,45E+01	3,53E+01	1,70E+01	2,35E+01	1,69E+01	2,44E+01	9,72E+00	2,10E+01	8,46E+00
Bulldozer 12-35 t dry/wet	h	2,81E+01	1,75E+01	2,19E+00	1,48E+01	1,42E+01	1,60E+01	2,47E+01	1,45E+01	3,53E+01	1,70E+01	2,35E+01	1,69E+01	2,44E+01	9,72E+00	2,10E+01	8,46E+00
sheep-foot roller	h	1,41E+01	8,74E+00	1,09E+00	7,40E+00	7,10E+00	7,98E+00	1,24E+01	7,25E+00	1,76E+01	8,48E+00	1,17E+01	8,43E+00	1,22E+01	4,86E+00	1,05E+01	4,23E+00
Applying top soil																	
top soil	m3	1,22E+03	6,58E+02	8,23E+01	3,94E+02	6,16E+02	5,88E+02	4,27E+02	1,22E+03	1,32E+03	1,03E+03	5,92E+02	1,59E+03	1,63E+03	5,00E+02	1,54E+03	1,31E+02
Transport truck bulk	tonkm	1,49E+05	8,03E+04	1,00E+04	4,81E+04	7,51E+04	7,17E+04	5,21E+04	1,49E+05	1,62E+05	1,25E+05	7,22E+04	1,94E+05	1,98E+05	6,10E+04	1,88E+05	1,60E+04
Processing																	
Hydraulic excavator (2000L)	h	1,22E+01	6,58E+00	8,23E-01	3,94E+00	6,16E+00	5,88E+00	4,27E+00	1,22E+01	1,32E+01	1,03E+01	5,92E+00	1,59E+01	1,63E+01	5,00E+00	1,54E+01	1,31E+00
Bulldozer 12-35 t dry/wet	h	1,22E+01	6,58E+00	8,23E-01	3,94E+00	6,16E+00	5,88E+00	4,27E+00	1,22E+01	1,32E+01	1,03E+01	5,92E+00	1,59E+01	1,63E+01	5,00E+00	1,54E+01	1,31E+00
sheep-foot roller	h	6,11E+01	3,29E+01	4,12E+00	1,97E+01	3,08E+01	2,94E+01	2,14E+01	6,10E+01	6,62E+01	5,14E+01	2,96E+01	7,96E+01	8,13E+01	2,50E+01	7,70E+01	6,54E+00

									Cross-section								
Equipment/Material	**Units**	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**no data**	**4570**	**4600**	**4610**	**4630**
Applying clay class 3																	
Clay, erosion class 3	m3	2,34E+03	3,43E+03	1,00E+04	6,66E+03	1,70E+04	1,46E+03	5,57E+02	0,00E+00	1,50E+03	1,67E+03	3,75E+03	0,00E+00	6,72E+03	3,89E+02	1,98E+03	4,37E+03
Transport truck bulk	tonkm	1,87E+05	2,74E+05	8,02E+05	5,32E+05	1,36E+06	1,17E+05	4,45E+04	0,00E+00	1,20E+05	1,33E+05	3,00E+05	0,00E+00	5,38E+05	3,11E+04	1,59E+05	3,50E+05
Processing																	
Hydraulic excavator (2000L)	h	1,63E+00	2,22E+00	1,56E+01	1,20E+01	2,16E+01	1,17E+00	3,19E-01	0,00E+00	1,19E+00	1,26E+00	5,73E+00	0,00E+00	4,32E+00	1,54E+00	4,70E+00	8,91E+00
Hydraulic excavator (2000L)	h	2,34E+01	3,43E+01	1,00E+02	6,66E+01	1,70E+02	1,46E+01	5,57E+00	0,00E+00	1,50E+01	1,67E+01	3,75E+01	0,00E+00	6,72E+01	3,89E+00	1,98E+01	4,37E+01
Bulldozer 12-35 t dry/wet	h	2,34E+01	3,43E+01	1,00E+02	6,66E+01	1,70E+02	1,46E+01	5,57E+00	0,00E+00	1,50E+01	1,67E+01	3,75E+01	0,00E+00	6,72E+01	3,89E+00	1,98E+01	4,37E+01
sheep-foot roller	h	7,20E+00	9,84E+00	6,89E+01	5,31E+01	9,58E+01	5,20E+00	1,41E+00	0,00E+00	5,29E+00	5,56E+00	2,54E+01	0,00E+00	1,91E+01	6,83E+00	2,08E+01	3,95E+01
Applying clay class 2																	
Clay, erosion class 2	m3	6,20E+02	8,52E+02	3,02E+03	2,15E+03	5,48E+03	4,05E+02	4,07E+02	0,00E+00	3,11E+02	2,02E+03	2,35E+03	0,00E+00	2,10E+03	1,94E+02	6,72E+02	4,69E+02
Transport truck bulk	tonkm	7,44E+04	1,02E+05	3,63E+05	2,58E+05	6,58E+05	4,86E+04	4,88E+04	0,00E+00	3,73E+04	2,43E+05	2,82E+05	0,00E+00	2,52E+05	2,33E+04	8,06E+04	5,63E+04
Processing																	
Hydraulic excavator (2000L)	h	6,20E+00	8,52E+00	3,02E+01	2,15E+01	5,48E+01	4,05E+00	4,07E+00	0,00E+00	3,11E+00	2,02E+01	2,35E+01	0,00E+00	2,10E+01	1,94E+00	6,72E+00	4,69E+00
Bulldozer 12-35 t dry/wet	h	6,20E+00	8,52E+00	3,02E+01	2,15E+01	5,48E+01	4,05E+00	4,07E+00	0,00E+00	3,11E+00	2,02E+01	2,35E+01	0,00E+00	2,10E+01	1,94E+00	6,72E+00	4,69E+00
sheep-foot roller	h	3,10E+00	4,26E+00	1,51E+01	1,07E+01	2,74E+01	2,03E+00	2,04E+00	0,00E+00	1,55E+00	1,01E+01	1,17E+01	0,00E+00	1,05E+01	9,70E-01	3,36E+00	2,34E+00
Applying top soil																	
top soil	m3	2,06E+02	2,82E+02	1,56E+03	1,28E+03	2,30E+03	1,44E+02	6,90E+01	0,00E+00	1,37E+02	3,14E+02	5,92E+02	0,00E+00	5,93E+02	1,56E+02	4,83E+02	8,36E+02
Transport truck bulk	tonkm	2,51E+04	3,44E+04	1,90E+05	1,56E+05	2,80E+05	1,76E+04	8,41E+03	0,00E+00	1,67E+04	3,82E+04	7,21E+04	0,00E+00	7,23E+04	1,90E+04	5,89E+04	1,02E+05
Processing																	
Hydraulic excavator (2000L)	h	2,06E+00	2,82E+00	1,56E+01	1,28E+01	2,30E+01	1,44E+00	6,90E-01	0,00E+00	1,37E+00	3,14E+00	5,92E+00	0,00E+00	5,93E+00	1,56E+00	4,83E+00	8,36E+00
Bulldozer 12-35 t dry/wet	h	2,06E+00	2,82E+00	1,56E+01	1,28E+01	2,30E+01	1,44E+00	6,90E-01	0,00E+00	1,37E+00	3,14E+00	5,92E+00	0,00E+00	5,93E+00	1,56E+00	4,83E+00	8,36E+00
sheep-foot roller	h	1,03E+01	1,41E+01	7,81E+01	6,38E+01	1,15E+02	7,22E+00	3,45E+00	0,00E+00	6,84E+00	1,57E+01	2,96E+01	0,00E+00	2,96E+01	7,80E+00	2,42E+01	4,18E+01

Table 42: Results of the backfilling process per unit

	Cross-section															
Equipment/Material	**1810**	**1980**	**2120**	**no data**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
Applying clay class 3																
Clay, erosion class 3	8,40E+03	6,05E+03	9,82E+03	0,00E+00	1,11E+04	8,08E+03	1,12E+04	9,13E+03	9,16E+03	7,76E+03	2,83E+03	2,42E+04	1,74E+04	1,99E+04	1,03E+04	5,32E+03
Transport truck bulk	2,98E+05	2,15E+05	3,49E+05	0,00E+00	3,95E+05	2,87E+05	3,98E+05	3,24E+05	3,26E+05	2,76E+05	1,01E+05	8,58E+05	6,18E+05	7,08E+05	3,65E+05	1,89E+05
Processing																
Hydraulic excavator (2000L)	1,23E+03	1,65E+03	5,72E+02	0,00E+00	6,71E+02	9,74E+02	6,88E+02	5,03E+02	1,45E+03	4,17E+02	1,84E+02	1,88E+03	2,40E+03	2,05E+03	7,92E+02	3,49E+02
Hydraulic excavator (2000L)	7,36E+03	5,30E+03	8,61E+03	0,00E+00	9,74E+03	7,09E+03	9,83E+03	8,00E+03	8,03E+03	6,80E+03	2,48E+03	2,12E+04	1,52E+04	1,75E+04	9,00E+03	4,67E+03
Bulldozer 12-35 t dry/wet	7,12E+03	5,13E+03	8,33E+03	0,00E+00	9,43E+03	6,86E+03	9,51E+03	7,74E+03	7,77E+03	6,58E+03	2,40E+03	2,05E+04	1,48E+04	1,69E+04	8,71E+03	4,52E+03
sheep-foot roller	5,10E+03	6,87E+03	2,38E+03	0,00E+00	2,80E+03	4,06E+03	2,87E+03	2,10E+03	6,03E+03	1,74E+03	7,66E+02	7,83E+03	1,00E+04	8,53E+03	3,30E+03	1,46E+03
Applying clay class 2																
Clay, erosion class 2	5,32E+03	2,56E+03	3,81E+03	0,00E+00	1,81E+03	7,44E+02	1,79E+03	1,25E+03	4,83E+03	2,68E+03	3,15E+03	1,56E+04	4,15E+03	5,12E+03	1,42E+03	1,26E+03
Transport truck bulk	2,83E+05	1,36E+05	2,03E+05	0,00E+00	9,62E+04	3,96E+04	9,53E+04	6,64E+04	2,57E+05	1,43E+05	1,68E+05	8,32E+05	2,21E+05	2,73E+05	7,55E+04	6,69E+04
Processing																
Hydraulic excavator (2000L)	4,66E+03	2,24E+03	3,34E+03	0,00E+00	1,58E+03	6,52E+02	1,57E+03	1,09E+03	4,23E+03	2,35E+03	2,76E+03	1,37E+04	3,64E+03	4,49E+03	1,24E+03	1,10E+03
Bulldozer 12-35 t dry/wet	4,51E+03	2,17E+03	3,23E+03	0,00E+00	1,53E+03	6,31E+02	1,52E+03	1,06E+03	4,10E+03	2,27E+03	2,67E+03	1,32E+04	3,52E+03	4,35E+03	1,20E+03	1,06E+03
sheep-foot roller	2,19E+03	1,06E+03	1,57E+03	0,00E+00	7,45E+02	3,07E+02	7,38E+02	5,14E+02	1,99E+03	1,10E+03	1,30E+03	6,44E+03	1,71E+03	2,11E+03	5,85E+02	5,18E+02
Applying top soil																
top soil	1,77E+03	1,92E+03	9,58E+02	0,00E+00	8,58E+02	1,06E+03	8,74E+02	6,33E+02	1,94E+03	6,89E+02	5,01E+02	3,46E+03	2,65E+03	2,37E+03	9,41E+02	4,78E+02
Transport truck bulk	9,58E+04	1,04E+05	5,19E+04	0,00E+00	4,65E+04	5,73E+04	4,73E+04	3,43E+04	1,05E+05	3,73E+04	2,71E+04	1,87E+05	1,43E+05	1,28E+05	5,10E+04	2,59E+04
Processing																
Hydraulic excavator (2000L)	1,55E+03	1,69E+03	8,40E+02	0,00E+00	7,53E+02	9,28E+02	7,66E+02	5,55E+02	1,70E+03	6,04E+02	4,39E+02	3,03E+03	2,32E+03	2,08E+03	8,25E+02	4,19E+02
Bulldozer 12-35 t dry/wet	1,50E+03	1,63E+03	8,13E+02	0,00E+00	7,28E+02	8,98E+02	7,42E+02	5,37E+02	1,65E+03	5,84E+02	4,25E+02	2,94E+03	2,25E+03	2,01E+03	7,99E+02	4,06E+02
sheep-foot roller	7,30E+03	7,93E+03	3,95E+03	0,00E+00	3,54E+03	4,37E+03	3,61E+03	2,61E+03	8,02E+03	2,84E+03	2,07E+03	1,43E+04	1,09E+04	9,78E+03	3,88E+03	1,97E+03

	Cross-section															
Equipment/Material	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
Applying clay class 3																
Clay, erosion class 3	8,62E+03	7,42E+03	9,28E+02	2,36E+03	4,51E+03	5,23E+03	1,97E+03	3,95E+03	9,12E+03	6,48E+03	4,51E+03	3,06E+03	5,38E+03	3,35E+03	5,87E+03	6,52E+02
Transport truck bulk	3,06E+05	2,64E+05	3,30E+04	8,37E+04	1,60E+05	1,86E+05	6,98E+04	1,40E+05	3,24E+05	2,30E+05	1,60E+05	1,09E+05	1,91E+05	1,19E+05	2,08E+05	2,31E+04
Processing																
Hydraulic excavator (2000L)	5,59E+02	2,87E+02	3,59E+01	1,46E+02	2,82E+02	2,54E+02	1,07E+02	6,39E+02	5,77E+02	5,10E+02	2,74E+02	8,46E+02	8,21E+02	2,39E+02	7,90E+02	2,74E+01
Hydraulic excavator (2000L)	7,55E+03	6,50E+03	8,13E+02	2,06E+03	3,95E+03	4,59E+03	1,72E+03	3,46E+03	8,00E+03	5,68E+03	3,96E+03	2,68E+03	4,72E+03	2,94E+03	5,14E+03	5,71E+02
Bulldozer 12-35 t dry/wet	7,31E+03	6,30E+03	7,87E+02	2,00E+03	3,83E+03	4,44E+03	1,67E+03	3,35E+03	7,74E+03	5,49E+03	3,83E+03	2,60E+03	4,57E+03	2,84E+03	4,98E+03	5,53E+02
sheep-foot roller	2,33E+03	1,20E+03	1,50E+02	6,09E+02	1,17E+03	1,06E+03	4,45E+02	2,66E+03	2,41E+03	2,12E+03	1,14E+03	3,52E+03	3,42E+03	9,97E+02	3,29E+03	1,14E+02
Applying clay class 2																
Clay, erosion class 2	1,69E+03	1,05E+03	1,31E+02	8,88E+02	8,51E+02	9,57E+02	1,48E+03	8,70E+02	2,12E+03	1,02E+03	1,41E+03	1,01E+03	1,47E+03	5,83E+02	1,26E+03	5,08E+02
Transport truck bulk	9,00E+04	5,59E+04	6,99E+03	4,73E+04	4,54E+04	5,10E+04	7,91E+04	4,64E+04	1,13E+05	5,42E+04	7,51E+04	5,39E+04	7,81E+04	3,11E+04	6,71E+04	2,71E+04
Processing																
Hydraulic excavator (2000L)	1,48E+03	9,19E+02	1,15E+02	7,78E+02	7,46E+02	8,39E+02	1,30E+03	7,63E+02	1,85E+03	8,92E+02	1,24E+03	8,86E+02	1,28E+03	5,11E+02	1,10E+03	4,45E+02
Bulldozer 12-35 t dry/wet	1,43E+03	8,90E+02	1,11E+02	7,53E+02	7,22E+02	8,12E+02	1,26E+03	7,38E+02	1,79E+03	8,63E+02	1,20E+03	8,58E+02	1,24E+03	4,95E+02	1,07E+03	4,31E+02
sheep-foot roller	6,96E+02	4,33E+02	5,41E+01	3,66E+02	3,51E+02	3,95E+02	6,12E+02	3,59E+02	8,72E+02	4,20E+02	5,81E+02	4,17E+02	6,04E+02	2,41E+02	5,20E+02	2,09E+02
Applying top soil																
top soil	7,34E+02	3,95E+02	4,94E+01	2,37E+02	3,70E+02	3,53E+02	2,56E+02	7,32E+02	7,95E+02	6,17E+02	3,55E+02	9,56E+02	9,75E+02	3,00E+02	9,24E+02	7,85E+01
Transport truck bulk	3,97E+04	2,14E+04	2,67E+03	1,28E+04	2,00E+04	1,91E+04	1,39E+04	3,96E+04	4,30E+04	3,34E+04	1,92E+04	5,17E+04	5,28E+04	1,63E+04	5,00E+04	4,25E+03
Processing																
Hydraulic excavator (2000L)	6,43E+02	3,46E+02	4,33E+01	2,07E+02	3,24E+02	3,09E+02	2,25E+02	6,42E+02	6,97E+02	5,41E+02	3,11E+02	8,38E+02	8,55E+02	2,63E+02	8,10E+02	6,88E+01
Bulldozer 12-35 t dry/wet	6,22E+02	3,35E+02	4,19E+01	2,01E+02	3,13E+02	2,99E+02	2,18E+02	6,21E+02	6,74E+02	5,23E+02	3,01E+02	8,11E+02	8,28E+02	2,55E+02	7,84E+02	6,66E+01
sheep-foot roller	3,03E+03	1,63E+03	2,04E+02	9,76E+02	1,52E+03	1,45E+03	1,06E+03	3,02E+03	3,28E+03	2,54E+03	1,46E+03	3,94E+03	4,02E+03	1,24E+03	3,81E+03	3,24E+02

	Cross-section															
Equipment/Material	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**no data**	**4570**	**4600**	**4610**	**4630**
Applying clay class 3																
Clay, erosion class 3	1,41E+03	2,06E+03	6,02E+03	3,99E+03	1,02E+04	8,78E+02	3,34E+02	0,00E+00	8,99E+02	1,00E+03	2,25E+03	0,00E+00	4,03E+03	2,33E+02	1,19E+03	2,62E+03
Transport truck bulk	4,99E+04	7,31E+04	2,14E+05	1,42E+05	3,62E+05	3,12E+04	1,19E+04	0,00E+00	3,19E+04	3,56E+04	7,99E+04	0,00E+00	1,43E+05	8,29E+03	4,23E+04	9,32E+04
Processing																
Hydraulic excavator (2000L)	8,55E+01	1,17E+02	8,19E+02	6,31E+02	1,14E+03	6,17E+01	1,68E+01	0,00E+00	6,28E+01	6,60E+01	3,01E+02	0,00E+00	2,27E+02	8,11E+01	2,47E+02	4,69E+02
Hydraulic excavator (2000L)	1,23E+03	1,80E+03	5,27E+03	3,50E+03	8,94E+03	7,69E+02	2,93E+02	0,00E+00	7,88E+02	8,77E+02	1,97E+03	0,00E+00	3,53E+03	2,05E+02	1,04E+03	2,30E+03
Bulldozer 12-35 t dry/wet	1,19E+03	1,74E+03	5,10E+03	3,39E+03	8,65E+03	7,45E+02	2,83E+02	0,00E+00	7,63E+02	8,49E+02	1,91E+03	0,00E+00	3,42E+03	1,98E+02	1,01E+03	2,23E+03
sheep-foot roller	3,56E+02	4,87E+02	3,41E+03	2,63E+03	4,74E+03	2,57E+02	6,99E+01	0,00E+00	2,62E+02	2,75E+02	1,25E+03	0,00E+00	9,47E+02	3,38E+02	1,03E+03	1,95E+03
Applying clay class 2																
Clay, erosion class 2	3,72E+02	5,11E+02	1,81E+03	1,29E+03	3,29E+03	2,43E+02	2,44E+02	0,00E+00	1,86E+02	1,21E+03	1,41E+03	0,00E+00	1,26E+03	1,16E+02	4,03E+02	2,81E+02
Transport truck bulk	1,98E+04	2,72E+04	9,67E+04	6,87E+04	1,75E+05	1,29E+04	1,30E+04	0,00E+00	9,93E+03	6,47E+04	7,50E+04	0,00E+00	6,72E+04	6,20E+03	2,15E+04	1,50E+04
Processing																
Hydraulic excavator (2000L)	3,26E+02	4,48E+02	1,59E+03	1,13E+03	2,88E+03	2,13E+02	2,14E+02	0,00E+00	1,63E+02	1,06E+03	1,23E+03	0,00E+00	1,10E+03	1,02E+02	3,53E+02	2,47E+02
Bulldozer 12-35 t dry/wet	3,16E+02	4,34E+02	1,54E+03	1,09E+03	2,79E+03	2,06E+02	2,07E+02	0,00E+00	1,58E+02	1,03E+03	1,19E+03	0,00E+00	1,07E+03	9,87E+01	3,42E+02	2,39E+02
sheep-foot roller	1,53E+02	2,11E+02	7,48E+02	5,32E+02	1,36E+03	1,00E+02	1,01E+02	0,00E+00	7,68E+01	5,01E+02	5,81E+02	0,00E+00	5,20E+02	4,80E+01	1,66E+02	1,16E+02
Applying top soil																
top soil	1,24E+02	1,69E+02	9,37E+02	7,66E+02	1,38E+03	8,66E+01	4,14E+01	0,00E+00	8,21E+01	1,88E+02	3,55E+02	0,00E+00	3,56E+02	9,36E+01	2,90E+02	5,02E+02
Transport truck bulk	6,69E+03	9,16E+03	5,07E+04	4,15E+04	7,46E+04	4,69E+03	2,24E+03	0,00E+00	4,45E+03	1,02E+04	1,92E+04	0,00E+00	1,93E+04	5,07E+03	1,57E+04	2,72E+04
Processing																
Hydraulic excavator (2000L)	1,08E+02	1,48E+02	8,21E+02	6,72E+02	1,21E+03	7,59E+01	3,63E+01	0,00E+00	7,19E+01	1,65E+02	3,11E+02	0,00E+00	3,12E+02	8,20E+01	2,54E+02	4,40E+02
Bulldozer 12-35 t dry/wet	1,05E+02	1,44E+02	7,95E+02	6,50E+02	1,17E+03	7,35E+01	3,51E+01	0,00E+00	6,96E+01	1,60E+02	3,01E+02	0,00E+00	3,02E+02	7,94E+01	2,46E+02	4,26E+02
sheep-foot roller	5,10E+02	6,98E+02	3,86E+03	3,16E+03	5,68E+03	3,57E+02	1,71E+02	0,00E+00	3,39E+02	7,76E+02	1,46E+03	0,00E+00	1,47E+03	3,86E+02	1,20E+03	2,07E+03

Table 43: Results of the kg CO_2-eq calculation for the backfilling process per cross-section

	Cross-section															
Equipment/Material	**1810**	**1980**	**2120**	**no data**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
Applying clay class 3																
Clay, erosion class 3	€ 699,75	€ 503,80	€ 818,40	€ 0,00	€ 926,10	€ 673,60	€ 934,50	€ 760,50	€ 763,70	€ 646,45	€ 236,00	€ 2.012,85	€ 1.449,60	€ 1.661,63	€ 855,38	€ 443,60
Transport truck bulk	€ 45.231,84	€ 32.565,63	€ 52.901,38	€ 0,00	€ 59.863,10	€ 43.541,50	€ 60.406,08	€ 49.158,72	€ 49.365,57	€ 41.786,53	€ 15.255,04	€ 130.110,62	€ 93.702,14	€ 107.407,44	€ 55.291,44	€ 28.674,30
Processing																
Hydraulic excavator (2000L)	€ 214,77	€ 289,22	€ 100,21	€ 0,00	€ 117,65	€ 170,77	€ 120,69	€ 88,22	€ 253,66	€ 73,11	€ 32,23	€ 329,51	€ 421,02	€ 358,99	€ 138,78	€ 61,23
Hydraulic excavator (2000L)	€ 1.290,34	€ 929,01	€ 1.509,13	€ 0,00	€ 1.707,73	€ 1.242,12	€ 1.723,22	€ 1.402,36	€ 1.408,26	€ 1.192,05	€ 435,18	€ 3.711,70	€ 2.673,06	€ 3.064,04	€ 1.577,31	€ 818,00
Bulldozer 12-35 t dry/wet	€ 1.589,83	€ 1.144,63	€ 1.859,40	€ 0,00	€ 2.104,10	€ 1.530,42	€ 2.123,18	€ 1.727,86	€ 1.735,13	€ 1.468,73	€ 536,19	€ 4.573,20	€ 3.293,49	€ 3.775,21	€ 1.943,41	€ 1.007,86
sheep-foot roller	€ 895,13	€ 1.205,44	€ 417,68	€ 0,00	€ 490,33	€ 711,76	€ 503,01	€ 367,68	€ 1.057,22	€ 304,71	€ 134,32	€ 1.373,35	€ 1.754,75	€ 1.496,22	€ 578,41	€ 255,19
Applying clay class 2																
Clay, erosion class 2	€ 443,25	€ 213,40	€ 317,40	€ 0,00	€ 150,50	€ 62,00	€ 149,00	€ 103,80	€ 402,50	€ 222,95	€ 262,75	€ 1.301,40	€ 345,60	€ 427,00	€ 118,13	€ 104,60
Transport truck bulk	€ 42.977,52	€ 20.691,26	€ 30.775,10	€ 0,00	€ 14.592,48	€ 6.011,52	€ 14.447,04	€ 10.064,45	€ 39.026,40	€ 21.617,23	€ 25.476,24	€ 126.183,74	€ 33.509,38	€ 41.401,92	€ 11.453,40	€ 10.142,02
Processing																
Hydraulic excavator (2000L)	€ 817,35	€ 393,51	€ 585,29	€ 0,00	€ 277,52	€ 114,33	€ 274,76	€ 191,41	€ 742,21	€ 411,12	€ 484,51	€ 2.399,78	€ 637,29	€ 787,39	€ 217,82	€ 192,88
Bulldozer 12-35 t dry/wet	€ 1.007,06	€ 484,84	€ 721,13	€ 0,00	€ 341,94	€ 140,86	€ 338,53	€ 235,83	€ 914,48	€ 506,54	€ 596,97	€ 2.956,78	€ 785,20	€ 970,14	€ 268,38	€ 237,65
sheep-foot roller	€ 384,74	€ 185,23	€ 275,50	€ 0,00	€ 130,63	€ 53,82	€ 129,33	€ 90,10	€ 349,37	€ 193,52	€ 228,07	€ 1.129,62	€ 299,98	€ 370,64	€ 102,53	€ 90,79
Applying top soil																
top soil	€ 147,45	€ 160,22	€ 79,86	€ 0,00	€ 71,54	€ 88,20	€ 72,85	€ 52,74	€ 162,05	€ 57,40	€ 41,75	€ 288,36	€ 220,72	€ 197,58	€ 78,45	€ 39,86
Transport truck bulk	€ 14.529,22	€ 15.787,04	€ 7.869,13	€ 0,00	€ 7.049,31	€ 8.690,93	€ 7.178,39	€ 5.196,82	€ 15.967,85	€ 5.656,00	€ 4.113,90	€ 28.414,01	€ 21.749,00	€ 19.468,37	€ 7.730,20	€ 3.927,67
Processing																
Hydraulic excavator (2000L)	€ 271,90	€ 295,44	€ 147,26	€ 0,00	€ 131,92	€ 162,64	€ 134,34	€ 97,25	€ 298,82	€ 105,85	€ 76,99	€ 531,74	€ 407,01	€ 364,33	€ 144,66	€ 73,50
Bulldozer 12-35 t dry/wet	€ 335,01	€ 364,01	€ 181,44	€ 0,00	€ 162,54	€ 200,39	€ 165,52	€ 119,83	€ 368,18	€ 130,41	€ 94,86	€ 655,15	€ 501,48	€ 448,89	€ 178,24	€ 90,56
sheep-foot roller	€ 1.279,87	€ 1.390,67	€ 693,18	€ 0,00	€ 620,97	€ 765,58	€ 632,34	€ 457,78	€ 1.406,59	€ 498,23	€ 362,39	€ 2.502,96	€ 1.915,85	€ 1.714,95	€ 680,95	€ 345,98

	Cross-section															
Equipment/Material	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
Applying clay class 3																
Clay, erosion class 3	€ 718,20	€ 618,40	€ 77,30	€ 196,30	€ 375,90	€ 436,00	€ 163,80	€ 329,00	€ 760,25	€ 539,60	€ 376,25	€ 255,00	€ 448,53	€ 279,45	€ 488,75	€ 54,30
Transport truck bulk	€ 46.424,45	€ 39.973,38	€ 4.996,67	€ 12.688,83	€ 24.298,18	€ 28.183,04	€ 10.588,03	€ 21.266,56	€ 49.142,56	€ 34.879,74	€ 24.320,80	€ 16.483,20	€ 28.992,66	€ 18.063,65	€ 31.592,80	€ 3.509,95
Processing																
Hydraulic excavator (2000L)	€ 98,03	€ 50,36	€ 6,29	€ 25,64	€ 49,36	€ 44,59	€ 18,73	€ 111,94	€ 101,21	€ 89,38	€ 48,11	€ 148,28	€ 143,87	€ 41,95	€ 138,49	€ 4,81
Hydraulic excavator (2000L)	€ 1.324,36	€ 1.140,33	€ 142,54	€ 361,98	€ 693,16	€ 803,98	€ 302,05	€ 606,68	€ 1.401,90	€ 995,02	€ 693,80	€ 470,22	€ 827,08	€ 515,31	€ 901,26	€ 100,13
Bulldozer 12-35 t dry/wet	€ 1.631,75	€ 1.405,00	€ 175,63	€ 445,99	€ 854,04	€ 990,59	€ 372,15	€ 747,49	€ 1.727,29	€ 1.225,97	€ 854,84	€ 579,36	€ 1.019,05	€ 634,91	€ 1.110,44	€ 123,37
sheep-foot roller	€ 408,57	€ 209,88	€ 26,24	€ 106,85	€ 205,72	€ 185,86	€ 78,08	€ 466,55	€ 421,85	€ 372,55	€ 200,51	€ 618,02	€ 599,61	€ 174,86	€ 577,22	€ 20,05
Applying clay class 2																
Clay, erosion class 2	€ 140,70	€ 87,40	€ 10,93	€ 74,00	€ 70,95	€ 79,75	€ 123,73	€ 72,50	€ 176,25	€ 84,80	€ 117,42	€ 84,25	€ 122,10	€ 48,60	€ 105,00	€ 42,30
Transport truck bulk	€ 13.642,27	€ 8.474,30	€ 1.059,29	€ 7.175,04	€ 6.879,31	€ 7.732,56	€ 11.996,38	€ 7.029,60	€ 17.089,20	€ 8.222,21	€ 11.385,53	€ 8.168,88	€ 11.838,82	€ 4.712,26	€ 10.180,80	€ 4.101,41
Processing																
Hydraulic excavator (2000L)	€ 259,45	€ 161,17	€ 20,15	€ 136,46	€ 130,83	€ 147,06	€ 228,15	€ 133,69	€ 325,01	€ 156,37	€ 216,53	€ 155,36	€ 225,15	€ 89,62	€ 193,62	€ 78,00
Bulldozer 12-35 t dry/wet	€ 319,67	€ 198,57	€ 24,82	€ 168,13	€ 161,20	€ 181,19	€ 281,10	€ 164,72	€ 400,44	€ 192,67	€ 266,79	€ 191,42	€ 277,41	€ 110,42	€ 238,56	€ 96,11
sheep-foot roller	€ 122,13	€ 75,86	€ 9,48	€ 64,23	€ 61,58	€ 69,22	€ 107,39	€ 62,93	€ 152,99	€ 73,61	€ 101,92	€ 73,13	€ 105,98	€ 42,18	€ 91,14	€ 36,72
Applying top soil																
top soil	€ 61,14	€ 32,92	€ 4,12	€ 19,71	€ 30,80	€ 29,39	€ 21,37	€ 61,00	€ 66,23	€ 51,40	€ 29,59	€ 79,63	€ 81,29	€ 25,01	€ 77,00	€ 6,54
Transport truck bulk	€ 6.024,53	€ 3.243,82	€ 405,48	€ 1.942,16	€ 3.034,43	€ 2.895,74	€ 2.105,48	€ 6.010,73	€ 6.525,59	€ 5.064,78	€ 2.915,94	€ 7.845,98	€ 8.010,04	€ 2.463,91	€ 7.587,32	€ 644,43
Processing																
Hydraulic excavator (2000L)	€ 112,74	€ 60,70	€ 7,59	€ 36,35	€ 56,79	€ 54,19	€ 39,40	€ 112,48	€ 122,12	€ 94,78	€ 54,57	€ 146,83	€ 149,90	€ 46,11	€ 141,99	€ 12,06
Bulldozer 12-35 t dry/wet	€ 138,91	€ 74,79	€ 9,35	€ 44,78	€ 69,97	€ 66,77	€ 48,55	€ 138,59	€ 150,46	€ 116,78	€ 67,23	€ 180,91	€ 184,69	€ 56,81	€ 174,94	€ 14,86
sheep-foot roller	€ 530,70	€ 285,75	€ 35,72	€ 171,08	€ 267,30	€ 255,08	€ 185,47	€ 529,48	€ 574,83	€ 446,15	€ 256,86	€ 691,15	€ 705,60	€ 217,04	€ 668,36	€ 56,77

	Cross-section															
Equipment/Material	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**no data**	**4570**	**4600**	**4610**	**4630**
Applying clay class 3																
Clay, erosion class 3	€ 117,10	€ 171,38	€ 501,30	€ 332,80	€ 850,00	€ 73,15	€ 27,83	€ 0,00	€ 74,93	€ 83,40	€ 187,35	€ 0,00	€ 336,05	€ 19,45	€ 99,15	€ 218,57
Transport truck bulk	€ 7.569,34	€ 11.077,68	€ 32.404,03	€ 21.512,19	€ 54.944,00	€ 4.728,42	€ 1.798,61	€ 0,00	€ 4.843,15	€ 5.390,98	€ 12.110,30	€ 0,00	€ 21.722,27	€ 1.257,25	€ 6.409,06	€ 14.128,69
Processing																
Hydraulic excavator (2000L)	€ 14,98	€ 20,49	€ 143,57	€ 110,59	€ 199,59	€ 10,82	€ 2,94	€ 0,00	€ 11,01	€ 11,57	€ 52,79	€ 0,00	€ 39,86	€ 14,22	€ 43,30	€ 82,18
Hydraulic excavator (2000L)	€ 215,93	€ 316,02	€ 924,40	€ 613,68	€ 1.567,40	€ 134,89	€ 51,31	€ 0,00	€ 138,16	€ 153,79	€ 345,47	€ 0,00	€ 619,68	€ 35,87	€ 182,83	€ 403,05
Bulldozer 12-35 t dry/wet	€ 266,05	€ 389,36	€ 1.138,95	€ 756,12	€ 1.931,20	€ 166,20	€ 63,22	€ 0,00	€ 170,23	€ 189,48	€ 425,66	€ 0,00	€ 763,51	€ 44,19	€ 225,27	€ 496,60
sheep-foot roller	€ 62,45	€ 85,41	€ 598,40	€ 460,91	€ 831,87	€ 45,09	€ 12,26	€ 0,00	€ 45,90	€ 48,24	€ 220,04	€ 0,00	€ 166,14	€ 59,28	€ 180,46	€ 342,53
Applying clay class 2																
Clay, erosion class 2	€ 31,00	€ 42,60	€ 151,20	€ 107,40	€ 274,13	€ 20,25	€ 20,35	€ 0,00	€ 15,53	€ 101,18	€ 117,30	€ 0,00	€ 105,05	€ 9,70	€ 33,60	€ 23,45
Transport truck bulk	€ 3.005,76	€ 4.130,50	€ 14.660,35	€ 10.413,50	€ 26.579,16	€ 1.963,44	€ 1.973,14	€ 0,00	€ 1.505,30	€ 9.809,93	€ 11.373,41	€ 0,00	€ 10.185,65	€ 940,51	€ 3.257,86	€ 2.273,71
Processing																
Hydraulic excavator (2000L)	€ 57,16	€ 78,55	€ 278,81	€ 198,05	€ 505,49	€ 37,34	€ 37,53	€ 0,00	€ 28,63	€ 186,57	€ 216,30	€ 0,00	€ 193,71	€ 17,89	€ 61,96	€ 43,24
Bulldozer 12-35 t dry/wet	€ 70,43	€ 96,79	€ 343,53	€ 244,01	€ 622,81	€ 46,01	€ 46,24	€ 0,00	€ 35,27	€ 229,87	€ 266,51	€ 0,00	€ 238,67	€ 22,04	€ 76,34	€ 53,28
sheep-foot roller	€ 26,91	€ 36,98	€ 131,24	€ 93,22	€ 237,94	€ 17,58	€ 17,66	€ 0,00	€ 13,48	€ 87,82	€ 101,82	€ 0,00	€ 91,18	€ 8,42	€ 29,16	€ 20,35
Applying top soil																
top soil	€ 10,30	€ 14,10	€ 78,06	€ 63,84	€ 114,75	€ 7,22	€ 3,45	€ 0,00	€ 6,84	€ 15,68	€ 29,58	€ 0,00	€ 29,65	€ 7,80	€ 24,15	€ 41,81
Transport truck bulk	€ 1.014,43	€ 1.389,37	€ 7.691,77	€ 6.290,58	€ 11.307,07	€ 711,43	€ 339,70	€ 0,00	€ 673,99	€ 1.544,56	€ 2.914,71	€ 0,00	€ 2.921,12	€ 768,59	€ 2.379,66	€ 4.119,57
Processing																
Hydraulic excavator (2000L)	€ 18,98	€ 26,00	€ 143,94	€ 117,72	€ 211,60	€ 13,31	€ 6,36	€ 0,00	€ 12,61	€ 28,90	€ 54,55	€ 0,00	€ 54,67	€ 14,38	€ 44,53	€ 77,09
Bulldozer 12-35 t dry/wet	€ 23,39	€ 32,04	€ 177,35	€ 145,04	€ 260,71	€ 16,40	€ 7,83	€ 0,00	€ 15,54	€ 35,61	€ 67,21	€ 0,00	€ 67,35	€ 17,72	€ 54,87	€ 94,99
sheep-foot roller	€ 89,36	€ 122,39	€ 677,56	€ 554,13	€ 996,03	€ 62,67	€ 29,92	€ 0,00	€ 59,37	€ 136,06	€ 256,75	€ 0,00	€ 257,32	€ 67,70	€ 209,62	€ 362,89

Table 44: Results of the MKI calculation for the backfilling process per cross-section

E. Calculation of the CO_2-eq and MKI for the sowing process

Table 45: Summary of specifications for the sowing process

Activity	Equipment/Material	Distance (km)	Capacity	Capacity unit	Source	kg CO2-eq /	unit	Source	MKI euro /	unit
finishing dike cover										
sowing the dike body	grass seeds (D1 150 kg/ha)		66,667	m2/kg	Dick van den Heuvel	2,91333 /	kg	Estimating the energy requirments and CO2 emissions from production of grasses	0,2585 /	kg
	Transport truck bulk	75	1000	kg/tonkm	DuboCalc - Transport bulk (over de weg)	0,26645608 /	tonkm	DuboCalc - Transport bulk (over de weg)	0,0404 /	tonkm
	tractor + sowing combi		400	m2/h	Dick van den Heuvel	34,4 /	h	LCA Rapportage categorie 3 data Nationale Milieudatabase	3,19 /	h

Table 46: Results of the sowing process per unit

		Cross-section															
Equipment/Material	**Units**	**1810**	**1980**	**2120**	**no data**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
grass seeds (D1 150 kg/ha)	kg	4,42E+02	4,81E+02	2,40E+02	0,00E+00	2,15E+02	2,65E+02	2,19E+02	1,58E+02	4,86E+02	1,72E+02	1,25E+02	8,65E+02	6,62E+02	5,93E+02	2,35E+02	1,20E+02
Transport truck bulk	tkm	3,32E+01	3,60E+01	1,80E+01	0,00E+00	1,61E+01	1,98E+01	1,64E+01	1,19E+01	3,65E+01	1,29E+01	9,39E+00	6,49E+01	4,97E+01	4,45E+01	1,77E+01	8,97E+00
tractor + sowing combi	h	7,37E+01	8,01E+01	3,99E+01	0,00E+00	3,58E+01	4,41E+01	3,64E+01	2,64E+01	8,10E+01	2,87E+01	2,09E+01	1,44E+02	1,10E+02	9,88E+01	3,92E+01	1,99E+01
		Cross-section															
Equipment/Material	**Units**	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
grass seeds (D1 150 kg/ha)	kg	1,83E+02	9,88E+01	1,23E+01	5,91E+01	9,24E+01	8,82E+01	6,41E+01	1,83E+02	1,99E+02	1,54E+02	8,88E+01	2,39E+02	2,44E+02	7,50E+01	2,31E+02	1,96E+01
Transport truck bulk	tkm	1,38E+01	7,41E+00	9,26E-01	4,43E+00	6,93E+00	6,61E+00	4,81E+00	1,37E+01	1,49E+01	1,16E+01	6,66E+00	1,79E+01	1,83E+01	5,63E+00	1,73E+01	1,47E+00
tractor + sowing combi	h	3,06E+01	1,65E+01	2,06E+00	9,86E+00	1,54E+01	1,47E+01	1,07E+01	3,05E+01	3,31E+01	2,57E+01	1,48E+01	3,98E+01	4,06E+01	1,25E+01	3,85E+01	3,27E+00
		Cross-section															
Equipment/Material	**Units**	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**no data**	**4570**	**4600**	**4610**	**4630**
grass seeds (D1 150 kg/ha)	kg	3,09E+01	4,23E+01	2,34E+02	1,92E+02	3,44E+02	2,17E+01	1,03E+01	0,00E+00	2,05E+01	4,70E+01	8,87E+01	0,00E+00	8,89E+01	2,34E+01	7,24E+01	1,25E+02
Transport truck bulk	tkm	2,32E+00	3,17E+00	1,76E+01	1,44E+01	2,58E+01	1,62E+00	7,76E-01	0,00E+00	1,54E+00	3,53E+00	6,66E+00	0,00E+00	6,67E+00	1,75E+00	5,43E+00	9,41E+00
tractor + sowing combi	h	5,15E+00	7,05E+00	3,90E+01	3,19E+01	5,74E+01	3,61E+00	1,72E+00	0,00E+00	3,42E+00	7,84E+00	1,48E+01	0,00E+00	1,48E+01	3,90E+00	1,21E+01	2,09E+01

Table 47: Results of the kg CO_2-eq calculation for the sowing process per cross-section

	Cross-section															
Equipment/Material	**1810**	**1980**	**2120**	**no data**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
grass seeds (D1 150 kg/ha)	1,29E+03	1,40E+03	6,98E+02	0,00E+00	6,25E+02	7,71E+02	6,37E+02	4,61E+02	1,42E+03	5,02E+02	3,65E+02	2,52E+03	1,93E+03	1,73E+03	6,86E+02	3,48E+02
Transport truck bulk	8,84E+00	9,61E+00	4,79E+00	0,00E+00	4,29E+00	5,29E+00	4,37E+00	3,16E+00	9,72E+00	3,44E+00	2,50E+00	1,73E+01	1,32E+01	1,18E+01	4,70E+00	2,39E+00
tractor + sowing combi	2,54E+03	2,76E+03	1,37E+03	0,00E+00	1,23E+03	1,52E+03	1,25E+03	9,07E+02	2,79E+03	9,87E+02	7,18E+02	4,96E+03	3,80E+03	3,40E+03	1,35E+03	6,86E+02
	Cross-section															
Equipment/Material	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
grass seeds (D1 150 kg/ha)	5,34E+02	2,88E+02	3,60E+01	1,72E+02	2,69E+02	2,57E+02	1,87E+02	5,33E+02	5,79E+02	4,49E+02	2,59E+02	6,96E+02	7,10E+02	2,19E+02	6,73E+02	5,72E+01
Transport truck bulk	3,67E+00	1,97E+00	2,47E-01	1,18E+00	1,85E+00	1,76E+00	1,28E+00	3,66E+00	3,97E+00	3,08E+00	1,77E+00	4,77E+00	4,87E+00	1,50E+00	4,62E+00	3,92E-01
tractor + sowing combi	1,05E+03	5,66E+02	7,08E+01	3,39E+02	5,30E+02	5,05E+02	3,68E+02	1,05E+03	1,14E+03	8,84E+02	5,09E+02	1,37E+03	1,40E+03	4,30E+02	1,32E+03	1,12E+02
	Cross-section															
Equipment/Material	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**no data**	**4570**	**4600**	**4610**	**4630**
grass seeds (D1 150 kg/ha)	9,00E+01	1,23E+02	6,82E+02	5,58E+02	1,00E+03	6,31E+01	3,01E+01	0,00E+00	5,98E+01	1,37E+02	2,59E+02	0,00E+00	2,59E+02	6,82E+01	2,11E+02	3,65E+02
Transport truck bulk	6,17E-01	8,45E-01	4,68E+00	3,83E+00	6,88E+00	4,33E-01	2,07E-01	0,00E+00	4,10E-01	9,40E-01	1,77E+00	0,00E+00	1,78E+00	4,68E-01	1,45E+00	2,51E+00
tractor + sowing combi	1,77E+02	2,43E+02	1,34E+03	1,10E+03	1,97E+03	1,24E+02	5,93E+01	0,00E+00	1,18E+02	2,70E+02	5,09E+02	0,00E+00	5,10E+02	1,34E+02	4,15E+02	7,19E+02

Table 48: Results of the MKI calculation for the sowing process per cross-section

	Cross-section															
Equipment/Material	**1810**	**1980**	**2120**	**no data**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
grass seeds (D1 150 kg/ha)	€ 114	€ 124	€ 62	€ 0	€ 55	€ 68	€ 56	€ 41	€ 126	€ 45	€ 32	€ 224	€ 171	€ 153	€ 61	€ 31
Transport truck bulk	€ 1	€ 1	€ 1	€ 0	€ 1	€ 1	€ 1	€ 0	€ 1	€ 1	€ 0	€ 3	€ 2	€ 2	€ 1	€ 0
tractor + sowing combi	€ 235	€ 256	€ 127	€ 0	€ 114	€ 141	€ 116	€ 84	€ 258	€ 92	€ 67	€ 460	€ 352	€ 315	€ 125	€ 64
	Cross-section															
Equipment/Material	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
grass seeds (D1 150 kg/ha)	€ 47	€ 26	€ 3	€ 15	€ 24	€ 23	€ 17	€ 47	€ 51	€ 40	€ 23	€ 62	€ 63	€ 19	€ 60	€ 5
Transport truck bulk	€ 1	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 1	€ 1	€ 0	€ 0	€ 1	€ 1	€ 0	€ 1	€ 0
tractor + sowing combi	€ 98	€ 53	€ 7	€ 31	€ 49	€ 47	€ 34	€ 97	€ 106	€ 82	€ 47	€ 127	€ 130	€ 40	€ 123	€ 10
	Cross-section															
Equipment/Material	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**no data**	**4570**	**4600**	**4610**	**4630**
grass seeds (D1 150 kg/ha)	€ 8	€ 11	€ 61	€ 50	€ 89	€ 6	€ 3	€ 0	€ 5	€ 12	€ 23	€ 0	€ 23	€ 6	€ 19	€ 32
Transport truck bulk	€ 0	€ 0	€ 1	€ 1	€ 1	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
tractor + sowing combi	€ 16	€ 22	€ 125	€ 102	€ 183	€ 12	€ 5	€ 0	€ 11	€ 25	€ 47	€ 0	€ 47	€ 12	€ 39	€ 67

F. Calculation of the CO_2-eq and MKI for the placement of erosion screens

Table 49: Summary of specifications for placement of the erosion screens

Activity	Equipment/Material	Distance (km)	Capacity	Capacity unit	Source	kg CO2-eq	/	unit	Source	MKI euro	/	unit
Placement of erosion screens												
Sheet pile	AZ 17-700 unanchored		0,104	t/m2	https://www.stalen-damwand.nl/knowledge/	908	/	t	DuboCalc - Staal GWW (gemiddeld)	67,53	/	t
Pile driving	Vibratory hammer		12	m2/h	DuboCalc - Heiblok tril elektr. (gemiddeld, per vermogen)	0,66711	/	h	DuboCalc - Heiblok tril elektr. (gemiddeld, per vermogen)	0,05	/	h
	Dragline		12	m2/h	DuboCalc - Dragline	79,74994	/	h	DuboCalc - Dragline	6,25	/	h
Transport	Transport truck steel	50	1	tkm	DuboCalc - Transport staal	0,266456	/	tkm	DuboCalc - Transport staal	0,0404	/	tkm
Placement of concrete cover gap												
Concrete	Concrete type C20/25 (CEMIII)		2,44	t/m3	DuboCalc - Betonmortel C20/25 (CEMIII)	56,69921	/	t	DuboCalc - Betonmortel C20/25 (CEMIII)	5,37	/	t
Reinforcement	Steel B500 reinforcement		0,05635	t/m3	DuboCalc - Betonstaal (gemiddeld)	908	/	t	DuboCalc - Betonstaal (gemiddeld)	68,88	/	t
Formwork	Wood formwork		1,5	m2/m	DuboCalc - Trad.bekisting werk (gemiddeld, per type)	1,52917	/	m2	DuboCalc - Trad.bekisting werk (gemiddeld,	0,26	/	m2
Applying	Hydraulic tele crane		2,7	t/h	DuboCalc - Kraan hydr.tele. Band (gemiddeld)	79,74994	/	h	DuboCalc - Kraan hydr.tele. Band (gemiddel	6,25	/	h
	Concrete pump + truck		105,042	m3/h	DuboCalc - Betonpomp incl. voertuig	6,167986	/	h	DuboCalc - Betonpomp incl. voertuig	0,48	/	h
Compacting	Poker vibrator		2,5	m3/h	DuboCalc - Verdichten beton (trilnaad)	0,096717	/	h	DuboCalc - Verdichten beton (trilnaad)	0,01	/	h
Transport	Transport truck bulk - concrete	20	1	tkm	DuboCalc - Transport bulk (over de weg)	0,266456	/	tkm	DuboCalc - Transport bulk (over de weg)	0,0404	/	tkm
	Transport truck bulk - steel	50	1	tkm	DuboCalc - Transport staal	0,266456	/	tkm	DuboCalc - Transport staal	0,0404	/	tkm
	Transport truck bulk - formwork	25	0,0104	tkm/m2	DuboCalc - Transport hout	0,266456	/	tkm	DuboCalc - Transport hout	0,0404	/	tkm

Table 50: Results for placement of the erosion screens per unit

Sub-section		**1.1**	**5.1**	**5.2**	**6**	**7.2**	**11.2**		**13.1**		**13.2**		**13.3**	**14.1**		**14.2**	**15.1**	15.3
Cross-section	**Units**	**1810**	**2430**	**2500**	**2660**	**2850**	**3700**	**3780**	**4100**	**4130**	**4180**	**4190**	**4290**	**4400**	**4470**	**4500**	**4570**	4630
Amount of locations	-	2	1	1	2	1	2	3	1	1	2	2	3	1	2	3	2	2
Erosion screen length	m	100	50	50	100	50	100	150	50	50	100	100	150	50	100	150	100	100
Erosion screen surface	m2	1500	750	750	1500	750	1500	2250	750	750	1500	1500	2250	750	1500	2250	1500	1500
Concrete volume	m3	25	12,5	12,5	25	12,5	25	37,5	12,5	12,5	25	25	37,5	12,5	25	37,5	25	25
Equipment/Material erosion screens																		
AZ 17-700 unanchored	t	1,56E+02	7,80E+01	7,80E+01	1,56E+02	7,80E+01	1,56E+02	2,34E+02	7,80E+01	7,80E+01	1,56E+02	1,56E+02	2,34E+02	7,80E+01	1,56E+02	2,34E+02	1,56E+02	1,56E+02
Vibratory hammer	h	1,25E+02	6,25E+01	6,25E+01	1,25E+02	6,25E+01	1,25E+02	1,88E+02	6,25E+01	6,25E+01	1,25E+02	1,25E+02	1,88E+02	6,25E+01	1,25E+02	1,88E+02	1,25E+02	1,25E+02
Dragline	h	1,25E+02	6,25E+01	6,25E+01	1,25E+02	6,25E+01	1,25E+02	1,88E+02	6,25E+01	6,25E+01	1,25E+02	1,25E+02	1,88E+02	6,25E+01	1,25E+02	1,88E+02	1,25E+02	1,25E+02
Transport truck steel	tkm	7,80E+03	3,90E+03	3,90E+03	7,80E+03	3,90E+03	7,80E+03	1,17E+04	3,90E+03	3,90E+03	7,80E+03	7,80E+03	1,17E+04	3,90E+03	7,80E+03	1,17E+04	7,80E+03	7,80E+03
Equipment/Material cover gap																		
Concrete type C20/25 (CEMIII)	t	6,10E+01	3,05E+01	3,05E+01	6,10E+01	3,05E+01	6,10E+01	9,15E+01	3,05E+01	3,05E+01	6,10E+01	6,10E+01	9,15E+01	3,05E+01	6,10E+01	9,15E+01	6,10E+01	6,10E+01
Steel B500 reinforcement	t	1,41E+00	7,04E-01	7,04E-01	1,41E+00	7,04E-01	1,41E+00	2,11E+00	7,04E-01	7,04E-01	1,41E+00	1,41E+00	2,11E+00	7,04E-01	1,41E+00	2,11E+00	1,41E+00	1,41E+00
Wood formwork	m2	1,50E+02	7,50E+01	7,50E+01	1,50E+02	7,50E+01	1,50E+02	2,25E+02	7,50E+01	7,50E+01	1,50E+02	1,50E+02	2,25E+02	7,50E+01	1,50E+02	2,25E+02	1,50E+02	1,50E+02
Hydraulic tele crane	h	5,22E-01	2,61E-01	2,61E-01	5,22E-01	2,61E-01	5,22E-01	7,83E-01	2,61E-01	2,61E-01	5,22E-01	5,22E-01	7,83E-01	2,61E-01	5,22E-01	7,83E-01	5,22E-01	5,22E-01
Concrete pump + truck	h	2,38E-01	1,19E-01	1,19E-01	2,38E-01	1,19E-01	2,38E-01	3,57E-01	1,19E-01	1,19E-01	2,38E-01	2,38E-01	3,57E-01	1,19E-01	2,38E-01	3,57E-01	2,38E-01	2,38E-01
Poker vibrator	h	1,00E+01	5,00E+00	5,00E+00	1,00E+01	5,00E+00	1,00E+01	1,50E+01	5,00E+00	5,00E+00	1,00E+01	1,00E+01	1,50E+01	5,00E+00	1,00E+01	1,50E+01	1,00E+01	1,00E+01
Transport truck bulk - concrete	tkm	1,22E+03	6,10E+02	6,10E+02	1,22E+03	6,10E+02	1,22E+03	1,83E+03	6,10E+02	6,10E+02	1,22E+03	1,22E+03	1,83E+03	6,10E+02	1,22E+03	1,83E+03	1,22E+03	1,22E+03
Transport truck bulk - steel	tkm	7,04E+01	3,52E+01	3,52E+01	7,04E+01	3,52E+01	7,04E+01	1,06E+02	3,52E+01	3,52E+01	7,04E+01	7,04E+01	1,06E+02	3,52E+01	7,04E+01	1,06E+02	7,04E+01	7,04E+01
Transport truck bulk - formwork	tkm	3,90E+01	1,95E+01	1,95E+01	3,90E+01	1,95E+01	3,90E+01	5,85E+01	1,95E+01	1,95E+01	3,90E+01	3,90E+01	5,85E+01	1,95E+01	3,90E+01	5,85E+01	3,90E+01	3,90E+01

Table 51: Results of the kg CO_2-eq calculation for placing erosion screens per cross-section

								Cross-section									
Equipment/Material erosion screens	**1810**	**2430**	**2500**	**2660**	**2850**	**3700**	**3780**	**4100**	**4130**	**4180**	**4190**	**4290**	**4400**	**4470**	**4500**	**4570**	4630
AZ 17-700 unanchored	1,42E+05	7,08E+04	7,08E+04	1,42E+05	7,08E+04	1,42E+05	2,12E+05	7,08E+04	7,08E+04	1,42E+05	1,42E+05	2,12E+05	7,08E+04	1,42E+05	2,12E+05	1,42E+05	1,42E+05
Vibratory hammer	8,34E+01	4,17E+01	4,17E+01	8,34E+01	4,17E+01	8,34E+01	1,25E+02	4,17E+01	4,17E+01	8,34E+01	8,34E+01	1,25E+02	4,17E+01	8,34E+01	1,25E+02	8,34E+01	8,34E+01
Dragline	9,97E+03	4,98E+03	4,98E+03	9,97E+03	4,98E+03	9,97E+03	1,50E+04	4,98E+03	4,98E+03	9,97E+03	9,97E+03	1,50E+04	4,98E+03	9,97E+03	1,50E+04	9,97E+03	9,97E+03
Transport truck steel	2,08E+03	1,04E+03	1,04E+03	2,08E+03	1,04E+03	2,08E+03	3,12E+03	1,04E+03	1,04E+03	2,08E+03	2,08E+03	3,12E+03	1,04E+03	2,08E+03	3,12E+03	2,08E+03	2,08E+03
Equipment/Material cover gap																	
Concrete type C20/25 (CEMIII)	3,46E+03	1,73E+03	1,73E+03	3,46E+03	1,73E+03	3,46E+03	5,19E+03	1,73E+03	1,73E+03	3,46E+03	3,46E+03	5,19E+03	1,73E+03	3,46E+03	5,19E+03	3,46E+03	3,46E+03
Steel B500 reinforcement	1,28E+03	6,40E+02	6,40E+02	1,28E+03	6,40E+02	1,28E+03	1,92E+03	6,40E+02	6,40E+02	1,28E+03	1,28E+03	1,92E+03	6,40E+02	1,28E+03	1,92E+03	1,28E+03	1,28E+03
Wood formwork	2,29E+02	1,15E+02	1,15E+02	2,29E+02	1,15E+02	2,29E+02	3,44E+02	1,15E+02	1,15E+02	2,29E+02	2,29E+02	3,44E+02	1,15E+02	2,29E+02	3,44E+02	2,29E+02	2,29E+02
Hydraulic tele crane	4,16E+01	2,08E+01	2,08E+01	4,16E+01	2,08E+01	4,16E+01	6,24E+01	2,08E+01	2,08E+01	4,16E+01	4,16E+01	6,24E+01	2,08E+01	4,16E+01	6,24E+01	4,16E+01	4,16E+01
Concrete pump + truck	1,47E+00	7,34E-01	7,34E-01	1,47E+00	7,34E-01	1,47E+00	2,20E+00	7,34E-01	7,34E-01	1,47E+00	1,47E+00	2,20E+00	7,34E-01	1,47E+00	2,20E+00	1,47E+00	1,47E+00
Poker vibrator	9,67E-01	4,84E-01	4,84E-01	9,67E-01	4,84E-01	9,67E-01	1,45E+00	4,84E-01	4,84E-01	9,67E-01	9,67E-01	1,45E+00	4,84E-01	9,67E-01	1,45E+00	9,67E-01	9,67E-01
Transport truck bulk - concrete	3,25E+02	1,63E+02	1,63E+02	3,25E+02	1,63E+02	3,25E+02	4,88E+02	1,63E+02	1,63E+02	3,25E+02	3,25E+02	4,88E+02	1,63E+02	3,25E+02	4,88E+02	3,25E+02	3,25E+02
Transport truck bulk - steel	1,88E+01	9,38E+00	9,38E+00	1,88E+01	9,38E+00	1,88E+01	2,82E+01	9,38E+00	9,38E+00	1,88E+01	1,88E+01	2,82E+01	9,38E+00	1,88E+01	2,82E+01	1,88E+01	1,88E+01
Transport truck bulk - formwork	1,04E+01	5,20E+00	5,20E+00	1,04E+01	5,20E+00	1,04E+01	1,56E+01	5,20E+00	5,20E+00	1,04E+01	1,04E+01	1,56E+01	5,20E+00	1,04E+01	1,56E+01	1,04E+01	1,04E+01

Table 52: Results of the MKI calculation for placing the erosion screens per cross-section

	Cross-section																
Equipment/Material erosion screens	**1810**	**2430**	**2500**	**2660**	**2850**	**3700**	**3780**	**4100**	**4130**	**4180**	**4190**	**4290**	**4400**	**4470**	**4500**	**4570**	4630
AZ 17-700 unanchored	€ 10.535	€ 5.267	€ 5.267	€ 10.535	€ 5.267	€ 10.535	€ 15.802	€ 5.267	€ 5.267	€ 10.535	€ 10.535	€ 15.802	€ 5.267	€ 10.535	€ 15.802	€ 10.535	€ 10.535
Vibratory hammer	€ 6	€ 3	€ 3	€ 6	€ 3	€ 6	€ 9	€ 3	€ 3	€ 6	€ 6	€ 9	€ 3	€ 6	€ 9	€ 6	€ 6
Dragline	€ 781	€ 391	€ 391	€ 781	€ 391	€ 781	€ 1.172	€ 391	€ 391	€ 781	€ 781	€ 1.172	€ 391	€ 781	€ 1.172	€ 781	€ 781
Transport truck steel	€ 315	€ 158	€ 158	€ 315	€ 158	€ 315	€ 473	€ 158	€ 158	€ 315	€ 315	€ 473	€ 158	€ 315	€ 473	€ 315	€ 315
Equipment/Material cover gap																	
Concrete type C20/25 (CEMIII)	€ 328	€ 164	€ 164	€ 328	€ 164	€ 328	€ 491	€ 164	€ 164	€ 328	€ 328	€ 491	€ 164	€ 328	€ 491	€ 328	€ 328
Steel B500 reinforcement	€ 97	€ 49	€ 49	€ 97	€ 49	€ 97	€ 146	€ 49	€ 49	€ 97	€ 97	€ 146	€ 49	€ 97	€ 146	€ 97	€ 97
Wood formwork	€ 39	€ 20	€ 20	€ 39	€ 20	€ 39	€ 59	€ 20	€ 20	€ 39	€ 39	€ 59	€ 20	€ 39	€ 59	€ 39	€ 39
Hydraulic tele crane	€ 3	€ 2	€ 2	€ 3	€ 2	€ 3	€ 5	€ 2	€ 2	€ 3	€ 3	€ 5	€ 2	€ 3	€ 5	€ 3	€ 3
Concrete pump + truck	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
Poker vibrator	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0	€ 0
Transport truck bulk - concrete	€ 49	€ 25	€ 25	€ 49	€ 25	€ 49	€ 74	€ 25	€ 25	€ 49	€ 49	€ 74	€ 25	€ 49	€ 74	€ 49	€ 49
Transport truck bulk - steel	€ 3	€ 1	€ 1	€ 3	€ 1	€ 3	€ 4	€ 1	€ 1	€ 3	€ 3	€ 4	€ 1	€ 3	€ 4	€ 3	€ 3
Transport truck bulk - formwork	€ 2	€ 1	€ 1	€ 2	€ 1	€ 2	€ 2	€ 1	€ 1	€ 2	€ 2	€ 2	€ 1	€ 2	€ 2	€ 2	€ 2

G. Calculation of the CO_2-eq and MKI for the repairs of the provincial road

Table 53: Summary of specifications for repairing the provincial road

Activity	Equipment/Material	Distance (km)	Capacity	Capacity unit	Source	kg CO2-eq	/	unit	Source	MKI euro	/	unit
Removal top layer												
Milling	Cold milling machine		28	t/h	DuboCalc - Koudfrees (gemiddeld, per type)	91,9525404	/	h	DuboCalc - Koudfrees (gemiddeld, per type)	16,24	/	h
Cleaning	Sweep-suction car		40	t/h	DuboCalc - Vr.auto reiniging - veeg zuig 6-8m3	74,18489	/	h	DuboCalc - Vr.auto reiniging - veeg zuig 6-8m3	13,02	/	h
Transport	Transport truck bulk	30	1	tkm	DuboCalc - Transport bulk (over de weg)	0,26645608	/	tkm	DuboCalc - Transport bulk (over de weg)	0,0404	/	tkm
Apply adhesive layer												
Adhesive material	Bitumen emulsion sublayer		0,0003	t/m2	DuboCalc - Bitumen emulsie tussenlaag	277,31822	/	t	DuboCalc - Bitumen emulsie tussenlaag	40,81	/	t
Spraying	Spraying car		0,001333	h/m2	DuboCalc - Sproeiwagen (gemiddeld)	9,9177661	/	h	DuboCalc - Sproeiwagen (gemiddeld)	1,74	/	h
Transport	Transport truck bulk	50	0,0003	tkm/m2	DuboCalc - Transport bulk (over de weg)	0,26645608	/	tkm	DuboCalc - Transport bulk (over de weg)	0,0404	/	tkm
Apply top asphalt layer												
Asphalt	Asphalt SMA 0/11		1	t	DuboCalc - SMA 0/11, gemiddeld	80,893222	/	t	DuboCalc - SMA 0/11, gemiddeld	9,14	/	t
Applying	Asphalt truck		0,0133	h/t	DuboCalc - Asfaltauto 25 t: 240 kW: 8x4	74,184891	/	h	DuboCalc - Asfaltauto 25 t: 240 kW: 8x4	13,02	/	h
	Roller		0,0133	h/t	DuboCalc - Wals (gemiddeld)	49,49952	/	h	DuboCalc - Wals (gemiddeld)	8,68	/	h
	Paver		0,0133	h/t	DuboCalc - Afwerkmachine asfalt (gemiddeld, per type)	46,142928	/	h	DuboCalc - Afwerkmachine asfalt (gemiddeld, per type)	8,09	/	h
Transport	Transport truck bulk	30	1	tkm	DuboCalc - Asfalt (SMA 0/11)	0,26645608	/	tkm	DuboCalc - Asfalt (SMA 0/11)	0,0404	/	tkm
Apply road markings												
Marking material	Thermoplastic marking		0,002	t/m	DuboCalc - Thermoplastische markering	2566,759	/	t	DuboCalc - Thermoplastische markering	270,32	/	t
Applying	Marking machine		0,0014286	h/m	DuboCalc - Mark. Strepentrekmachine	56,292628	/	h	DuboCalc - Mark. Strepentrekmachine	6,07	/	h
Transport	Transport truck bulk	50	0,002	tkm/m	DuboCalc - Transport bulk (over de weg)	0,26645608	/	tkm	DuboCalc - Transport bulk (over de weg)	0,0404	/	tkm

Table 54: Results for calculation of the provincial road per cross-section

Cross-section		**1810**	**1980**	**2120**	**2310**	**2660**	**2790**	**2850**	**3070**
Length	m	1500	1100	1200	1400	1400	700	500	2700
Surface	m2	5625	4125	4500	5250	5250	2625	1875	10125
Asphalt volume	m3	225	165	180	210	210	105	75	405
Tons Asphalt	t	562,5	412,5	450	525	525	262,5	187,5	1012,5
Equipment/Material erosion screens									
Removal top layer									
Cold milling machine	h	2,01E+01	1,47E+01	1,61E+01	1,88E+01	1,88E+01	9,37E+00	6,70E+00	3,62E+01
Sweep-suction car	h	1,41E+01	1,03E+01	1,13E+01	1,31E+01	1,31E+01	6,56E+00	4,69E+00	2,53E+01
Transport truck bulk	tkm	1,69E+04	1,24E+04	1,35E+04	1,58E+04	1,58E+04	7,87E+03	5,63E+03	3,04E+04
Apply adhesive layer									
Bitumen emulsion sublayer	t	1,69E+00	1,24E+00	1,35E+00	1,58E+00	1,58E+00	7,87E-01	5,63E-01	3,04E+00
Spraying car	h	7,50E+00	5,50E+00	6,00E+00	7,00E+00	7,00E+00	3,50E+00	2,50E+00	1,35E+01
Transport truck bulk	tkm	8,44E+01	6,19E+01	6,75E+01	7,87E+01	7,87E+01	3,94E+01	2,81E+01	1,52E+02
Apply top asphalt layer									
Asphalt SMA 0/11	t	5,63E+02	4,12E+02	4,50E+02	5,25E+02	5,25E+02	2,63E+02	1,88E+02	1,01E+03
Asphalt truck	h	7,48E+00	5,49E+00	5,99E+00	6,98E+00	6,98E+00	3,49E+00	2,49E+00	1,35E+01
Roller	h	7,48E+00	5,49E+00	5,99E+00	6,98E+00	6,98E+00	3,49E+00	2,49E+00	1,35E+01
Paver	h	7,48E+00	5,49E+00	5,99E+00	6,98E+00	6,98E+00	3,49E+00	2,49E+00	1,35E+01
Transport truck bulk	tkm	1,69E+04	1,24E+04	1,35E+04	1,58E+04	1,58E+04	7,87E+03	5,63E+03	3,04E+04
Apply road markings									
Thermoplastic marking	t	4,50E+00	3,30E+00	3,60E+00	4,20E+00	4,20E+00	2,10E+00	1,50E+00	8,10E+00
Marking machine	h	3,21E+00	2,36E+00	2,57E+00	3,00E+00	3,00E+00	1,50E+00	1,07E+00	5,79E+00
Transport truck bulk	tkm	2,25E+02	1,65E+02	1,80E+02	2,10E+02	2,10E+02	1,05E+02	7,50E+01	4,05E+02

Table 55: Results of the kg CO2-eq calculation for repairing of the provincial road per cross-section

	Cross-section							
Equipment/Material erosion screens	**1810**	**1980**	**2120**	**2310**	**2660**	**2790**	**2850**	**3070**
Removal top layer								
Cold milling machine	1,85E+03	1,35E+03	1,48E+03	1,72E+03	1,72E+03	8,62E+02	6,16E+02	3,33E+03
Sweep-suction car	1,04E+03	7,65E+02	8,35E+02	9,74E+02	9,74E+02	4,87E+02	3,48E+02	1,88E+03
Transport truck bulk	4,50E+03	3,30E+03	3,60E+03	4,20E+03	4,20E+03	2,10E+03	1,50E+03	8,09E+03
Apply adhesive layer								
Bitumen emulsion sublayer	4,68E+02	3,43E+02	3,74E+02	4,37E+02	4,37E+02	2,18E+02	1,56E+02	8,42E+02
Spraying car	7,44E+01	5,45E+01	5,95E+01	6,94E+01	6,94E+01	3,47E+01	2,48E+01	1,34E+02
Transport truck bulk	2,25E+01	1,65E+01	1,80E+01	2,10E+01	2,10E+01	1,05E+01	7,49E+00	4,05E+01
Apply top asphalt layer								
Asphalt SMA 0/11	4,55E+04	3,34E+04	3,64E+04	4,25E+04	4,25E+04	2,12E+04	1,52E+04	8,19E+04
Asphalt truck	5,55E+02	4,07E+02	4,44E+02	5,18E+02	5,18E+02	2,59E+02	1,85E+02	9,99E+02
Roller	3,70E+02	2,72E+02	2,96E+02	3,46E+02	3,46E+02	1,73E+02	1,23E+02	6,67E+02
Paver	3,45E+02	2,53E+02	2,76E+02	3,22E+02	3,22E+02	1,61E+02	1,15E+02	6,21E+02
Transport truck bulk	4,50E+03	3,30E+03	3,60E+03	4,20E+03	4,20E+03	2,10E+03	1,50E+03	8,09E+03
Apply road markings								
Thermoplastic marking	1,16E+04	8,47E+03	9,24E+03	1,08E+04	1,08E+04	5,39E+03	3,85E+03	2,08E+04
Marking machine	1,81E+02	1,33E+02	1,45E+02	1,69E+02	1,69E+02	8,44E+01	6,03E+01	3,26E+02
Transport truck bulk	6,00E+01	4,40E+01	4,80E+01	5,60E+01	5,60E+01	2,80E+01	2,00E+01	1,08E+02

Table 56: Results of the MKI calculation for repairing of the provincial road per cross-section

	Cross-section							
Equipment/Material erosion screens	**1810**	**1980**	**2120**	**2310**	**2660**	**2790**	**2850**	**3070**
Removal top layer								
Cold milling machine	€ 326	€ 239	€ 261	€ 305	€ 305	€ 152	€ 109	€ 587
Sweep-suction car	€ 183	€ 134	€ 146	€ 171	€ 171	€ 85	€ 61	€ 330
Transport truck bulk	€ 682	€ 500	€ 545	€ 636	€ 636	€ 318	€ 227	€ 1.227
Apply adhesive layer								
Bitumen emulsion sublayer	€ 69	€ 51	€ 55	€ 64	€ 64	€ 32	€ 23	€ 124
Spraying car	€ 13	€ 10	€ 10	€ 12	€ 12	€ 6	€ 4	€ 23
Transport truck bulk	€ 3	€ 2	€ 3	€ 3	€ 3	€ 2	€ 1	€ 6
Apply top asphalt layer								
Asphalt SMA 0/11	€ 5.141	€ 3.770	€ 4.113	€ 4.799	€ 4.799	€ 2.399	€ 1.714	€ 9.254
Asphalt truck	€ 97	€ 71	€ 78	€ 91	€ 91	€ 45	€ 32	€ 175
Roller	€ 65	€ 48	€ 52	€ 61	€ 61	€ 30	€ 22	€ 117
Paver	€ 61	€ 44	€ 48	€ 56	€ 56	€ 28	€ 20	€ 109
Transport truck bulk	€ 682	€ 500	€ 545	€ 636	€ 636	€ 318	€ 227	€ 1.227
Apply road markings								
Thermoplastic marking	€ 1.216	€ 892	€ 973	€ 1.135	€ 1.135	€ 568	€ 405	€ 2.190
Marking machine	€ 20	€ 14	€ 16	€ 18	€ 18	€ 9	€ 7	€ 35
Transport truck bulk	€ 9	€ 7	€ 7	€ 8	€ 8	€ 4	€ 3	€ 16

H. Calculation of the CO_2-eq and MKI for the reconstruction of a cycling path

Table 57: Summary of specifications for reconstruction of the cycling paths

Activity	Equipment/Material	Distance (km)	Capacity	Capacity unit	Source	kg CO2-eq / unit	Source	MKI euro / unit
Removal old cycling path								
Removal slabs	Wheel loader		40	m2/h	DuboCalc - Prefab betonplaten	43,493578 / h	DuboCalc - Wiellaadschop	7,63 / h
Transport slabs	Transport truck bulk	50	0,35	m2/tkm	DuboCalc - Prefab betonplaten	0,26645608 / tonkm	DuboCalc - Transport bulk (over de weg)	0,0404 / tonkm
Placement of a 30 cm sand layer								
Sand	Sand		0,3	m3/m2	DuboCalc - Landzand (ophoogzand)	4,62 / m3	DuboCalc - Landzand (ophoogzand)	0,41 / m3
Placement	Wheel loader		100	m3/h	DuboCalc - Wiellaadschop	43,493578 / h	DuboCalc - Wiellaadschop	7,63 / h
	Roller		100	m3/h	DuboCalc - Wals (gemiddeld)	49,49952 / h	DuboCalc - Wals (gemiddeld)	8,68 / h
Transport	Transport truck bulk	75	0,588	m3/tonkm	DuboCalc - Transport bulk (over de weg)	0,26645608 / tonkm	DuboCalc - Transport bulk (over de weg)	0,0404 / tonkm
Placement of prefab concrete slabs								
Concrete slabs	Concrete mortar C55/67		0,35	t/m2	DuboCalc - Prefab betonplaten	85,053773 / t	DuboCalc - Betonmortel C55/67	7,62 / t
Placement	Wheel loader		24	m2/h	DuboCalc - Prefab betonplaten	43,493578 / h	DuboCalc - Wiellaadschop	7,63 / h
Transport	Transport truck bulk	50	0,35	m2/tkm	DuboCalc - Prefab betonplaten	0,26645608 / tonkm	DuboCalc - Transport bulk (over de weg)	0,0404 / tonkm

Table 58: Results for calculation of the cycling path per cross-section

Cross-section		3170	3380	3950	4010	4250	4290	4330
Length	m	1600	1750	350	500	600	400	850
Surface	m2	3200	3500	700	1000	1200	800	1700
Equipment/Material erosion screens								
Removal of old cycling path								
Wheel loader	h	8,00E+01	8,75E+01	1,75E+01	2,50E+01	3,00E+01	2,00E+01	4,25E+01
Transport truck bulk	tkm	5,60E+04	6,13E+04	1,23E+04	1,75E+04	2,10E+04	1,40E+04	2,98E+04
Placement of a 30 cm sand layer								
Sand	m3	9,60E+02	1,05E+03	2,10E+02	3,00E+02	3,60E+02	2,40E+02	5,10E+02
Wheel loader	h	9,60E+00	1,05E+01	2,10E+00	3,00E+00	3,60E+00	2,40E+00	5,10E+00
Roller	h	9,60E+00	1,05E+01	2,10E+00	3,00E+00	3,60E+00	2,40E+00	5,10E+00
Transport truck bulk	tkm	1,22E+05	1,34E+05	2,68E+04	3,83E+04	4,59E+04	3,06E+04	6,51E+04
Placement of prefab concrete slabs								
Concrete mortar C55/67	t	1,12E+03	1,23E+03	2,45E+02	3,50E+02	4,20E+02	2,80E+02	5,95E+02
Wheel loader	h	1,33E+02	1,46E+02	2,92E+01	4,17E+01	5,00E+01	3,33E+01	7,08E+01
Transport truck bulk	tkm	5,60E+04	6,13E+04	1,23E+04	1,75E+04	2,10E+04	1,40E+04	2,98E+04

Table 59: Results of the kg CO2-eq calculation for reconstruction of the cycling path per cross-section

	Cross-section						
Equipment/Material erosion screens	**3170**	**3380**	**3950**	**4010**	**4250**	**4290**	**4330**
Removal of old cycling path							
Wheel loader	3,48E+03	3,81E+03	7,61E+02	1,09E+03	1,30E+03	8,70E+02	1,85E+03
Transport truck bulk	1,49E+04	1,63E+04	3,26E+03	4,66E+03	5,60E+03	3,73E+03	7,93E+03
Placement of a 30 cm sand layer							
Sand	4,44E+03	4,85E+03	9,70E+02	1,39E+03	1,66E+03	1,11E+03	2,36E+03
Wheel loader	4,18E+02	4,57E+02	9,13E+01	1,30E+02	1,57E+02	1,04E+02	2,22E+02
Roller	4,75E+02	5,20E+02	1,04E+02	1,48E+02	1,78E+02	1,19E+02	2,52E+02
Transport truck bulk	3,26E+04	3,57E+04	7,14E+03	1,02E+04	1,22E+04	8,16E+03	1,73E+04
Placement of prefab concrete slabs							
Concrete mortar C55/67	9,53E+04	1,04E+05	2,08E+04	2,98E+04	3,57E+04	2,38E+04	5,06E+04
Wheel loader	5,80E+03	6,34E+03	1,27E+03	1,81E+03	2,17E+03	1,45E+03	3,08E+03
Transport truck bulk	1,49E+04	1,63E+04	3,26E+03	4,66E+03	5,60E+03	3,73E+03	7,93E+03

Table 60: Results of the MKI calculation for reconstruction of the cycling paths per cross-section

	Cross-section						
Equipment/Material erosion screens	**3170**	**3380**	**3950**	**4010**	**4250**	**4290**	**4330**
Removal of old cycling path							
Wheel loader	€ 610	€ 668	€ 134	€ 191	€ 229	€ 153	€ 324
Transport truck bulk	€ 2.262	€ 2.475	€ 495	€ 707	€ 848	€ 566	€ 1.202
Placement of a 30 cm sand layer							
Sand	€ 394	€ 431	€ 86	€ 123	€ 148	€ 98	€ 209
Wheel loader	€ 73	€ 80	€ 16	€ 23	€ 27	€ 18	€ 39
Roller	€ 83	€ 91	€ 18	€ 26	€ 31	€ 21	€ 44
Transport truck bulk	€ 4.947	€ 5.411	€ 1.082	€ 1.546	€ 1.855	€ 1.237	€ 2.628
Placement of prefab concrete slabs							
Concrete mortar C55/67	€ 8.534	€ 9.335	€ 1.867	€ 2.667	€ 3.200	€ 2.134	€ 4.534
Wheel loader	€ 1.017	€ 1.113	€ 223	€ 318	€ 382	€ 254	€ 540
Transport truck bulk	€ 2.262	€ 2.475	€ 495	€ 707	€ 848	€ 566	€ 1.202

I. Calculation of the CO_2-eq and MKI for the mowing maintenance

Table 61: Summary of specifications for mowing of the dike body

Activity	Equipment/Material	Distance (km)	Capacity	Capacity unit	Source	kg CO2-eq	/	unit	Source	MKI euro	/	unit
Mowing dike surface												
Mowing	tractor + mowing/suction combi		1000	m2/h	Dick van den Heuvel	34,4	/	h	LCA Rapportage categorie 3 data Nationale Milieudatabase	3,19	/	h
Transport	Transport truck bulk - grass	25	0,4882562	kg/m2	https://www.thelawninstitute.org/pages/environment/	0,26645608	/	tkm	DuboCalc - Transport truck bulk	0,0404	/	tkm

Table 62: Results for the calculation of dike body mowing per cross-section

		Cross-section															
Equipment/Material	**Units**	**1810**	**1980**	**2120**	**no data**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
tractor + mowing/suction combi	h	1,10E+03	1,63E+03	0,00E+00	0,00E+00	0,00E+00	7,13E+02	0,00E+00	0,00E+00	1,22E+03	0,00E+00	1,41E+02	5,54E+02	2,01E+03	1,57E+03	2,08E+02	0,00E+00
Transport truck bulk - grass	tkm	1,34E+04	1,98E+04	0,00E+00	0,00E+00	0,00E+00	8,70E+03	0,00E+00	0,00E+00	1,49E+04	0,00E+00	1,72E+03	6,76E+03	2,46E+04	1,91E+04	2,54E+03	0,00E+00
		Cross-section															
Equipment/Material	**Units**	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
grass seeds (D1 150 kg/ha)	h	0,00E+00	-2,27E+02	-2,84E+01	1,03E+02	0,00E+00	0,00E+00	0,00E+00	4,22E+02	0,00E+00	0,00E+00	-1,26E+01	4,65E+02	5,03E+02	1,28E+02	6,10E+02	-8,36E+01
Transport truck bulk	tkm	0,00E+00	-2,77E+03	-3,46E+02	1,25E+03	0,00E+00	0,00E+00	0,00E+00	5,15E+03	0,00E+00	0,00E+00	-1,54E+02	5,67E+03	6,14E+03	1,56E+03	7,45E+03	-1,02E+03
		Cross-section															
Equipment/Material	**Units**	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**no data**	**4570**	**4600**	**4610**	**4630**
grass seeds (D1 150 kg/ha)	h	3,21E+01	-6,39E+01	3,96E+02	6,06E+02	6,29E+02	3,71E+01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	2,72E+02	0,00E+00	-4,63E+02	9,51E+01	1,92E+02	2,36E+02
Transport truck bulk	tkm	3,92E+02	-7,80E+02	4,83E+03	7,40E+03	7,68E+03	4,53E+02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,33E+03	0,00E+00	-5,65E+03	1,16E+03	2,34E+03	2,88E+03

Table 63: Results of the kg CO2-eq calculation for mowing of the dike body per cross-section

								Cross-section								
Equipment/Material	**1810**	**1980**	**2120**	**no data**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
tractor + mowing/suction combi	3,79E+04	5,59E+04	0,00E+00	0,00E+00	0,00E+00	2,45E+04	0,00E+00	0,00E+00	4,19E+04	0,00E+00	4,85E+03	1,90E+04	6,93E+04	5,39E+04	7,15E+03	0,00E+00
Transport truck bulk - grass	3,58E+03	5,29E+03	0,00E+00	0,00E+00	0,00E+00	2,32E+03	0,00E+00	0,00E+00	3,96E+03	0,00E+00	4,59E+02	1,80E+03	6,55E+03	5,10E+03	6,76E+02	0,00E+00
								Cross-section								
Equipment/Material	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
grass seeds (D1 150 kg/ha)	0,00E+00	-7,80E+03	-9,75E+02	3,54E+03	0,00E+00	0,00E+00	0,00E+00	1,45E+04	0,00E+00	0,00E+00	-4,33E+02	1,60E+04	1,73E+04	4,41E+03	2,10E+04	-2,88E+03
Transport truck bulk	0,00E+00	-7,38E+02	-9,22E+01	3,34E+02	0,00E+00	0,00E+00	0,00E+00	1,37E+03	0,00E+00	0,00E+00	-4,10E+01	1,51E+03	1,64E+03	4,17E+02	1,98E+03	-2,72E+02
								Cross-section								
Equipment/Material	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**no data**	**4570**	**4600**	**4610**	**4630**
grass seeds (D1 150 kg/ha)	1,10E+03	-2,20E+03	1,36E+04	2,08E+04	2,16E+04	1,28E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	9,37E+03	0,00E+00	-1,59E+04	3,27E+03	6,59E+03	8,10E+03
Transport truck bulk	1,04E+02	-2,08E+02	1,29E+03	1,97E+03	2,05E+03	1,21E+02	0,00E+00	0,00E+00	0,00E+00	0,00E+00	8,86E+02	0,00E+00	-1,50E+03	3,09E+02	6,23E+02	7,66E+02

Table 64: Results of the MKI calculation for mowing of the dike body per cross-section

								Cross-section								
Equipment/Material	**1810**	**1980**	**2120**	**no data**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
tractor + mowing/suction combi	€ 3.512	€ 5.186	€ 0	€ 0	€ 0	€ 2.274	€ 0	€ 0	€ 3.885	€ 0	€ 450	€ 1.766	€ 6.426	€ 5.002	€ 663	€ 0
Transport truck bulk - grass	€ 543	€ 802	€ 0	€ 0	€ 0	€ 352	€ 0	€ 0	€ 601	€ 0	€ 70	€ 273	€ 993	€ 773	€ 102	€ 0
								Cross-section								
Equipment/Material	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
grass seeds (D1 150 kg/ha)	€ 0	-€ 723	-€ 90	€ 328	€ 0	€ 0	€ 0	€ 1.346	€ 0	€ 0	-€ 40	€ 1.482	€ 1.605	€ 409	€ 1.946	-€ 267
Transport truck bulk	€ 0	-€ 112	-€ 14	€ 51	€ 0	€ 0	€ 0	€ 208	€ 0	€ 0	-€ 6	€ 229	€ 248	€ 63	€ 301	-€ 41
								Cross-section								
Equipment/Material	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**no data**	**4570**	**4600**	**4610**	**4630**
grass seeds (D1 150 kg/ha)	€ 102	-€ 204	€ 1.263	€ 1.933	€ 2.007	€ 118	€ 0	€ 0	€ 0	€ 0	€ 869	€ 0	-€ 1.476	€ 303	€ 612	€ 751
Transport truck bulk	€ 16	-€ 32	€ 195	€ 299	€ 310	€ 18	€ 0	€ 0	€ 0	€ 0	€ 134	€ 0	-€ 228	€ 47	€ 95	€ 116

J. Emission results of the wave research

Table 65: Full calculation of the emission results for the wave research

Process/material	**Quantity**	**Unit**	**kg CO2-eq/unit**	**kg CO2-eq**	**MKI/unit**	**MKI euro**	**Source for emissions**
Diesel	5343	L	3,300	17631,729	0,58	3098,94	DuboCalc - Diesel
Mobile crane for using WIG	40	h	52,593	2103,730	9,22	368,80	DuboCalc - Gr.mach.Hydr. (gemiddeld)
Truck with hydraulic crane for moving the WOS	8	h	13,100	104,800	1,75	14,00	LCA Rapportage categorie 3 data Nationale Milieudatabase - Vrachtwagenkraan, diesel
Placement of the driving plates	12	h	13,100	157,200	1,75	21,00	LCA Rapportage categorie 3 data Nationale Milieudatabase - Vrachtwagenkraan, diesel
Removing driving plates	8	h	13,100	104,800	1,75	14,00	LCA Rapportage categorie 3 data Nationale Milieudatabase - Vrachtwagenkraan, diesel
Transport	3209,8	km	1,000	3209,800	0,12	385,18	DuboCalc - Voertuig km vervoer vrachtwagen
Total			**kg CO2-eq**	*2,33E+04*	**MKI**	*€ 3.901,92*	
			t CO2-eq	*2,33E+01*			

K. Kg CO_2-eq results per cross-section

Note: the dike cover does not have to be replaced in sub-sections 3 and 14.3. Also no changes are made in cross-section 4420.

Table 66: kg CO_2-results per cross-section

				Sub-section												
Cross section	**1810**	**1980**	**2120**	**3**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
Length cross section m	*1500*	*1100*	*1200*	*700*	*1400*	*800*	*1000*	*600*	*1400*	*700*	*500*	*2700*	*1600*	*1750*	*750*	*400*
Excavating process	6,68E+04	4,36E+04	6,82E+04	0,00E+00	6,45E+04	4,28E+04	6,50E+04	5,17E+04	6,72E+04	5,21E+04	2,57E+04	2,00E+05	1,05E+05	1,22E+05	1,06E+04	3,29E+04
Backfilling of clay inner slope	3,28E+05	2,40E+05	3,79E+05	0,00E+00	4,29E+05	3,14E+05	4,33E+05	3,52E+05	3,58E+05	2,99E+05	1,09E+05	9,34E+05	6,78E+05	7,73E+05	3,97E+05	2,05E+05
Backfilling of clay crest	3,00E+05	1,45E+05	2,15E+05	0,00E+00	1,02E+05	4,20E+04	1,01E+05	7,03E+04	2,73E+05	1,51E+05	1,78E+05	8,81E+05	2,34E+05	2,89E+05	8,00E+04	7,08E+04
Backfilling of top soil	1,08E+05	1,17E+05	5,85E+04	0,00E+00	5,24E+04	6,46E+04	5,33E+04	3,86E+04	1,19E+05	4,20E+04	3,06E+04	2,11E+05	1,62E+05	1,45E+05	5,74E+04	2,92E+04
Sowing process	3,83E+03	4,17E+03	2,08E+03	0,00E+00	1,86E+03	2,29E+03	1,89E+03	1,37E+03	4,21E+03	1,49E+03	1,09E+03	7,50E+03	5,74E+03	5,14E+03	2,04E+03	1,04E+03
Erosion screens	1,59E+05	-	-	-	-	7,96E+04	7,96E+04	-	1,59E+05	-	7,96E+04	-	-	-	-	-
Provincial road	7,10E+04	5,21E+04	5,68E+04	-	6,63E+04	-	-	-	6,63E+04	3,31E+04	2,37E+04	1,28E+05	-	-	-	-
Cycling paths	-	-	-	-	-	-	-	-	-	-	-	-	1,72E+05	1,88E+05	-	-
Maintenance	4,15E+04	6,12E+04	0,00E+00	0,00E+00	0,00E+00	2,68E+04	0,00E+00	0,00E+00	4,59E+04	0,00E+00	5,31E+03	2,08E+04	7,58E+04	5,90E+04	7,82E+03	0,00E+00
Total kg CO2-eq	**1,08E+06**	**6,63E+05**	**7,79E+05**	**0,00E+00**	**7,16E+05**	**5,72E+05**	**7,33E+05**	**5,14E+05**	**1,09E+06**	**5,79E+05**	**4,53E+05**	**2,38E+06**	**1,43E+06**	**1,58E+06**	**5,55E+05**	**3,39E+05**

Cross section	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
Length cross section m	*600*	*400*	*50*	*200*	*300*	*250*	*350*	*500*	*500*	*400*	*350*	*500*	*550*	*300*	*500*	*200*
Excavating process	5,16E+04	1,31E+04	1,63E+03	1,56E+04	2,68E+04	3,08E+04	1,73E+04	2,38E+04	5,99E+04	3,76E+04	2,87E+04	2,11E+04	3,69E+04	1,05E+04	2,19E+04	4,61E+02
Backfilling of clay inner slope	3,33E+05	2,85E+05	3,57E+04	9,09E+04	1,74E+05	2,01E+05	7,57E+04	1,54E+05	3,52E+05	2,50E+05	1,74E+05	1,21E+05	2,10E+05	1,30E+05	2,28E+05	2,51E+04
Backfilling of clay crest	9,53E+04	5,92E+04	7,40E+03	5,01E+04	4,80E+04	5,40E+04	8,38E+04	4,91E+04	1,19E+05	5,74E+04	7,95E+04	5,70E+04	8,27E+04	3,29E+04	7,11E+04	2,86E+04
Backfilling of top soil	4,48E+04	2,41E+04	3,01E+03	1,44E+04	2,25E+04	2,15E+04	1,56E+04	4,47E+04	4,85E+04	3,76E+04	2,17E+04	5,83E+04	5,95E+04	1,83E+04	5,64E+04	4,79E+03
Sowing process	1,59E+03	8,56E+02	1,07E+02	5,12E+02	8,01E+02	7,64E+02	5,56E+02	1,59E+03	1,72E+03	1,34E+03	7,69E+02	2,07E+03	2,11E+03	6,50E+02	2,00E+03	1,70E+02
Erosion screens	-	-	-	1,59E+05	-	-	2,39E+05	-	-	-	-	-	-	7,96E+04	7,96E+04	1,59E+05
Provincial road	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cycling paths	-	-	-	-	-	-	-	-	-	-	3,77E+04	5,39E+04	-	-	-	-
Maintenance	0,00E+00	-8,54E+03	-1,07E+03	3,87E+03	0,00E+00	0,00E+00	0,00E+00	1,59E+04	0,00E+00	0,00E+00	-4,74E+02	1,75E+04	1,89E+04	4,82E+03	2,30E+04	-3,15E+03
Total kg CO2-eq	**5,26E+05**	**3,74E+05**	**4,68E+04**	**3,35E+05**	**2,72E+05**	**3,09E+05**	**4,32E+05**	**2,89E+05**	**5,81E+05**	**3,84E+05**	**3,42E+05**	**3,31E+05**	**4,10E+05**	**2,76E+05**	**4,82E+05**	**2,15E+05**

												Sub-section				
Cross section	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**14.3**	**4570**	**4600**	**4610**	**4630**
Length cross section m	*100*	*150*	*600*	*400*	*850*	*100*	*50*	*400*	*150*	*150*	*300*	*200*	*550*	*100*	*150*	*350*
Excavating process	3,34E+03	5,33E+03	1,18E+04	5,35E+03	1,90E+04	3,91E+03	2,61E+03	0,00E+00	4,61E+03	1,05E+04	1,89E+04	0,00E+00	2,01E+03	9,06E+02	1,12E+03	1,47E+04
Backfilling of clay inner slope	5,42E+04	7,93E+04	2,34E+05	1,56E+05	3,96E+05	3,39E+04	1,29E+04	0,00E+00	3,47E+04	3,86E+04	8,76E+04	0,00E+00	1,55E+05	9,35E+03	4,68E+04	1,03E+05
Backfilling of clay crest	2,10E+04	2,88E+04	1,02E+05	7,27E+04	1,86E+05	1,37E+04	1,38E+04	0,00E+00	1,05E+04	6,85E+04	7,94E+04	0,00E+00	7,11E+04	6,57E+03	2,28E+04	1,59E+04
Backfilling of top soil	7,54E+03	1,03E+04	5,71E+04	4,67E+04	8,40E+04	5,29E+03	2,52E+03	0,00E+00	5,01E+03	1,15E+04	2,17E+04	0,00E+00	2,17E+04	5,71E+03	1,77E+04	3,06E+04
Sowing process	2,68E+02	3,67E+02	2,03E+03	1,66E+03	2,98E+03	1,88E+02	8,96E+01	0,00E+00	1,78E+02	4,08E+02	7,69E+02	0,00E+00	7,71E+02	2,03E+02	6,28E+02	1,09E+03
Erosion screens	1,59E+05	-	-	2,39E+05	-	7,96E+04	-	-	-	1,59E+05	2,39E+05	-	1,59E+05	-	-	1,59E+05
Provincial road	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cycling paths	-	-	6,46E+04	4,31E+04	9,16E+04	-	-	-	-	-	-	-	-	-	-	-
Maintenance	1,21E+03	-2,41E+03	1,49E+04	2,28E+04	2,37E+04	1,40E+03	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,03E+04	0,00E+00	-1,74E+04	3,58E+03	7,22E+03	8,87E+03
Total kg CO2-eq	**2,47E+05**	**1,22E+05**	**4,87E+05**	**5,87E+05**	**8,03E+05**	**1,38E+05**	**3,19E+04**	**0,00E+00**	**5,50E+04**	**2,89E+05**	**4,57E+05**	**0,00E+00**	**3,93E+05**	**2,63E+04**	**9,62E+04**	**3,33E+05**

L. MKI results per cross-section

Note: the dike cover does not have to be replaced in sub-sections 3 and 14.3. Also no changes are made in cross-section 4420.

Table 67: MKI results per cross-section

Cross section	**1810**	**1980**	**2120**	**Sub-section 3**	**2310**	**2430**	**2500**	**2550**	**2660**	**2790**	**2850**	**3070**	**3170**	**3380**	**3530**	**3570**
Length cross section m	*1500*	*1100*	*1200*	*700*	*1400*	*800*	*1000*	*600*	*1400*	*700*	*500*	*2700*	*1600*	*1750*	*750*	*400*
Excavating process	€ 10.407,96	€ 6.713,32	€ 10.700,37	€ 0,00	€ 10.135,57	€ 6.675,90	€ 10.201,98	€ 8.128,91	€ 10.452,33	€ 8.184,27	€ 4.026,44	€ 31.317,68	€ 16.329,24	€ 19.030,74	€ 1.581,00	€ 5.166,83
Backfilling of clay inner slope	€ 49.921,65	€ 36.637,73	€ 57.606,21	€ 0,00	€ 65.209,01	€ 47.870,17	€ 65.810,67	€ 53.505,34	€ 54.583,54	€ 45.471,59	€ 16.628,97	€ 142.111,22	€ 103.294,06	€ 117.763,51	€ 60.384,73	€ 31.260,18
Backfilling of clay crest	€ 45.629,93	€ 21.968,25	€ 32.674,43	€ 0,00	€ 15.493,07	€ 6.382,53	€ 15.338,66	€ 10.685,59	€ 41.434,96	€ 22.951,36	€ 27.048,54	€ 133.971,32	€ 35.577,45	€ 43.957,09	€ 12.160,26	€ 10.767,94
Backfilling of top soil	€ 16.563,44	€ 17.997,37	€ 8.970,88	€ 0,00	€ 8.036,27	€ 9.907,73	€ 8.183,43	€ 5.924,42	€ 18.203,50	€ 6.447,89	€ 4.689,89	€ 32.392,22	€ 24.794,05	€ 22.194,11	€ 8.812,49	€ 4.477,58
Sowing process	€ 350,87	€ 381,25	€ 190,03	€ 0,00	€ 170,24	€ 209,88	€ 173,35	€ 125,50	€ 385,61	€ 136,59	€ 99,35	€ 686,18	€ 525,22	€ 470,15	€ 186,68	€ 94,85
Erosion screens	€ 12.158,09	-	-	-	-	€ 6.079,04	€ 6.079,04	-	€ 12.158,09	-	€ 6.079,04	-	-	-	-	-
Provincial road	€ 8.567,32	€ 6.282,70	€ 6.853,86	-	€ 7.996,17	-	-	-	€ 7.996,17	€ 3.998,08	€ 2.855,77	€ 15.421,18	-	-	-	-
Cycling paths	-	-	-	-	-	-	-	-	-	-	-	-	€ 20.184,05	€ 22.076,30	-	-
Maintenance	€ 4.055,14	€ 5.988,05	€ 0,00	€ 0,00	€ 0,00	€ 2.625,34	€ 0,00	€ 0,00	€ 4.486,06	€ 0,00	€ 519,32	€ 2.038,62	€ 7.419,31	€ 5.775,16	€ 765,17	€ 0,00
Total MKI	**€ 147.654,40**	**€ 95.968,65**	**€ 116.995,77**	**€ 0,00**	**€ 107.040,33**	**€ 79.750,60**	**€ 105.787,14**	**€ 78.369,75**	**€ 149.700,26**	**€ 87.189,79**	**€ 61.947,32**	**€ 357.938,42**	**€ 208.123,38**	**€ 231.267,06**	**€ 83.890,33**	**€ 51.767,38**

Cross section	**3610**	**3690**	**3690**	**3700**	**3730**	**3760**	**3780**	**3830**	**3880**	**3930**	**3950**	**4010**	**4070**	**4100**	**4130**	**4180**
Length cross section m	*600*	*400*	*50*	*200*	*300*	*250*	*350*	*500*	*500*	*400*	*350*	*500*	*550*	*300*	*500*	*200*
Excavating process	€ 8.092,97	€ 2.031,62	€ 253,95	€ 2.454,68	€ 4.208,71	€ 4.847,18	€ 2.710,73	€ 3.689,46	€ 9.414,04	€ 5.895,23	€ 4.515,24	€ 3.249,10	€ 5.742,61	€ 1.628,89	€ 3.374,86	€ 65,07
Backfilling of clay inner slope	€ 50.605,35	€ 43.397,35	€ 5.424,67	€ 13.825,59	€ 26.476,35	€ 30.644,07	€ 11.522,84	€ 23.528,21	€ 53.555,06	€ 38.102,27	€ 26.494,31	€ 18.554,08	€ 32.030,79	€ 19.710,13	€ 34.808,96	€ 3.812,61
Backfilling of clay crest	€ 14.484,22	€ 8.997,31	€ 1.124,66	€ 7.617,86	€ 7.303,88	€ 8.209,78	€ 12.736,75	€ 7.463,44	€ 18.143,88	€ 8.729,65	€ 12.088,20	€ 8.673,03	€ 12.569,46	€ 5.003,08	€ 10.809,12	€ 4.354,53
Backfilling of top soil	€ 6.868,01	€ 3.697,99	€ 462,25	€ 2.214,08	€ 3.459,28	€ 3.301,17	€ 2.400,27	€ 6.852,29	€ 7.439,23	€ 5.773,89	€ 3.324,20	€ 8.944,48	€ 9.131,52	€ 2.808,88	€ 8.649,61	€ 734,66
Sowing process	€ 145,49	€ 78,34	€ 9,79	€ 46,90	€ 73,28	€ 69,93	€ 50,85	€ 145,15	€ 157,59	€ 122,31	€ 70,42	€ 189,47	€ 193,44	€ 59,50	€ 183,23	€ 15,56
Erosion screens	-	-	-	€ 12.158,09	-	-	€ 18.237,13	-	-	-	-	-	-	€ 6.079,04	€ 6.079,04	€ 12.158,09
Provincial road	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cycling paths	-	-	-	-	-	-	-	-	-	-	€ 4.415,26	€ 6.307,52	-	-	-	-
Maintenance	€ 0,00	-€ 835,34	-€ 104,42	€ 378,63	€ 0,00	€ 0,00	€ 0,00	€ 1.554,28	€ 0,00	€ 0,00	-€ 46,41	€ 1.710,82	€ 1.853,54	€ 471,81	€ 2.246,71	-€ 307,91
Total MKI	**€ 80.196,05**	**€ 57.367,26**	**€ 7.170,91**	**€ 38.695,82**	**€ 41.521,50**	**€ 47.072,14**	**€ 47.658,57**	**€ 43.232,84**	**€ 88.709,80**	**€ 58.623,35**	**€ 50.861,22**	**€ 47.628,50**	**€ 61.521,36**	**€ 35.761,33**	**€ 66.151,53**	**€ 20.832,61**

Cross section	**4190**	**4200**	**4250**	**4290**	**4330**	**4400**	**4410**	**4420**	**4460**	**4470**	**4500**	**Sub-section 14.3**	**4570**	**4600**	**4610**	**4630**
Length cross section m	*100*	*150*	*600*	*400*	*850*	*100*	*50*	*400*	*150*	*150*	*300*	*200*	*550*	*100*	*150*	*350*
Excavating process	€ 516,07	€ 826,93	€ 1.779,15	€ 770,87	€ 2.875,42	€ 610,83	€ 410,01	€ 0,00	€ 722,49	€ 1.649,29	€ 2.953,75	€ 0,00	€ 283,20	€ 134,19	€ 147,82	€ 2.271,83
Backfilling of clay inner slope	€ 8.245,86	€ 12.060,34	€ 35.710,66	€ 23.786,29	€ 60.324,06	€ 5.158,56	€ 1.956,16	€ 0,00	€ 5.283,38	€ 5.877,46	€ 13.341,62	€ 0,00	€ 23.647,50	€ 1.430,26	€ 7.140,06	€ 15.671,64
Backfilling of clay crest	€ 3.191,26	€ 4.385,41	€ 15.565,13	€ 11.056,19	€ 28.219,52	€ 2.084,62	€ 2.094,91	€ 0,00	€ 1.598,21	€ 10.415,36	€ 12.075,33	€ 0,00	€ 10.814,27	€ 998,56	€ 3.458,92	€ 2.414,04
Backfilling of top soil	€ 1.156,46	€ 1.583,89	€ 8.768,68	€ 7.171,31	€ 12.890,16	€ 811,04	€ 387,27	€ 0,00	€ 768,35	€ 1.760,81	€ 3.322,80	€ 0,00	€ 3.330,10	€ 876,19	€ 2.712,83	€ 4.696,34
Sowing process	€ 24,50	€ 33,55	€ 185,75	€ 151,91	€ 273,06	€ 17,18	€ 8,20	€ 0,00	€ 16,28	€ 37,30	€ 70,39	€ 0,00	€ 70,54	€ 18,56	€ 57,47	€ 99,48
Erosion screens	€ 12.158,09	-	-	€ 18.237,13	-	€ 6.079,04	-	-	-	€ 12.158,09	€ 18.237,13	-	€ 12.158,09	-	-	€ 12.158,09
Provincial road	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cycling paths	-	-	€ 7.569,02	€ 5.046,01	€ 10.722,78	-	-	-	-	-	-	-	-	-	-	-
Maintenance	€ 118,23	-€ 235,35	€ 1.458,52	€ 2.231,98	€ 2.316,69	€ 136,64	€ 0,00	€ 0,00	€ 0,00	€ 0,00	€ 1.003,29	€ 0,00	-€ 1.703,64	€ 350,27	€ 706,06	€ 867,56
Total MKI	**€ 25.410,48**	**€ 18.654,77**	**€ 71.036,91**	**€ 68.451,70**	**€ 117.621,69**	**€ 14.897,92**	**€ 4.856,55**	**€ 0,00**	**€ 8.388,71**	**€ 31.898,32**	**€ 51.004,31**	**€ 0,00**	**€ 48.600,07**	**€ 3.808,03**	**€ 14.223,16**	**€ 38.178,99**